Anomaly Detection using Remote Sensing for the Archaeological Heritage Registration

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***Abstract*— The aim of this work is an approach using multisensor remote sensing techniques to recognize the potential remains and recreate the original landscape of three archaeological sites. We investigate the spectral characteristics of the reflectance parameter and emissivity in the pattern recognition of archaeological materials in several hyperspectral scenes of the prehispanic site in Palmar Sur (Costa Rica), the Jarama Valley site and the celtiberian city of Segeda in Spain. Spectral ranges of the visible-near infrared (VNIR), shortwave infrared (SWIR) and thermal infrared (TIR) from hyperspectral data cubes of HyMAP, AHS, MASTER and ATM have been used. Several experiments on natural scenarios of Costa Rica and Spain of different complexity, have been designed. Spectral patterns and thermal anomalies have been calculated as evidences of buried remains and change detection. First results, land cover change analyses and their consequences in the digital heritage registration are discussed.**

Keywords—spectra; anomaly detection; pattern recognition; hyperspectral; thermal data.

I. Introduction

Archaeological prospection by means of non-destructive techniques and the new technologies for detection and records in cultural heritage, out of which outstands remote sensing through active and passive sensors, different facets (space, airborne and short range), all represent an important tool [8] for the improvement, protection and prevention in the face of negative and destructive elements acting on the world heritage. Since their early stages, remote sensing techniques have been applied to archaelogical studies. A remote sensing instrument measures (usually covering a 2-D area and so rendering an image) the electromagnetic radiation coming from the study target; this radiation being either reflected sunlight, thermally emitted radiance or (in so-called active systems) energy sent by the instrument itself (microwaves in SAR or laser beam in a LIDAR).

Detection of spectral anomalies aims at extracting automatically pixels that show significant responses in relation of their surroundings. This research deals with the non supervised technique of target detection, also called anomaly detection, in archaeological sites.

In other sense, image spectrometry has proven to be efficient in the characterization of materials based on statistical methods using specific reflection and absorption bands [5]. Spectral configurations in the VNIR, SWIR and TIR have been successfully used for mapping materials in different archaeological scenarios [3][9].

An important aim in this research is to establish relationships that allow linking spectral anomalies with what can be called as informational anomalies and, therefore, identify heritage information related to anomalous responses rather than simply spotting differences from the natural background. We can measure biophysical parameters using remote sensing and calculate spectral and thermal anomalies that could be indicative of the presence of anthropomorphic structures in archaeological sites or pathologies that affect these structures. This work presents a multi-methodology approach, applied to the analysis of the correlations between spectral anomalies and archaeological materials in Palmar Sur site (Costa Rica), Jarama Valley and Segeda site in Spain.

II. Data and Study Cases

Three different areas have been studied as test zones for the research. These areas are in different ecosystems and different geomorphological landscapes. The result of these area definitions has been intentional trying to encompass as varied a spectrum as possible in order to be able to extrapolate and

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validate the results obtained through anomaly detection using remote sensing techniques.

A. Palmar Sur Archaeological Site

This region is basically the coastal Pacific plain in the southern part of Costa Rica close to the Osa Peninsula, centered in the city from which the region takes its name, and through which runs the Sierpes River, which drains into the Pacific, in the Golfito Gulf, running west and south from the Palmar Sur city. It is an area little known archaeologically, but with great archaeological potential since it is considered an obliged passage for the early movements of Amerind populations.

For this case we used reflectance images of the HyMAP Imaging Spectrometer [2] and the MASTER (MODIS/ASTER Simulator) sensor [4], acquired both the 7 March 2005 on the Palmar Sur site. The scene HyMAP (125 channels between 0.4589 μm and 2,491 μm) has a dimension of 710 x 2415 pixels, with a spatial resolution of 15 m. The MASTER scene is 1650 x 4466 pixels, with spatial resolution of 9 m and radiometric resolution of 16-bit. The 50 MASTER image channels are grouped in a port of 25 channels in the visible and infrared spectrum (0463 μm - 2,427 μm), and 25 thermal channels between 3,075 μm and 13 μm.

B. Jarama Valley. A Scenario of the Spanish War

The Battle of Jarama took place on the surroundings of Madrid between 6th and 27th February 1937 in the frame of the bloody and fratricidal Spanish Civil War. Currently the battle scenarios, consisting of a vast and intricate network of military facilities, are part of a large natural area listed as Southeast Regional Park of Madrid.

We have used for this case several images of the ATM (Airborne Thematic Mapper) sensor [3] with the aim to detect war infrastructure remains like walls, trenches, bunkers or tunnels. ATM is an opto-mechanical radiometer with image formation through the combination of a spinning mirror and the aircraft motion. It split the incoming radiation in 11 spectral bands, from visible through near infrared up to thermal infrared, and with a spatial resolutions of 3.4 m.

C. Celtiberian City of Segeda

The third case presented took place in the archaeological area of Segeda (Mara - Belmonte de Gracián, Spain), corresponding with the homonymous Celtiberian city. It is located in the Northeast third of the Iberian peninsula, next to the Perejiles river, affluent of the river Jalón, covering a 40 hectares area.

Despite its important value for archaeological research in the Iberian peninsula, this site was not made the object of any detailed research until the year 1998, its excavation works having exclusively centred upon the Celtiberian city of Segeda I (Poyo de Mara, Zaragoza). The results obtained during these years corroborated the veracity of the Roman historian Apiano, in his account referring to events which led to the destruction of this city by the Roman army in the year 153 B.C.

We have used reflectance images of the AHS (Airborne Hyperspectral System) [9] acquired on April 20, 2006 in the Celtiberian Segeda site. The AHS scene (80 channels between 0.4589 μm and 12.70 μm) has a dimension of 750 x 4075 pixels, with a spatial resolution of 3.4 m.

III. PATTERN RECOGNITION AND ANOMALY DETECTION FOR ARCHAEOLOGICAL REGISTRATION.

Data processing techniques are used to extract information from remote sensing data. They usually include geometric correction, radiometric correction and a number of image arithmetic and statistical analysis. The choice of techniques depends on image quality and in the required output.

A check of radiometric corrections of the images have been performed from data measured in field and laboratory with USB400 and ASD FieldSpec 4 Hi-Res spectroradiometers. The spectra have been used to characterize archaeological materials and to check reflectance images by an empirical linear regression.

The airborne images have been georeferenced directly using the geometry calculated from the position and the attitude data measured by inertial GPS/IMU (Inertial Measurement Unit) at the same time of acquisition over the study area. The georeferencing images has been tested using check points measured on the ground in projection UTM and WGS84 Datum by DGPS (Differential Global Positioning System).

In this research, anomalies obtained for the standard method RX [6] have been verified by those computed using methods based on subspaces, as the Subspace RX (SSRX) and the Orthogonal Subspace Projection (OSPRX) [1][5].

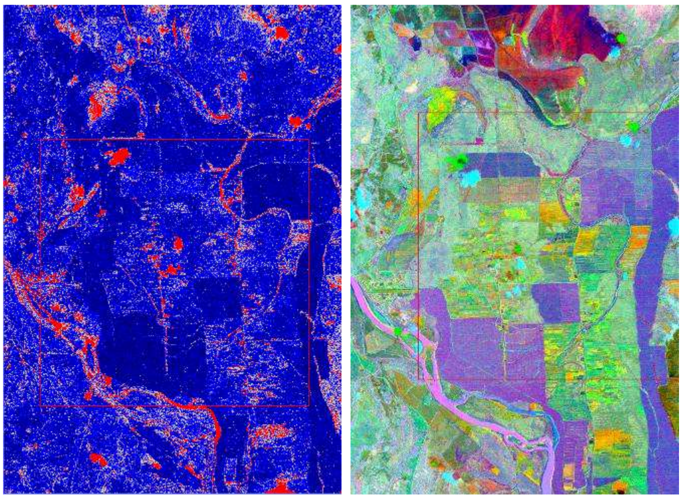

Fig. 1. Examples of HyMAP anomalies (left) and RGB combination of Principal Components (PCs) 10,7,2 for the Palmar Sur site (Costa Rica).

The computation in all methods has been carried out separately for spectral ranges of reflective channels and emissive for the AHS, ATM and MASTER test data set. The main challenge is how to accurately characterize "interestingness" in a numerical fashion. In the case of this paper "interestingness" can be defined in terms of outliers. In this sense, we have been calculated a thermal index [9], profiting from the separability between diagnostic bands in the emissive spectrum.

Three anomaly detectors were considered besides the global RX: subspace methods, local methods and segmentation based anomaly detection methods. For a global anomaly detection in HyMAP hyperspectral scenes and AHS of high complexity, OSPRX detector gives the best results, followed by SSRX. For a global anomaly detection in ATM scenes of low complexity, RXD gives the best results.

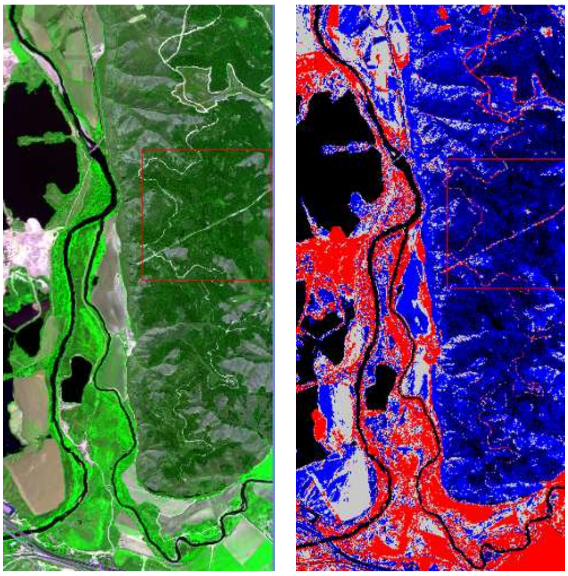

Fig. 3. Examples of ATM anomalies in red (right) and RGB combination of 9,7,1 channels for the Jarama Valley site (Spain).

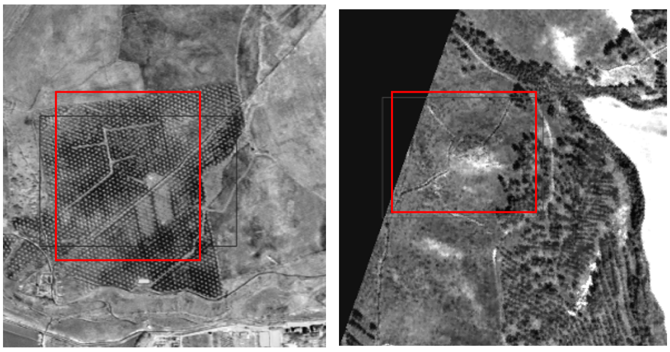

Fig. 4. Examples of the trenches remains (red frames) detected using ATM images of the Jarama Valley.

Anomalies detected for all methods have been classified with a non supervised K-Means algorithm in five clusters: error (cluster 1), background 1 (cluster 2), background 2 (cluster 3), anomaly at confidence level of 50 % (cluster 4) and anomaly at confidence level of 100% (cluster 5).

Three vegetation indeces and soil have been computed for the test data set: NDVI (Normalized Difference Vegetation Index), TCARI (Transformed Chlorophyll Absorption in Reflectance Index) and OSAVI (Optimized Soil-Adjusted Vegetation Index). These image transformations were carried out with the intention of assess the influence of vegetation cover in the subsequent image analysis and to estimate the LAI cover (Leaf Area Index).

The relationship between the spectral anomalies and the

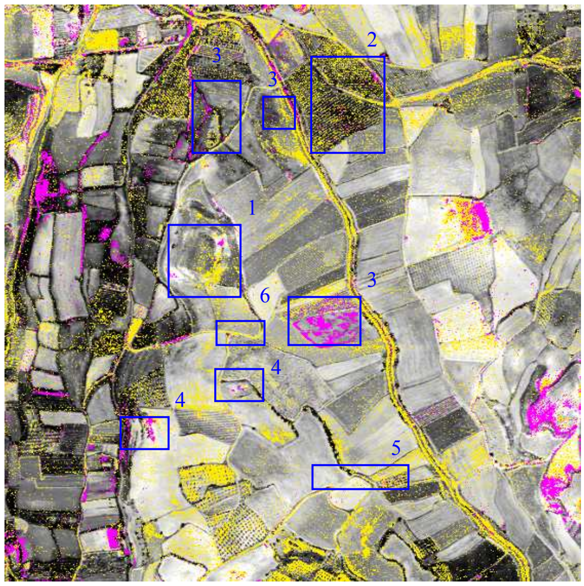

Fig. 2. AHS VNIR anomalies (magenta) and thermal (yellow) for the Celtiberian Segeda site. Blue frames with presence of archaeological remains: (1) Segeda town and celtiberian winepress, (2) roman villa, (3) remains of adobe houses, (4) mud walls, rock walls and forging material, (5) celtiberian city wall and (6) remains of the wall celtiberian destroyed.

diagnostic bands of the archaeological materials has been studied. It has been established a clear relationship between thermal anomalies and particular archaeological remains and materials, as wall, stones, as well as a clear relationship between VNIR anomalies and archaeological materials with a great influence of the diagnostics bands in SWIR spectrum (for example tiles, stone spheres, clay walls, trenches or buried remains).

Anomaly Detection			
Detector	*Palmar Sur site (*HyMAP*)*	*Jarama Valley* (ATM)	*Segeda site* (AHS)
RX	0.38	4.18	1.94
SSRX	0.44	3.85	1.50
OSPRX	0.31	3.91	1.89
RX-vnir	0.30	3.38	1.66
RX-tir	--	3.26	1.65
SSRX-vnir	0.29	3.38	1.48
SSRX-tir	--	4.00	1.92
OSPRX-vnir	0.24	2.86	1.36
OSPRX-tir	--	5.74	2.51

Table 1. Comparison of results (anomalies %) between anomaly detectors for Palmar Sur, Jarama Valley and Segeda sites in relation with their full scenes.

The relationship between spectral patterns and anomalies has been recognized. Thermal (TIR spectrum) anomalies in the Jarama Valley case are corresponding to geometric patterns and linear, most of them with an extraction and a very quick interpretation.

For the archaeologic site of Segeda we can separate two types of patterns associated with spectral anomalies. One of these is corresponding with spectral anomalies in the VNIR and SWIR spectrum associated with geometric patterns in the vegetation and soils. On the other hand, the thermal anomalies in the Segeda case are associated with patterns of irregular shapes and higher humidity contents below ground.

For the Palmar Sur site, spectral anomalies in the SWIR and TIR spectrum are corresponding to patterns of the vegetation with irregular shapes and mounds with some kind of forest's patology, probably due to the loss of vigor of the plants.

(a) (b) (c)

Fig. 5. Example of patterns observed in (a) the Palmar Sur site - Costa Rica (mounds), (b) Segeda city (remains of the celtiberian aqueduct) and (c) Jarama Valley (trenches).

IV. CONCLUSIONS

The characteristics of high resolution data, both spatial and spectral, for archaeological sites has been studied by different anomaly detection methods, using HyMAP, MASTER, ATM and AHS test data sets. This paper evaluates the performance of anomaly detection methods in scenes with different backgrounds and types of targets for Palmar Sur sites, Jarama Valley and Segeda.

The results confirm the ability of the remote sensing data to detect and quantify the effective distribution of various kinds of anomalies and covers and on a large areas of its surroundings. The hyperspectral images can improve the distinction of these surfaces in standard anomaly detection processes.

It has been observed that the thermal results of particular surfaces can help to characterize the types of anomalies associated with buried archaeological structures, that in other areas of the spectrum behave in a similar way and which can be distinguished by its response in TIR wavelengths.

Higher concentrations of some archaeological materials (clay walls, stones, trenches, etc.), in scenarios where the sources of error are minimized, are correlated with the anomalies in the VNIR range. Subjective evaluation of the detection results shows that the best performing detectors give complimentary results, and that "false alarms" are mainly due to objects with anomalous spectra in the scene.

We have confirmed that not all spectral anomalies detected correspond to archaeological information, archaeological remains in this case.

This paper improves the no supervised classification processes, searching areas and automatically detecting archaolgical materials of interest by virtue of their surface characteristics.

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