Deepening in the 3D Modelling: Multisource Analysis of a Polychrome Ceramic Vessel Through the Integration of Thermal and Hyperspectral Information

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Abstract:
The objective in the proposed paper is to give the process a particular multi-disciplinary perspective. Using the 3-dimensional models obtained from 3D laser scanners as a starting point, the information is analysed and thermal and hyperspectral data are incorporated. Reality, understood as a set of surfaces, now has n-dimensions available, n being the number of bands with information on the same study element. This makes it possible to use the prospecting option in search of the information underlying the visible features and thus proceeding one step beyond traditional 3D modelling. Although artefacts are usually graphically documented in drawings and photographs, we decided to combine data from different thermal and hyperspectral 3D modelling sources in a digital treatment. In this paper we present the application of the proposed methodology to a ceramic piece consisting of a polychrome ceramic vessel from the Nazca civilisation of Peru, measuring 20cm high and 15cm wide and decorated with geometrical patterns, describing data collection and the previous first analyses.

Key Words: *Hyperspectral Remote Sensing, Thermal Images, 3D Modelling, Short Range Photogrammetry and Laser Scanner*

Introduction

Our first project on airborne multispectral remote sensing areas applied to archaeology was at the Recópolis site and the surrounding area. The Visigothic Recópolis site dates from 350-450 AD and is located in Guadalajara, Spain. The aim of this first experience was to provide high spectral and spatial resolution images to support the archaeological study. The images acquired were used to make the preliminary site cartography, extract current land cover and to test the detection and/or confirmation models of possible buried archaeological structures.

The area of interest was surveyed from the

Figure 1. Sobel filter with AMDC red channel.

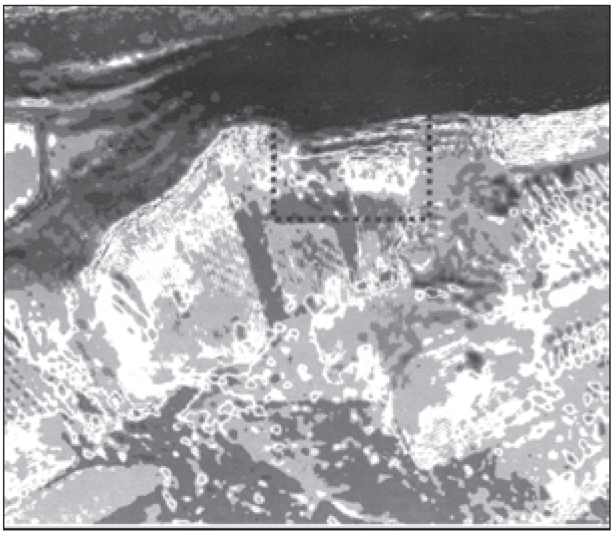

Figure 2. ISODATA classification using ATM11 and ATM12 with possible buried archaeological.

air in July and November 2002, including the archaeological site and a nearby Arab fortress, operating simultaneously with two airborne remote sensing instruments, a multispectral scanner Daedalus 1268 and a digital AMDC camera equipped with a (GPS/IMU) positioning and orientation system.

Data processing techniques were used to retrieve information from the remote sensing data. The fused images were used for a statistical classification using the standard ISODATA clustering algorithm.

The AMDC images processed with the Sobel filter revealed some patterns which were likely to represent buried structures (Fig. 1). After different trials, the ISODATA classification using the ATM11 and ATM12 bands (both combined with AMDC) was selected as the most useful. Classified image patterns similar to the ones observed in the filtered AMDC images were apparent. These patterns are consistent with signs of man-made structures (Fig. 2).

Multisensor Approach in Archeology

After the first attempt to apply airborne sensing techniques to archaeology, the study into documentation technologies continued at the Segeda site. For the study of remote sensing, one of the characteristics which makes the Segeda site particularly striking is the meticulous state of its sequential excavations, enabling the application of image methodologies which can be verified and improved as results are confirmed or rejected by strictly archaeological studies. At this research level, where the aim is to find evidence of buried man-made structures, the surface response of the appropriate wavelengths from the reflective (VIS-SWIR) and emissive (TIR) spectrum could provide important information to support archaeological exploration.

Since 2005 research at the Segeda site has aimed at applying active and passive remote sensing techniques using this approach. An acquisition campaign and hyperspectral data processing were carried out in the summer of 2005. Another one was carried out in 2006 with an airborne SAR (Synthetic Aperture Radar) sensor. The results obtained in these campaigns can be seen in figure 3.

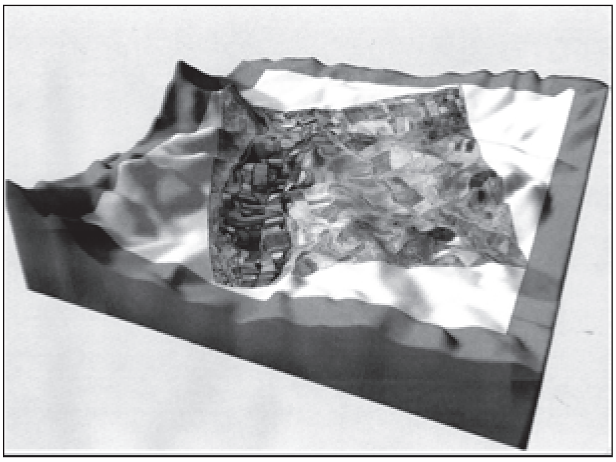

Figure 3. Results obtained from the first hyperspectral campaigns carried out at the Segeda site.

The study undertaken focused on the thermal bands, since previous experience (Belvedere et al. 2001; Farjas et al. 2003) has shown that this would be where phenomena related to archaeological structures could be distinguished. The methodologies developed made it possible to obtain satisfactory results from the hyperspectral images fused with aerial photographs. These results were contrasted with samples from field and laboratory radiometry (Rejas et al. 2006) and the methodology is been applied in other sites (Rejas, 2009).

Ground Data Acquisition and Processing

At this stage, we decided to add a new step to the investigation in the form of expanding the information sources by using additional technologies on the surface of the study. We thus added photogrammetry and 3D laser scanning (Farjas et al. 2009) to close range remote sensing and imaging spectrometry. To do this, data was collected from Area 4 of the Segeda site during the summer of 2007 with a 3D laser sensor, a short range photogrammetric camera and a Thermacam thermal sensor to contrast the possible structures detected as thermal anomalies with those based on spectral angle classification. The aim was to spectrally record, identify and characterise ideal areas and materials for subsequent excavations and validate the results obtained up to that point.

3D Laser

Field data was taken using a Trimble GX 3D laser scanner, with a scanning speed of up to 5000 points per second. For scanning distances under 50m, it guarantees a standard deviation of 1.4mm, increasing to 2.5mm for an approximate distance of 100m.

Thermal images

ThermaCAM is a passive sensor which records the radiation reflected from surfaces in wavelengths from 7.5 to 13.4µm. Its horizontal field of view l (FOVh) is 24° by 18° of the vertical field of view (FOVv), the spatial resolution for both being 1.3mrad (IFOV). Under these conditions, array type images of 320x240 pixels may be made, codifying thermal infrared radiation at 14 bits with a measurement precision of d +/- 2°C.

One of the features which make this sensor particularly interesting for close range remote sensing applications is that calculations of emissivities from the measured surfaces can be made thanks to its 3 internal calibration systems. It can therefore use the emissivity parameter to characterise different bodies in the thermal infrared region by a simple measurement process. To this end, 3cm diameter candles were used as a thermal reference and control points for geo-referencing the images.

Short-range photogrammetry

Photographic images were made using two types of camera. One was a pre-calibrated Nikon D70 digital camera and the other a small metric format Zeiss. The Nikon D70 is able to obtain images of 3,008 columns by

2,000 rows, whilst the Zeiss forms the image on conventional photographic film. The area was previously marked out to allow for subsequent orthorectification of the images. Some specially designed 3cm diameter targets were used for this. Photograms of 0.5cm and 0.7cm were obtained with a spatial resolution corresponding to the heights of 10 and 15m platforms respectively.

The main objective of the different processes applied to the data acquired was to produce a single perfectly co-recorded multi-sourced file so as to be able to undertake a subsequent analysis aimed at spatially correlating the elements of archaeological interest (walls, surfaces, structures, organic remains, etc.) at the surface temperature at which they were recorded.

Different resolutions were previously established according to the different characteristics of the objects measured by the 3D laser. The data were then processed at resolutions ranging from 2mm for spheres, given their importance for merging the different takes, to 50mm in less critical areas. Important items such as the bakery or the forge were scanned at a horizontal and vertical spatial resolution of 5mm, and the rest at 9mm. An approximate total number of 2,500,000 points were processed.

The photographic images acquired with the Nikon D70 camera were orthorectified using the OrthoEngine module of the Geomatic image digital treatment programme. An internal model of the camera was made based on the calibrated internal parameters of orientation, and a mosaic of orthoimages was made following a block adjustment. The RMS (root mean square) obtained in the adjustment by squared minimums were 0.7 and 0.4 pixels in X and Y, respectively. The analogue images acquired with the Zeiss metric camera were being processed.

The thermal images were processed using the ThermaCAM Researcher programme, transforming them into an image format compatible with the orthorectification module used. Apart from the geometric tasks, the thermographs were exported to Matlab for calculation by the material emissivity treatment program and corrected for possible thermal distortion patterns.

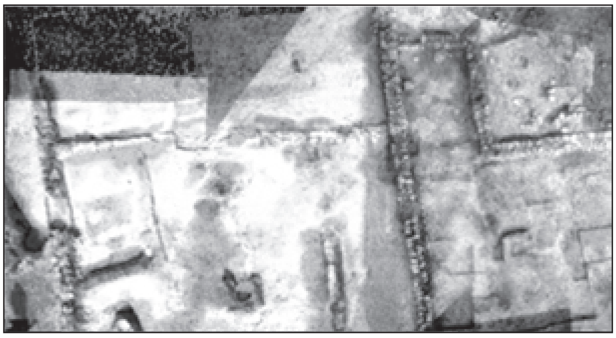

Figure 4. Multisource file (3D laser, short range orthophoto and thermographies).

The last pre-processing step was the fusion of data using two different systems. The thermography mosaic was combined with the short range photograph mosaic, to make layers in the visible and emissive spectra to the same spatial resolution over Area 4, which had been excavated in 2007. The hyperspectral images of the AHS sensor, acquired in 2005 and converted into reflectance values, were fused with aerial photography. A new subscene was then obtained of the Area 4 excavation site and its surroundings, maintaining the original spectral information (20 TIR channels, thermal infrared) and 0.5m spatial resolution. Imgfuse algorithms from the Geomatic program were applied in both image fusion processes (Fig. 4).

Anomaly Detection and Mineral Materials

The processed images began to be analysed in an exploratory fashion at the end of 2007. Using the file with short range photography layers and thermography information, diverse radiometric profiles were made to detect spectral variability

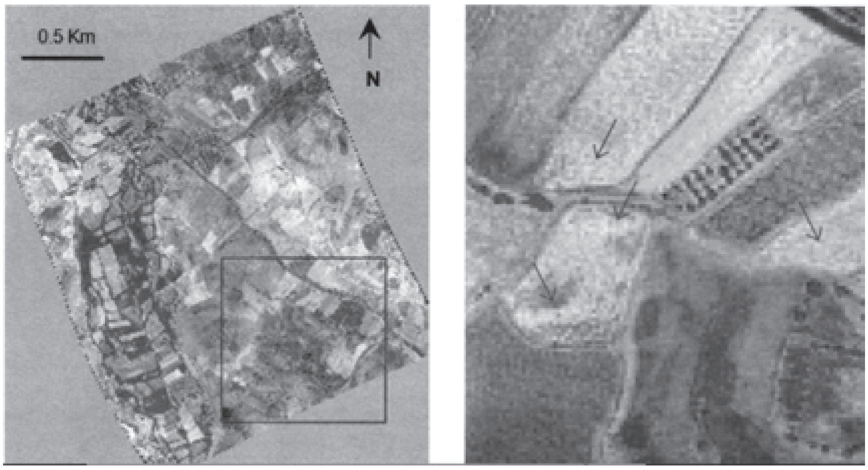

Figure 5. Detail of the main walls of the city detected in Segeda site, PCA 5, 4, 3 fused image with termical chanels of AHS (ch 65 to 80). The archaeological remains of the wall are pointed out with arrows

and establish spatial correlations between the characteristic elements found in the excavation. We can observe how the warmest structures correspond to the adobe walls, a material used by the Celtiberians for buildings. This type of wall may be thermally distinguished from the walls constructed of rock. The same type of structure with a sharp linear component can be easily separated according to its different composition. The refractory materials used by the Segeda Celtiberians appeared in the dwellings in Area 4, presenting a very low thermographic response, whilst the materials appearing next to the forge are the warmest (Fig. 4). These foreseeable responses are an advantage for the identification of dwellings or different buildings, to the extent that they may be detected in future extensions of the excavated area.

A Principal Components Analysis (PCA) was also performed, which focused solely on the thermal channels of the AHS sensor fused with aerial photography (Fig. 5). Previous studies (Rejas 2009a; Traviglia 2006) have revealed satisfactory results from applying this technique to hyperspectral data for the detection of buried archaeological remains. PCA is a technique which allows total variability to be analysed, simplifying the original data by eliminating all redundant information. In this way, the dimensions of the original data can be reduced, improving the thermal contrast in the surface area.

Each main component was measured in terms of the quantity of explained variation (variance). The main component 1 (PC1) is the one which contains the highest percentage of original information, whilst the proportions for the remaining PCs are increasingly lower. We can therefore be certain that the first three main components (PC1, PC2 and PC3) contain between 50% and 95% of the total variance of the original information.

The PC1 component, with the highest variance, creates an image with a preponderance of shiny pixels. The response of the n^{th} degree component (PCn) is totally opposed to that of PC1, since it generates a rather homogeneous image in which there is no outstanding response.

In our case, the first four main components (PC1, 2, 3 and 4) provided the detection and extraction of an obvious alignment which did not show up in the original images or in the optic images, which, in turn, present an abrupt change in the shape of a curve. This alignment and the sharp turn to the SW are in fact initiated at a sudden rise in the elevation of the terrain, and could be due to some type of buried structure.

The exploratory analysis of the data acquired in 2007 focused on the study of the spatial-thermal correlation between surfaces and materials taken from the Segeda excavation Area 4 (Rejas et al. 2009b). A multi-resource file was opened, spatial precision between the different layers of information being critical for subsequent data analysis as a proposal of methodologies as support for new explorations.

Spectral interval (nm)	335 – 2500
Sampling interval (nm)	335 – 1000: 1.4nm 1000 – 2500: 2nm
Spectral resolution (FWHM, nm)	350 – 1000: 3nm 1000 – 2500: 10nm
FOV	Standard - 25° Optional - 1°, 5°, 8°, 18°
Detectors	Array 512 Si 2 photodiodes In/Ga/As for IR
NEDL (x 109) at 400 nm	4.4
at 700 nm	1.2
at 900 nm	4.3
at 1500 nm	1.4
at 2200 nm	2.8
Digitilisation levels	16 bits

Table 1. Technical specifications of ASD-FR field spectroradiometer.

Aplications of 3D Modelling and Remote Sensing Methodologies to a Nazca Artefact

Although artefacts are usually graphically documented by drawings and photographs, we decided to combine data from different thermal infrared (TIR) and near infrared (NIR) 3D modelling sources in a digital treatment (Bragado et al. 2008; Rejas et al. 2003). In this section we describe the application of the proposed methodology to a ceramic piece consisting of a polychrome ceramic vessel from the Nazca civilisation of Peru, measuring 20cm high and 15cm wide and decorated with geometrical patterns.

In the data acquisition process, four different sources of information were identified:

- Hyperspectral image-processing techniques,
- Thermographs (to calculate temperature and surface emissivity),
- Spectroradiometry,
- 3D laser scanning techniques.

The procedures used for hyperspectral and thermographic techniques are similar to those described in the medium and long-range assays performed previous to the new approach taken by the study. As we have mentioned before, our objective was to define the multi-data acquisition methodology which we have used successfully in Segeda for a Nazca vessel. As in photogrammetry and 3D laser scanner sweeps the terminology of long, medium and short range is used, our objective could be defined as establishing how to apply hyperspectral, radiometric, thermal or metric data integration methodologies to short-range or “microscale” operations.

The objective of the lab radiometry in a first phase is to obtain spectral signatures of materials in order to analyse their mineralogical composition. In a second phase (now in process), these spectral signatures are searched in the hyperspectral images of the entire area of the Nazca region. The ASD-FR field spectroradiometer used to acquire data from the Nazca vessel has the following technical specifications (Table 1).

The ASD-FR (Table 1) really contains three spectroradiometers:

- VNIR: Operates in close-range visible and

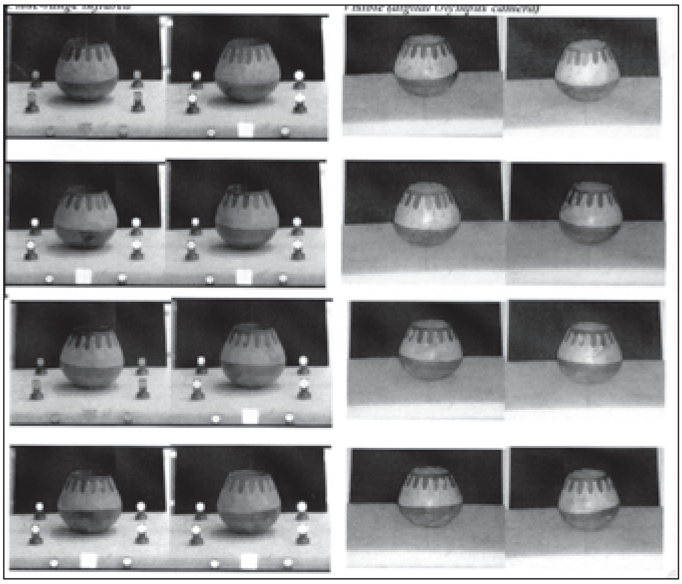

Figure 6. Images of Nazca vessel in close-range infrared and visible region.

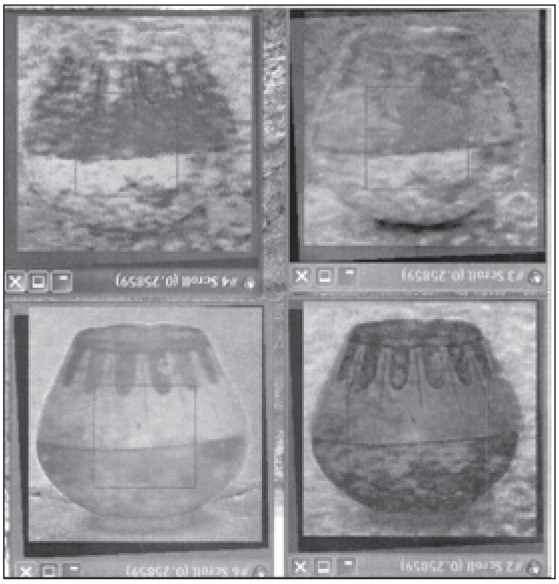

Figure 7. Images resulting of the Principal Components Analysis (PCA).

infra-red (335-1068nm). It consists of a fixed mesh (reflexive holographic) that disperses light over an array of 512 silica detectors. This provides a sampling interval of 1.4nm with a spectral resolution of 3nm.

- SWIR1: Operates in short-wave infra-red at the 1000 to 1800nm interval. It uses a variable mesh that sends sequentially dispersed light to a fixed Indium-Gallium-Arsenide detector. Sampling interval is 3nm and spectral resolution 10nm.

- SWIR2: Operates similarly to SWIR1 at the 1800-2500nm interval.

The light is picked up by an optical fibre (in our case, 3m long) which is really a package of 57 fibres of 110 and 220µm diameter. FOV is 25° although lenses can be attached to reduce this to 18°, 8° and 1°. The software can adjust integration time (between 17 milliseconds and over an hour) of the VNIR detectors as well as the gain of the SWIR 1 and SWIR 2 detectors. The effect of electronic noise (dark current) can be corrected at any time by an obturator.

Reflectance is measured in the following way:

- We start by measuring the reflected radiance of the reference target (SpectralonTM from Labsphere, with reflectance greater than 99% in the visible and close-range infra-red region), which is stored for the subsequent calculation of reflectance of targets.
- Integration time is 17 milliseconds.
- Each measurement is the mean of 20 spectra.

- Reflectance is automatically calculated as Ltarget/Lspectralon and then corrected with the spectralon reflectance spectrum.

Infrared (left) and digital Olympus camera (right) images of the Nazca vessel were then obtained (Fig. 6).

3D laser scanning was carried out by a low-cost multi-laser NextEngine precision system. This scanner contains laser optics, cameras and processing systems and can create point clouds and triangulated solid or texturised models. It acquires information on the geometry of the target object and takes photographs to record textures and colours. The scanner determined the coordinates of the points composing the outer surface of the vessel and produced the numerical structure of the surface data in the form of a quantitative and continuous variable.

The file containing the 3D model of the vessel, with accuracy within 1mm, together with the hyperspectral and thermal information, was then used for processing the acquired data. This stage of the project is still on-going and we hope to have the first results soon.

Conclusions

Multispectral and hyperspectral techniques applied to archaeology are proving the enormous potential of this method, not only for registering surface characteristics but also for non-destructive investigation. At the present time we are studying the possible applications of this technology at the Nazca vessel. We are adding metric and thermal data to hyperspectral image treatment in additional channels and testing the use of the tools made available by this multi-band methodology to extrapolate the line of research to the spatial and spectral modelling of objects on a larger scale.

This experience has led to the confirmation of how diverse low cost technologies may enable the recording and updating of high precision spatial and spectral data. The exploratory analysis of data, focused on the study of the spatial-thermal correlation between surfaces and materials. For this, a multi-resource file was made, the precise spatial co-register between the different layers of information being critical for subsequent data analysis. The analysis of the main components used in the hyperspectral image is shown in figure 7. The integration of these results with digital 3D models would lead to the establishment of relations between the points and the thermal variability extracted from the main components calculated.

We believe that the evolution of this technology should not only be in the direction of optimising processes and equipment but should also include the verification of quantitative and qualitative information by making use of the language and information offered by other fields of spatial documentation. The results have already shown that this is by no means a utopian aim.

Acknowledgements

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