Remote Sensing Applied to the Study of the Cultural and Natural Heritage in the Mesoamerican Corridor

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***Abstract*— The aim of this work is an approach using multisource remote sensing techniques to study and to evaluate the natural and cultural heritage within the framework of a global research in the Mesoamerican Corridor. Remote sensing, as a non-destructive technique, enable the measurement of spectral anomalies and biophysical parameters which may be indicative of the state of preservation of the big manmade structures, natural ecosystems or diseases that affect them. We investigate the spectral characteristics of the reflectance and emissivity in several multispectral scenes of the pre-Hispanic archaeological sites of the Guayabo (Costa Rica) and Fonseca Gulf (Nicaragua, Honduras and Salvador) what supposed an ancestral migration route. Spectral ranges of the visible-near infrared (VNIR), shortwave infrared (SWIR) and thermal infrared (TIR) from hyperspectral data cubes of HyMAP and MASTER have been used. Spectral patterns and thermal anomalies have been analyzed, as well as the capabilities of DInSAR as evidences of buried remains or pathologies in the natural environment. First results, land cover changes and their consequences in the cultural heritage study and protection are discussed.**

***Index Terms* — Mesoamerican Corridor (MC), Anomaly Detection, Pattern Recognition, Hyperspectral, Synthetic Aperture Radar (SAR), Natural Heritage, Cultural Heritage.**

I. INTRODUCTION

Currently, there are risk factors affecting the protection of the material or immaterial cultural heritage in the Mesoamerican Corridor in Central America. Natural disasters, bush fires, deforestation caused directly by phenomena associated with the seasons, or indirectly by the effects of climate change, all of which account for huge, and sometimes irreversible damage to cultural and natural heritage, and consequently to the communities living in the surrounding areas.

In the last few years active and passive sensors have been adopted as non-intrusive instrumentations that have a great application potential in archaeological prospection, as indicated by the corresponding scientific publications and events [2], [5], [6], [7]. At this stage of the study the response from the surfaces in terms of the appropriate wavelengths of the reflective (VIS-SWIR) and emitting (TR) spectrum on the one hand, and of the region of microwaves on the other, may represent relevant information in that it supports the exploration and detection of man-made structural signs.

In this sense, the hyperspectral data provide global information about a wide area of study, presumably, a medium or large scale archaeological site. However, an initial problem subject to investigation is that of the dimensional scope of the data, that is to say, to what potential in terms of wavelengths and bands should information be raised? That is, the information necessary to determine most accurately the extent to which separation can be carried out between materials present in either low or compound minerals associated with anthropic structures [3]. To address this difficulty, research has centered principally on three ways: improvement on the extraction or selection of features so as to reduce the dimensional scope of the information, regulation of the covariance matrix of the samples and structuring of a true

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covariance matrix determined by a small number of parameters. Following a multi-scale and multi-source work strategy, a research-based approximation has been carried out since 2006 with a view to applying active and passive remote sensing techniques in the Mesoamerican Corridor. An initial experience in hyperspectral information was presented in the 2nd International Conference of Remote sensing in Archaeology, held in Rome. The continual study carried out since then has focused on thermal bands, given that, in principle and on the basis of earlier experiences [1], [2] this is where remote sensing can help to distinguish phenomena that affect buried archaeological structures.

The project being presented serves as a review of the progress made during the geospatial and spectral study of the Mesoamerican Corridor, using hyperspectral data integrated with SAR data. 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 [6]. Spectral configurations in the VNIR, SWIR, TIR and SAR have been successfully used for mapping materials in different cultural heritage scenarios [2], [6], [7]. 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.

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 Guayabo site (Costa Rica) and Fonseca Gulf (Honduras-Nicaragua-El Salvador).

II. Study Area

Three different areas have been studied as test zones for the research in the Mesoamerican Corridor. 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 validate the results obtained through anomaly detection using remote sensing techniques.

A. *Guayabo Archaeological Site*

This region is basically the middle plain in the southern part of Costa Rica close to the Central Volcanic Range, close to the Turrialba city from which the main, now active, volcano takes its name, running west and south from the 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 and the MASTER (MODIS/ASTER Simulator) sensor, acquired both the 7 March 2005 on the Guayabo site.

B. *Fonseca Gulf*

The Fonseca Gulf took place on the surroundings of Honduras, Nicaragua and El Salvador in the Pacific coast. Currently the corridor scenarios, consisting of a vast and intricate network of ancient facilities, are part of a large natural area listed as Fonseca Region.

We have used for this case several images of the well know Thematic Mapper (TM) and the EO-1 spacecraft Advanced Land Imager (ALI) sensors [3], [5] with the aim to detect war infrastructure remains like walls, ancient paths, tunnels, etc. ALI 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 8 spectral bands, from visible through near infrared up to thermal infrared, and with a spatial resolution of 10 m (panchromatic).

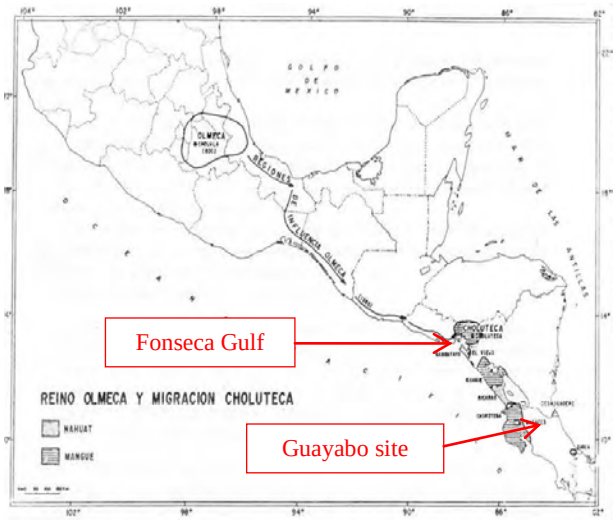

Fig. 1. Olmeca and Choluteca migration in the Mesoamerican Corridor. Fonseca Gulf and Guayabo study areas..

III. Remote Sensing Analysis.

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 surfaces and to check reflectance images by an empirical linear regression.

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

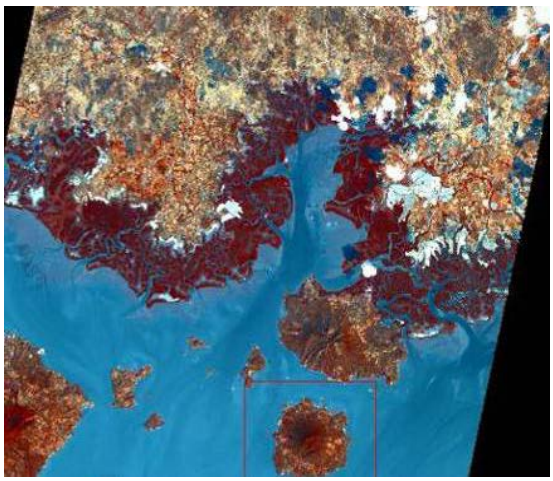

Fig. 2. Example of ALI scene in red (right) and RGB combination of 9,7,1 channels for the Fonseca Gulf (Honduras-Nicaragua-El Salvador).

In this research, anomalies obtained for the standard method RX [4] have been verified by those computed using methods based on subspaces, as the Subspace RX (SSRX) and the Orthogonal Subspace Projection (OSPRX) [1], [3]. The computation in all methods has been carried out separately for spectral ranges of reflective channels and emissive for the 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 [6], profiting from the separability between diagnostic bands in the emissive spectrum.

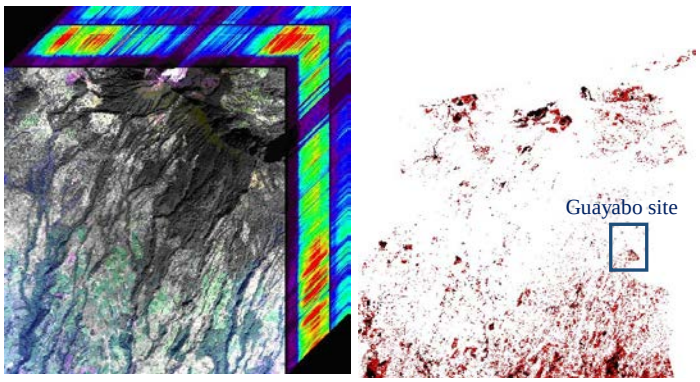

Fig. 3. Example of a cube HyMAP image rgb combination 10,7,2 (left) and OSPRX anomalies (right) for the Guyabo site (Costa Rica).

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 of high complexity, OSPRX detector gives the best results, followed by SSRX. For a global anomaly detection in TM and ALI scenes of low complexity, RXD gives the best results.

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

Fig. 4. Example of ALI anomalies (left) for the Potrerillos Island archaeological site in the Fonseca Gulf (Honduras).

Detector	*Guayabo site (*HyMAP*)*	*Fonseca Gulf (*ALI*)*
RX	0.38	4.18
SSRX	0.44	3.85
OSPRX	0.31	3.91

Table 1. Comparison of results (anomalies %) between anomaly detectors for Guayabo site and Fonseca Gulf sites in relation with their full scenes.

For the archaeologic site of Guayabo 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 Guayabo case are associated with patterns of irregular shapes and higher humidity contents below ground. 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 pathology, probably due to the loss of vigor of the plants.

An interferometric par has been developed from PALSAR images of 2010 and 2011. Currently, SAR data are being analyzed and integrated into Geographic Information Systems, together with the remaining pieces of information that has been generated, with the aim of exploring the possibilities for its

interconnection with possible Mesoamerican paths in the route between Fonseca Gulf and Costa Rica.

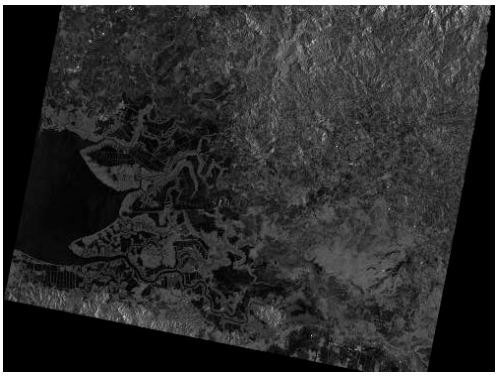

Fig. 5. Example PALSAR interferometric image for the Fonseca Gulf (Honduras).

The results obtained from the multispectral and hyperspectral analysis have been integrated with the preprocessed SAR data. The responses from the surfaces with humidity concentration in PALSAR images correspond to those detected in the ALI images and those that can be deduced from the NDVI vegetation index calculated for Fonseca Gulf. The main pre and post Mesoamerican archaeological sites found between Potrerillos Island (Honduras) and Guayabo (Costa Rica) have been recorded in the PALSAR interferometric par. Under current study is the possible spatial correlation of these sites with optimal routs calculated in a GIS for the two most likely alternatives of the usual route between both sites. This analysis has not been completed yet.

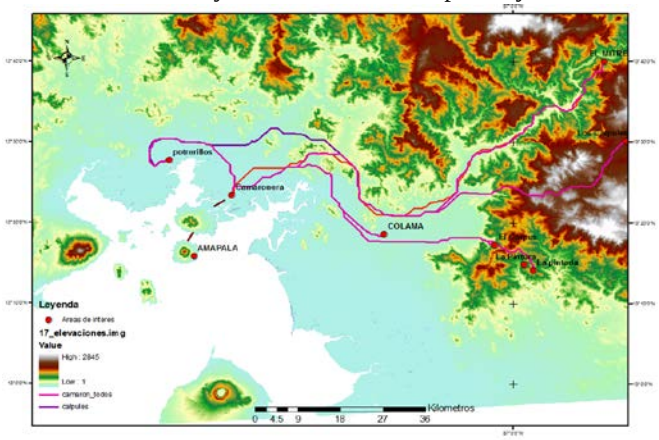

Fig. 6. Example of optimal routes between Potrerillos Island site (Honduras) and San Cristobal volcano (Nicaragua) calculated by ArcGIS from remote sensing data.

IV. CONCLUSIONS

This present project constitutes a review of the successive approximations in the application of active and passive remote sensing techniques and methodologies which have recently been used in cultural and natural areas of the Mesoamerican Corridor. The characteristics of high resolution data, both spatial and spectral, for archaeological sites has been studied by different anomaly detection methods, using HyMAP, MASTER, TM, ALI and PALSAR test data sets. This paper evaluates the performance of anomaly detection methods in scenes with different backgrounds and types of targets for Guayabo (Costa Rica) site and Fonseca Gulf (Honduras-Nicaragua-El Salvador).

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, in scenarios where the sources of error are minimized, are correlated with the anomalies in the VNIR range. We have confirmed that not all spectral anomalies detected correspond to heritage information, archaeological remains or vegetation pathologies.

Multi-source files have been generated in a way that an accurate spatial co-registration between the different pieces of information becomes crucial for the subsequent data analysis. The integration of these results with SAR data has allowed the establishment of relationships between ground deformations, thermal variability and optimal paths.

ACKNOWLEDGMENT

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