

Short Range Photogrammetry and Remote Sensing Application in the Celtiberian City of Segeda

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Abstract

The extension, peculiarity and heterogeneity of the layers in the archaeological site of the Celtiberian city of Segeda prompted the undertaking of prior research into different technologies designed for facilitating the detection and recording of buried or unearthed archaeological structures in excavations. To do this, during the summer of 2007 data was collected from the different areas of the Segeda site with a 3D laser sensor, a short range photogrammetric camera and a Thermacam thermal sensor. The aim was to use them to contrast the possible structures detected as thermal anomalies and those deduced based on spectral angle classification. This paper presents the particularities of the different acquisition campaigns and the methodology followed in the digital treatment of the multi-source data which have led to the contrasting and/or rejecting of the results from positively detected areas using exploration in the reflective and emissive spectrum.

Keywords

Segeda, 3D laser, thermal imaging, short range photogrammetry and hyperspectral remote sensing

1. Introduction and Background

For the effects of research in remote sensing, one of the characteristics which makes the Celtiberian site of Segeda (Burillo 2006) particularly striking is its sequential and meticulous state of excavation, enabling the application of image methodologies which can be contrasted and improved as results are confirmed or rejected by strictly archaeological research investigations. At this research level, where the aim is to find evidence of buried structures and man-made formations, the response of the surfaces in appropriate wavelengths from the reflective (VIS-SWIR) and emissive (TIR) spectrum could provide relevant information and support in archaeological exploration.

The extension, peculiarity and heterogeneity of the layers present in the archaeological site of Segeda are an added bonus here, prompting the use of prior research into the different technologies which help to facilitate the detection and recording of buried or unearthed archaeological structures in the different excavation areas.

Following this approach, since 2005 research has been pursued aiming at applying active and passive remote sensing techniques in Segeda. An acquisition

campaign and hyperspectral data processing was consequently carried out in the summer of 2005 and another in 2006 with an airborne SAR (*Synthetic Aperture Radar*) sensor.

The study undertaken focused on the thermal bands, since it was undertaken here initially and based on prior experiences (Belvedere *et al.* 2001; Farjas *et al.* 2003) where phenomena affecting the 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 of field and laboratory radiometry, and were presented at several events and congresses. (Rejas *et al.* 2006).

The work presented is therefore part of a continuation of the assessment of new methods for completing a geospatial study of the Celtiberian city of Segeda and offering support to new processes of archaeological excavation. In 2007 one specific objective was to increase the coverage of data (thermal, short range and 3D laser photogrammetry) over the Segeda I area 4 and its environs. The aim was to spectrally record, identify and characterise ideal areas and materials for the continuation of excavation

processes and validate the results obtained up to that date.

This article seeks to put forward the characteristics of the data acquisition campaigns which took place in 2007, the preprocessing of images and the initial results obtained.

2. Archaeological excavation areas in Segeda

The work presented took place in the archaeological area of Segeda (Mara-Belmonte de Gracián, Zaragoza), corresponding to 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 hectare 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 BC.

During these years the exploration and excavation works, developed by the team led by Francisco Burillo, verified the historical date of when the city was abandoned and observed the evolutionary configuration of the site, documented in the Poyo de Mara, the city acropolis, the existence of an older nucleus, with posterior expansion of the city in the environment of the said elevation, culminating its expansion with the process of sinoecism of the inhabitants of Segeda over their neighbours the Titos. The remains of this neighbourhood are located under a significant layer of alluvial sediments, with the course of the walls reflecting premeditated urban planning.

By following the route of water canalisation was discovered one kilometre south of the Poyo de Mara, with a width of some four metres. It is probably unfinished, and has been identified as the wall leading to the declaration of the war by Rome (Burillo 2007, 202). As a result the Roman Senate moved the election of the consuls from the ides of March to the 1st January (the basis of our current calendar) and mobilised an army of some 30,000 men. This army, according to Apiano, was defeated on 23rd August 153 BC by an alliance between the inhabitants of Segeda

and the Numantines under the command of Caro from Segeda. The death of 6000 Romans led to this day being declared ill-fated by Rome. This relevant role reflected by classical sources was confirmed by the fact that it was to be the first of the Celtiberian cities to mint coins in the central Iberian System, under the indigenous name of “*sekeida*”. Its silver coinage led to the hierarchical structuring of an extensive area which would cover some of today’s provinces of Zaragoza, Teruel and Guadalajara (Burillo 2006).

The Segeda I phase is only one part of the archaeological area of Segeda, and should be linked to two other important sites, the Roman-Celtiberian city of Segeda II in the immediate vicinity of Durón de Belmonte de Gracián (Zaragoza) and the Roman camp which was situated in the city of Segeda I located in the Planos de Mara. This archaeological area was declared a Cultural Interest Asset in the official bulletin of Aragón on 25th June 2001, making up the most extensive Archaeological Area of Aragón and a first grade national Historical Heritage site.

The remote sensing campaign developed in the year 2007 was focused on the so-called Area 4 and on some of the nearby plots. This is situated in the Archaeological area of the Celtiberian city of Segeda I, 400m to the south of the Poyo de Mara, the remainders of a Celtiberian housing precinct dating to the second century BC.

3. Data acquisition campaign

The hyperspectral remote sensing techniques developed in Segeda needed contrasting and validation through complementary metric survey methods. During the summer of 2007 data were taken from different areas of the Segeda site for this, with a short range photogrammetry camera, a thermal Thermacam sensor and a 3D laser scanner.

The close object photogrammetry and remote sensing campaign consisted of acquiring images in the thermal spectrum and 20% sequentially overlapping photographs over a ground platform (crane) and at a height of 10 and 15m, in such a way that the 2007 excavation in Area 4 of Segeda was covered. Moreover, another set of thermal images was taken, without following a specific spatial pattern, corresponding to the Poyo de Mara (Area 2 in *Fig. 1*) and the surrounding areas of Segeda I.

The idea behind these proceedings was partly to completely characterise the most representative layers appearing in Segeda throughout the reflective

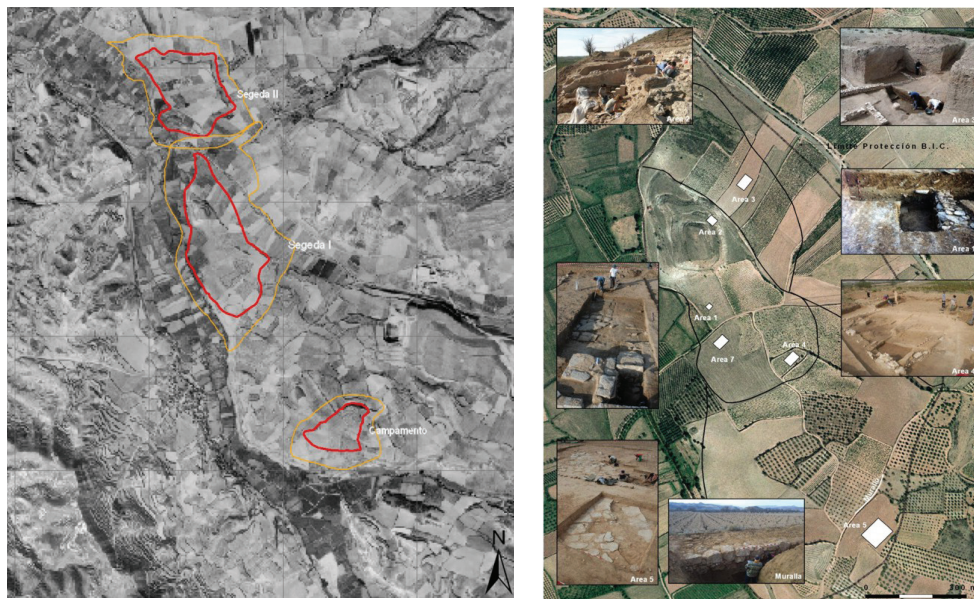


Fig. 1. Archaeological area of Segeda (Segeda 1, II and Roman Camp) and archaeological areas excavated in Segeda I.

and emissive electromagnetic spectrum and partly to contrast the possible structures detected as thermal anomalies and those deduced based on spectral angle classification of the hyperspectral images.

3.1. 3D laser scanner

Field data was taken using a 3D laser scanner from the company Trimble, specifically the Trimble GX 3D Scanner. This equipment has a scanning speed of up to 5000 points per second. For scanning distances under 50m, it guarantees a standard deviation of 1.4mm, rising to 2.5mm for an approximate distance of 100m. If we consider a single point, precision at 100m is around 12mm and 7mm for distance.

For station position planning it must be taken into account that this scanner has a horizontal angle range of 360°, presenting higher restrictions in vertical takes, given that it has a vertical limitation of 60°, 30° to each side of the horizontal. Beyond the positioning of auxiliary elements, data collection with the Trimble GX 3D needed, in this case, some magnetized spheres to allow us to quickly reference the different point-clouds and link the different stations together.

Five different stations were used to cover the area under study. From each one of the stations, images of the different objects to be raised were taken, scanning the nine spheres, which were located around the whole excavation.

3.2. Thermal images

ThermaCAM is a passive sensor which records the radiation coming off the surfaces in wave lengths from 7.5 to 134µm. Its horizontal field of vision (FOVh) is 24° by 18° of the vertical field of vision (FOVv), the spatial resolution for both being 1.3mrad (IFOV). The thermal sensitivity of this camera allows for the recording of data in a temperature range of between 0.08 °C to 30 °C, in a maximum image sequence of 50 per second. The environmental specifications of the ThermaCAM sensor are: operational humidity between 10% and 95%, and an operational temperature range of between -15 °C and 50 °C. Under these conditions array type images of 320 x 240 pixels may be made, codifying the radiation in the thermal infrared in 14 bit with a measurement precision of $d \pm 2$ °C.

One of the features which make this sensor particularly interesting for close range (or short range) remote sensing application is that calculations of the emissivities of the measured surfaces can be made thanks to its three internal calibration bodies. It can therefore characterise different bodies in the thermal infrared in a non-complex taking of measurements using the parameter of emissivity. To this end 3cm diameter candles (Fig. 2) have been used as a thermal reference and for the points of control for geo-referencing the images.

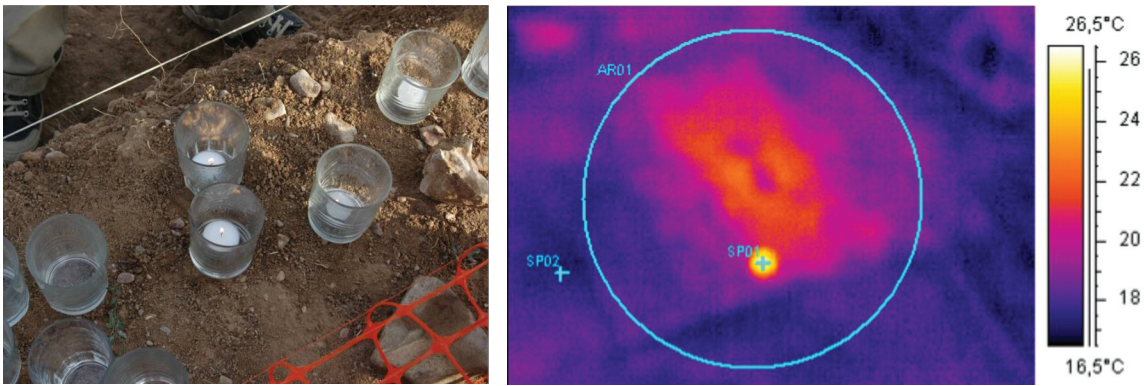


Fig. 2. Candles used as thermal reference and example of thermography (forge and candle) acquired with *ThermaCAM*.

3.3. Short range photogrammetry

Photographic images were made using two types of different cameras. On the one hand, with a previously calibrated Nikon D70 model digital camera, and on the other with a metric small format Zeiss camera. The Nikon D70 camera is able to obtain images of 3008 columns by 2000 rows, whilst the Zeiss camera photographs onto conventional photographic film. The area was previously marked out to allow for later orthorectification of the images. Some 3cm diameter bulls eyes designed to this effect were used for this. Thus photograms of 0.5cm and 0.7cm were obtained with a spatial resolution corresponding to the heights of 10 and 15m platforms, respectively.

4. Pre-processing of data

The main function of the different processes applied to the data acquired is to produce a single perfectly co-recorded multi-sourced file (Fig. 3). This aims at spatially correlating the elements of archaeological interest (walls, surfaces, structures, remains of organic origin, etc) with the superficial temperature at which they were recorded.

Depending on the characteristics of the objectives to be measured by the 3D laser different resolutions were previously established. The 3D laser data were processed at resolutions going from 2mm for spheres, given their importance for the point-cloud registration to up to 50mm in less critical areas. Relevant objects, such as the bakery or the forge, were surveyed with a spatial resolution of 5mm in horizontal and vertical, and the rest every 9mm, totalling an approximate number of 2,500,000 points.

Once the scanner data were processed it was necessary to eliminate those points relating

to noise, such as responses recorded on people, vegetation, structures and elements not belonging to the excavation area, etc. Once this noise was corrected and the point-cloud throughout the area in the working reference system was obtained, different processes could be undertaken. One of them was the representation, using level curves of structural elements from the site. It was also the tridimensional and spectral modelisation of the elements resulting from excavation, converting them into solids and applying textures to them. Another product arising from the 3D laser data was the detailed orthoimages of the excavation area.

The photographic images acquired with the Nikon D70 camera were orthorectified using the *OrthoEngine* module of the digital treatment programme of Geomatic images. An internal model of the camera was made based on the calibrated internal parameters of orientation, and a mosaic of

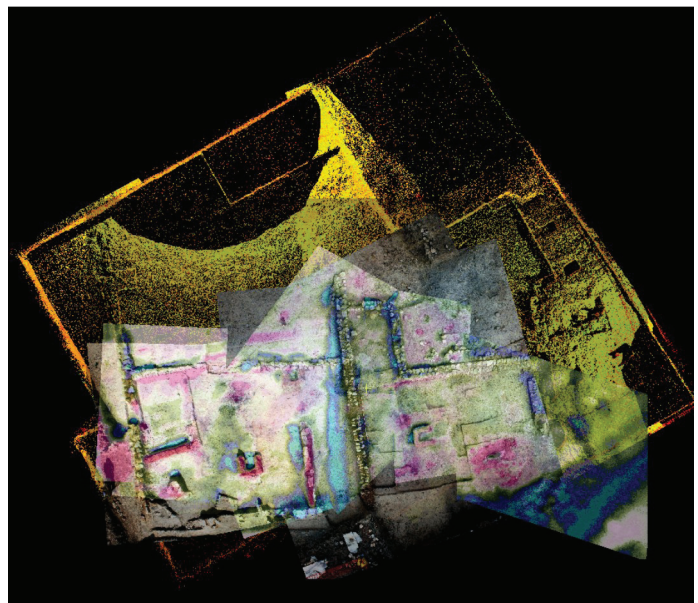


Fig. 3. Multisource file (3D laser, short range orthophoto and thermographies).

orthoimages was made following a block adjustment. The RMS (quadratic means error) obtained in the adjustment by squared minimals were of 0.7 and 0.4 pixels in X and Y, respectively. A subsequent re-sampling of the images was applied by the closest neighbour, rejecting photogrammes acquired outside the strict area of excavation. The photographic film images acquired with the Zeiss metric camera are currently being processed.

The thermal images were processed using the ThermaCAM Researcher programme, transforming it into an image format compatible with the orthorectification module used. Ten thermal references (candles) were used as points of control, as well as the other 47 extracted from the orthoimage generated by short range photography. A polynomic 1 order adjustment was applied, obtaining in this way a 2.7 pixel RMS, elevated, but sufficient bearing in mind the difficult visual recognition implicit in the infrared images.

Apart from these geometric tasks, the thermographs were exported to Matlab for calculation by this array treatment programme of material emissivities and correcting them for possible patterns of thermal distortion. Candles will be used for this, considered as thermal reference bodies, and the measurements of environmental temperature acquired by thermocouple sensors. This process is currently being carried out.

One last step in the pre-processing has been the fusion of data, in two senses. The thermography mosaic has been combined with the short range photograph mosaic, to make layers available over the area 4 excavated in 2007 in the visible spectrum and in the emissive spectrum to the same spatial resolution. Furthermore, the hyperspectral images of the AHS sensor, acquired in 2005 and converted

into reflectancy values, with aerial photography, have been fused.

As a result, a new subscene has been made, corresponding to the same excavation area 4 and its surrounding areas, maintaining the original spectral information (20 TIR channels, thermal infrared) and to the 0.5m spatial resolution. In both processes of image fusion the Imgfuse algorithms of the Geomatic programme have been applied.

5. Exploratory analysis

The processed images began to be analysed in an exploratory fashion at the end of 2007. Using the file with layers of short range photography and thermography information diverse radiometric profiles (*Fig. 4*) were made to detect spectral variability and establish spatial correlations between the characteristic elements resulting from the excavation. We can observe how the hottest structures correspond to the adobe walls, a building material used by the Celtiberians. This type of wall may be thermally distinguished from the walls constructed with rocky material. The same type of structure with a sharp lineal component can be easily separated according to its different formative composition.

The refractory materials used by the Celtiberians of Segeda appeared in the homes of the excavation area 4, presenting a very low response in the thermography, whilst the materials appearing next to the forge, are the hottest. These foreseeable responses are an advantage for the identification of houses or different buildings to the extent that they may be detected in future extensions of the excavated area.

Furthermore, a principal component analysis (PCA) was made, which focused solely on the thermal channels of the AHS sensor fused with

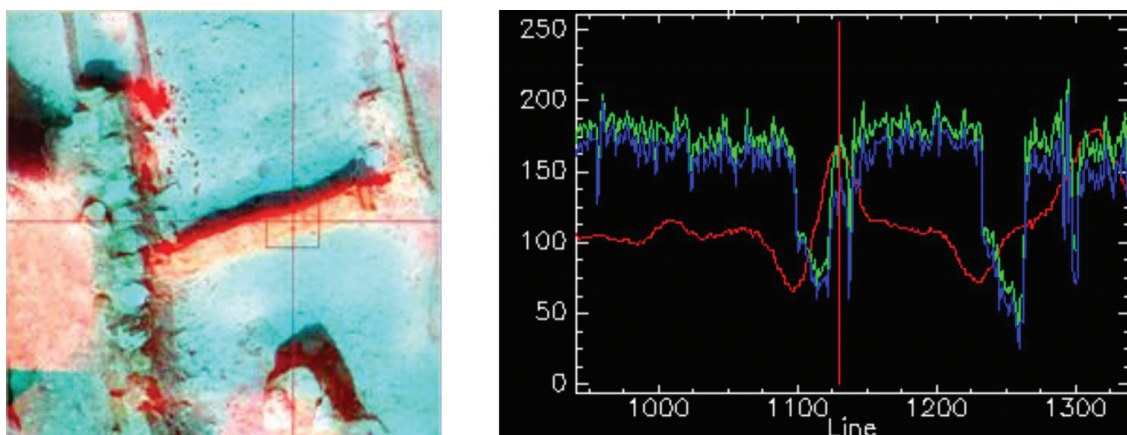


Fig. 4. Detail of adobe walls and stone in the fused image. Thermal (red) profile and visible (blue and green) profile.

aerial photography. Prior experiences (Traviglia 2006) have revealed satisfactory results of the application of this technique in hyperspectral data for the detection of buried archaeological remains. PCA is a technique which allows for analysis of the total variability, simplifying the original data by eliminating redundant information. In this way we reduce the dimensionality of the original data improving the contrast, thermal in surface area in this case.

Each main component is 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. There is therefore the certainty 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, being the one to exhibit the highest variances, puts forward an image where there is a preponderance of shiny pixels. The response of the nth degree component (PCn) is totally opposed to that of PC1, since it generates a rather homogeneous image where there is no outstanding response. In our case the first four main components (PC1, 2, 3 and 4) have provided the detection and extraction of an obvious alignment (blue dotted line in *Fig. 5*), which does not show up in the original, nor in the optic images, which in turn present a sharp turn in elbow shape. This alignment and the sharp turn experienced in the SW direction are precisely initiated in a point of inflexion in the elevation of the terrain, and could correspond to any type of buried structure, fortification wall or other.

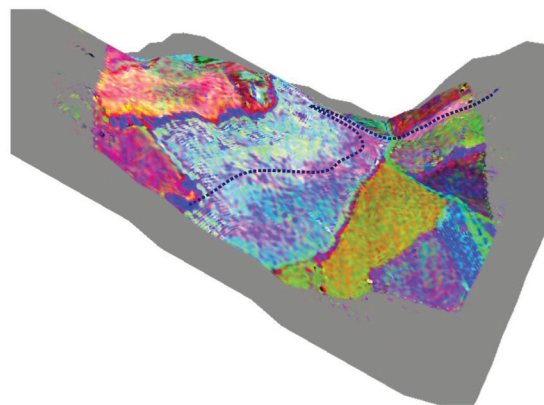
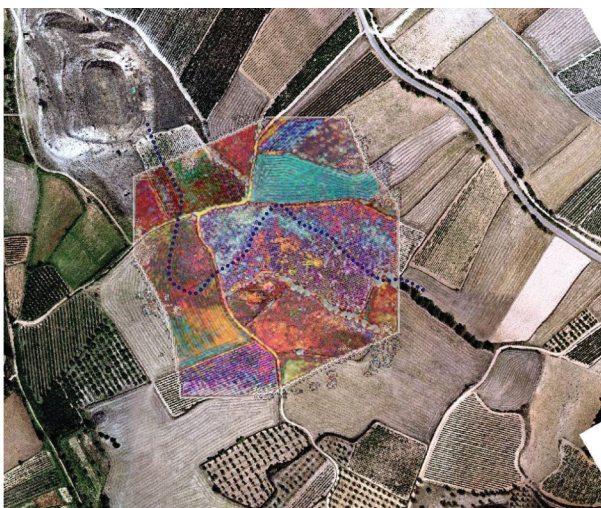


Fig. 5. Combination of rgb PC4, PC3 and PC2 colour superimposed onto aerial orthophoto. Combination of rgb PC1, PC2 and PC3 colour superimposed on digital model of slopes.

6. Conclusions

The work presented is an approximation in applying short range remote sensing and photogrammetry techniques and methodologies in the archaeological site of the Celtiberian city of Segeda. The characteristics and strategies for the acquisition of data measured in areas of the reflective and emissive spectrum were expounded by a 3D laser sweeper. 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 acquired in 2007 focused on the study of the spatial-thermal correlation between surfaces and materials resulting from the excavation of area 4 of Segeda. For this a multi-source 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 fused with aerial photography enabled the verification of the results obtained in 2005 on the surrounding terrain of area 4 in Segeda. The classification by spectral angle calculated in 2006 was thus validated, in which an alignment indicative in turn of possible buried archaeological remains was extracted. The integration of these results with digital models of elevation has led to the establishment of relations between the points of inflexion of the terrain and the thermal variability extracted from the main components calculated.

Finally, the work presented is part of the remote sensing line of research applied in Segeda, the general aim of which is the proposal of methodologies as support for new explorations.

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