ORTHOIMAGE PROCESSING IN ARCHEOLOGY. THE SITE OF COLONIA CLUNIA SULPICIA (PEÑALBA DE CASTRO, BURGOS – SPAIN)

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ABSTRACT:

In preserving and recovering cultural and archeological heritage, aerial photography and remote sensing, are useful tools, not only for the detection of new sites, but also for archeological documentation and investigation. Multi-source and multi-temporal imagery materials can guarantee a continuous monitoring of the state of site conservation.
We have studied some image processing techniques, with reference to archeological applications, achieving two goals: obtaining more readable and measurable images. This methodology is very different from the traditional use of aerial photography in archeology: not only stereo-photo-interpretation of the site, but digital filtering to magnify archeological evidence.
We have applied this experimental methodology to some sites in Spain. In this paper we present the results on the site of a Roman town in the Iberian peninsula, *Colonia Clunia Sulpicia* (Peñalba de Castro, Burgos). For some years, we have collected some information about urban texture without excavating, using nadiral and oblique photography. The main product of this research is the digital orthophotography of the entire site, that is very useful for archeologists.
3D exploration of digital orthophotography, makes the perception of micro-reliefs and slope irregularities in the site possible. The identification of alterations in micro-reliefs, provides the elements to identify layers of material from the ancient roman town and to highlight the urban texture and the access to the town.
Digital orthophotography is useful also for the reconstruction in virtual reality of the town, inserting the reconstructed models of the best known buildings.

1. HISTORICAL BACKGROUND

Colonia Clunia Sulpicia, capital of *Conventus Cluniensis* in the Province of *Tarraconensis* in *Hispania,* was the largest Roman city in the Iberian Peninsula.
Situated on a limestone plain at an altitude of 1000 m it reached an extension of 130 hectares. It was founded ex-novo in the Augustean/Tiberian epoch as a sinecism of two pre-existent celtic-iberian settlements the celtic-iberian nucleus of Clunioq (which gave its name to the Roman city) and the settlement known as Arauzo de Torre. The city underwent a remarkable economic development during the 1st and 2nd centuries A.D. and various archaeological expeditions have brought to light the forum, the basilica, roman baths, an abattoir and other blocks occupied by private houses as well as the theatre which exploits natural features of the terrain and has been a popular subject for prints since the 19th century.
We have been dealing with the problems of urban topography for some years now to try to solve two problems. The first is to try to understand if the entire area of 130 hectares was a single built-up area or if the urban layout took the form of separate city quarters. The second question regards some problems of urban orientation since, from the digs, we have discovered three different orientations.
With these problems in mind, years ago we decided to analyse the site using particular methods. The strategy adopted consisted of using photographs to reconstruct a 1:1000 scale model of the area, with details of the plateau on a scale of 1: 500. This model also contains details of buried archaeological evidence identified from aerial photographs. The data thus acquired are integrated with those obtained from a study of the excavated areas and from further studies of structures which, although buried, are visible on the terrain The product obtained is a digital relief model of all the data useful for an urbanistic analysis of the city.
The following step in the development of the methodology consists of improving the acquisition of the information present in the aerial photographs and in the Digital Terrain Model (DTM) of the hill on which the city is built. We decided to move in two directions which will be illustrated in the following pages.
First of all starting with the available data we created a digital orthoimage of the entire area of the hill using the DTM as a base and orthoprojecting onto it the photograms in scale 1: 12000 used for making the model. The purpose was to use the digital orthoimage obtained for evaluating micro-reliefs on the site, altimetry differences and other anomalies which might be useful in identifying means of access to the city, possible piles of rubble resulting from the ruins of ancient roman buildings etc.
Secondly, we decided to test some specific filters for image enhancing. In the present work we use a vertical photograph on scale 1: 4000, which represents a sector situated between the Casa de Taracena and Termas de Los Arcos. The purpose of enhancing the image is to discriminate between archaeological and non-archaeological traces, which are so numerous in aerial photos.

As we said above the use of these filters is not limited to photograms used in this work and connected with this site. We must mention the work done by J. Del Olmo, who took oblique photographs of the site at Clunia. These photograms are not only easier and cheaper to obtain but can be done repeatedly during the year to highlight seasonal differences.

2. MICRO-RELIEFS DETECTION

From an observation of the photogrammetric model, it is clear that some terrain elevations are not of natural origin. Photo-interpretation allows us to correlate these elevations with buried ruins, which in some case are quite visible in the photograms because of small colour variations. Because of the probability of finding hidden ruins where natural morphology has been changing, it is worthwhile creating a photogrammetric DTM.

2.1 Automatic DTM by autocorrelation

The Clunia plateau presents only small altitude variations, due to:

- natural orography, which has origin from the geological process of sedimentation and erosion;
- agriculture that require the formation of pits and furrows, boundary and field delimitations, accumulation of stones, terrain levelling, etc.;
- rubble piles.

These altitude variations are small, and it is not always possible to establish with certainty their origin without on-site checks. However, the analysis of the photogrammetric model can give information and measures that are difficult to acquire with the traditional topographic systems. The main advantages of the photogrammetry for archaeologists are:

- In a stereoscopic view the observer can quickly estimate the altimetry; this allows the photo-interpreter to read not only an image, but a three-dimensional model.
- The measurement (automatic or not) of a great number of points in the photogrammetric model is quick, fast and cheap. The products are profiles of the terrain and in some case digital terrain models (DTM).

Automatic DTMs can be computed using auto-correlation techniques (Kraus, 1993). The case of Clunia plateau is optimal to perform automatic DTM estimation by image correlation, because of the absence of trees, buildings and shadows.
We have computed three DTMs of Clunia hill:

- a global DTM of the hill, by using traditional photogrammetric techniques with Galileo Siscam Stereobit20 analytical stereoplotter; the photograms were taken at relative altitude of 2800 m with 158 mm focal length;
- an automatic DTM of the central area of the plateau, with 2 m resolution, by GeoSoft GCarto digital stereoplotter; the photograms were taken at relative altitude of 600 m with 158 mm focal length;
- an automatic DTM of the area between *Casa de Taracena* and *Termas de Los Arcos*, with 1 m resolution.

Better results can be achieved only using airborne laser scanning technique, and we hope that this will be possible in the future.

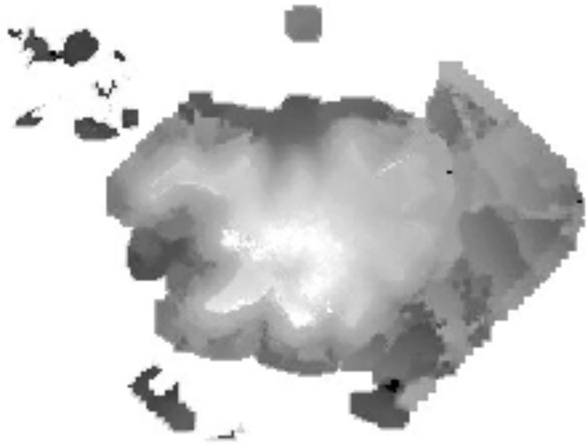

Figure 1. The DTM of Clunia hill made with traditional photogrammetric techniques.

Figure 2. The DTM computed by autocorrelation on the central area of the plateau. Some undulations (or micro-reliefs) are clearly non-natural. The white zones represent lack of data; this is due to the photogrammetric software used for DTM estimation.

DTM validation is in this case is performed only as internal reliability, observing the RMS of the estimated DTM points provided by the software GCarto.
The image in fig. 3 represents these RMS values. The biggest errors are in the east zone, and are produced by GCarto for unknown motives. Thus the DTM is not useful in this zone.

Figure 3. The DTM RMS values. The greyscale indicates the RMS values; higher values are darker and identify badly estimated DTM zones.

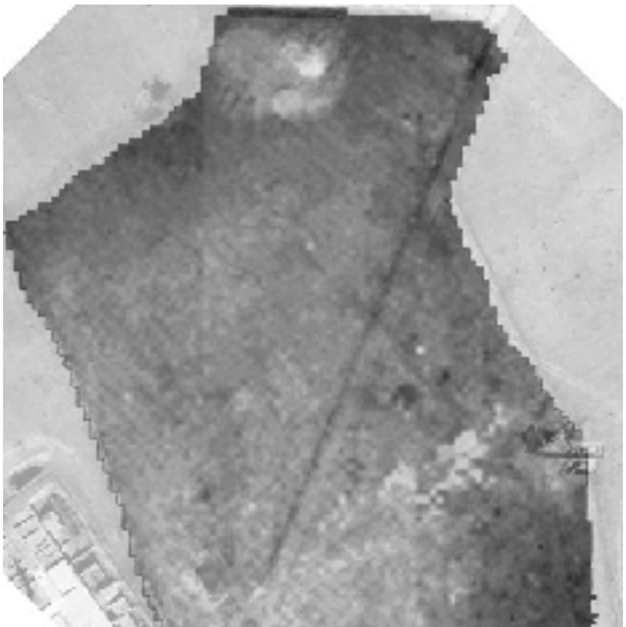

Figure 4. The DTM of the area between *Casa de Taracena* and *Termas de Los Arcos*, with 1 m resolution and the orthophoto superimposed.

2.2 Orthophoto

The next step is the orthophoto computation of Clunia plateau by using RSI ENVI software.

Is now possible using DTM and orthophoto to build a three-dimensional metric model of the archaeological site, and to navigate into the model itself. We have then used the orthophoto for image enhancement filtering, to emphasize archaeological traces, as will be described in the next chapter.

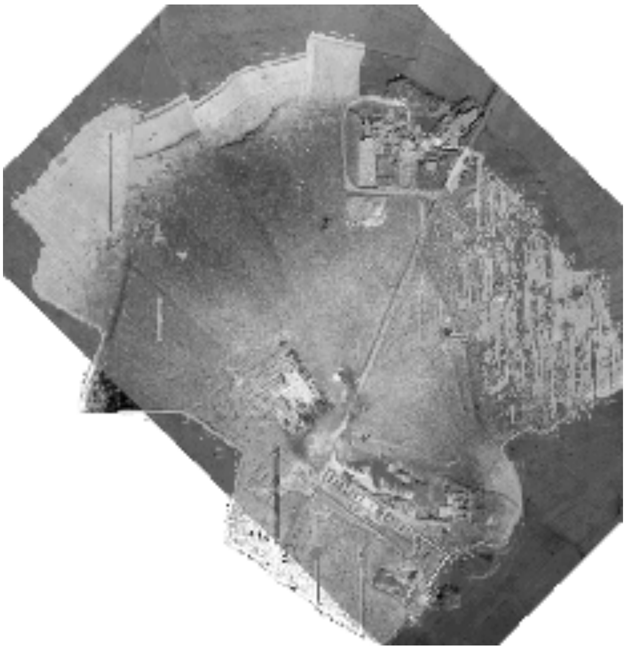

Figure 5. The DTM with orthophoto superimposed. The integration of altimetric and photographic data gives archaeologists a more readable model.

2.3 DTM analysis

DTM analysis makes evident the position and the shape of some buried buildings. At first, is clear that some low zones belong to the *Casa de Taracena*, and are underground premises and some cisterns. In the North direction we find a micro-relief with the same orientation of the *Casa de Taracena*, that fits the structures identified in 1995.

Then, a very interesting data is the presence of an other micro-relief in the South direction, that is parallel with the one discovered in 1995. This is an other building alignment that ends in the *Paredejas* zone, where are preserved the ruins of an "*opus caementicium"* building.

A first alignment of regular buildings was identified by Gillani in 1995; these are probably public buildings. He found also a possible extension between *Las Paredejas* and the *macellum*. Del Olmo in 2001 identified the same buildings which he hypothesized as a forum or market-place, due to the regularity of the building shape and the open space between the two alignments. This forum is smaller than the other already excavated. However he did not identified the second building alignment near *Las Paredejas*, where he localized the extension of a street that finishd in the forum of the Claudian epoch.

Thanks to DTM analysis we can note that the area between the two parallel building alignments is lower than the micro-reliefs that enclose it. So the micro-reliefs correspond to the ruins of the buildings, and the lower space to the market-place. Then, the analysis of the image and of the stereoscopic model has shown that in this area there are not building traces. Therefore it is an open area that maybe indeed a big square or a forum.

In the profile represented in fig. 6 we note five interesting micro-reliefs:

- relief 1: remains of building alignment;
- between reliefs 2 and 3: zone of *tabernae*;
- relief 5: possible prolungation of the *Paredejas* with orientation parallel to the traces discovered in 1995.

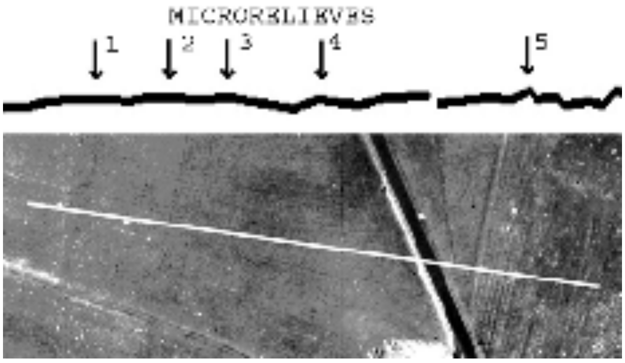

Figure 6. Micro-reliefs profile in the zone between *Casa de Taracena* and *Termas de Los Arcos* (direction N-S).

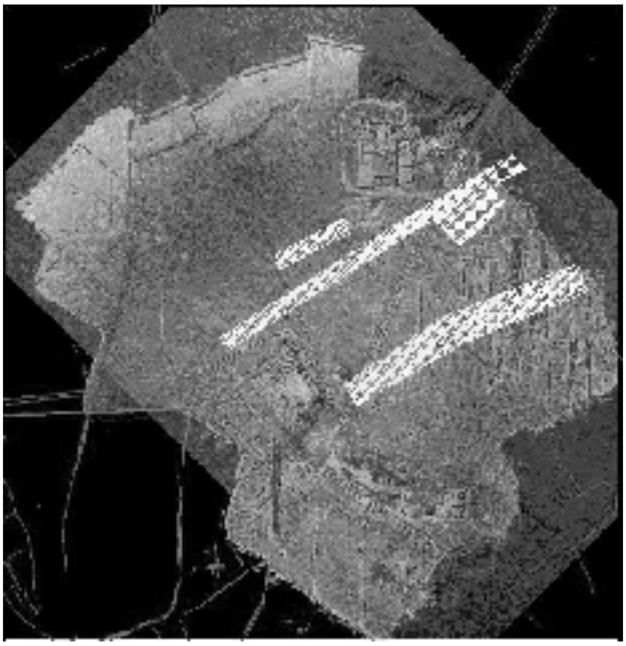

Figure 7. The detected urban areas. Three principal alignments of buildings are probably identified by DTM micro-reliefs. These alignments fit with *Casa De Taracena* orientation.

In conclusion, the altimetric data provided by DTM gives some interesting traces about building locations; however the quality of this DTM, estimated with photogrammetric methodology, is not so good to identify all the micro-reliefs, but only the most evident. We could identify and suggest an optimal solution by using airborne laser scanner DTMs, currently not available on this site.

3. FEATURE EXTRACTION

3.1 Image filtering

The process of image acquisition frequently leads (inadvertently) to image degradation. Due to mechanical problems, out-of-focus blur, motion, inappropriate illumination, and noise the quality of the digitized image can be inferior to the original. The goal of enhancement is, starting from a recorded image $c[m,n]$, to produce the most visually pleasing image $\hat{a}[m,n]$. The goal of restoration is, starting from a recorded image $c[m,n]$, to produce the best possible estimate $\hat{a}[m,n]$ of the original image $a[m,n]$. The goal of enhancement is beauty; the goal of restoration is truth. Obviously, for photo-interpretation purposes, restoration is not necessary but enhancement makes observer work quick.
We have performed image enhancement and filtering by using RSI ENVI software.

3.1.1 Histogram stretching

Frequently, an image is scanned in such a way that the resulting brightness values do not make full use of the available dynamic range. This can be easily observed in the histogram of the brightness values shown in fig. 8. By stretching the histogram over the available dynamic range we attempt to correct this situation. If the image is intended to go from brightness 0 to brightness 2^B-1, then one generally maps the 0% value (or minimum) to the value 0 and the 100% value (or maximum) to the value 2^B-1. The appropriate transformation is given by:

$$b[m,n] = \left(2^B - 1\right) \cdot \frac{a[m,n] - \min}{\max - \min} \quad [1]$$

where *a[m,n]* is the original pixel value and *b[m,n]* is the stretched pixel value.

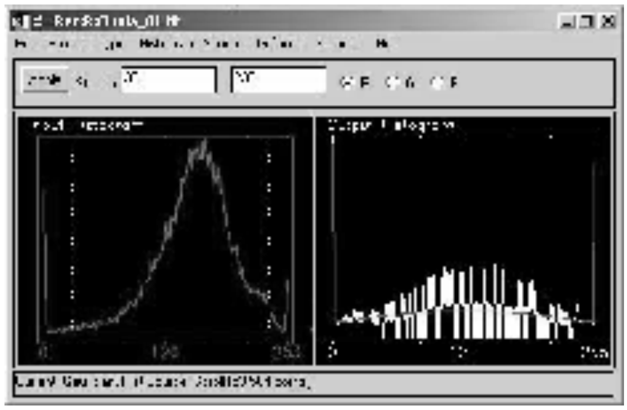

Figure 8. Image histogram Gaussian stretching. Note input and output histograms.

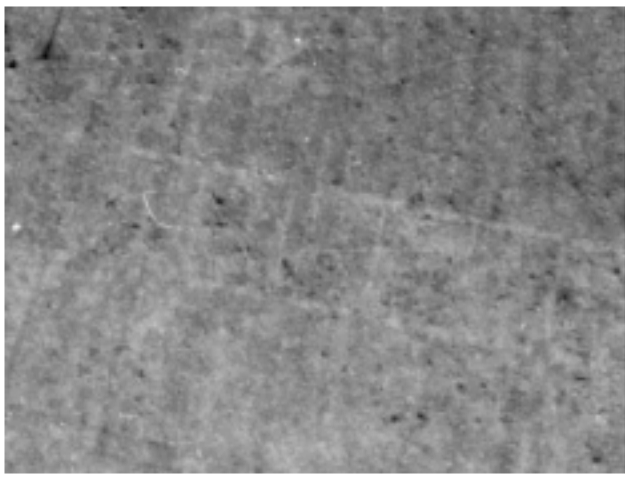

Figure 9. Original grey scale image of the test area between *Casa de Taracena* and *Termas de Los Arcos*. The building alignment (*tabernae*).

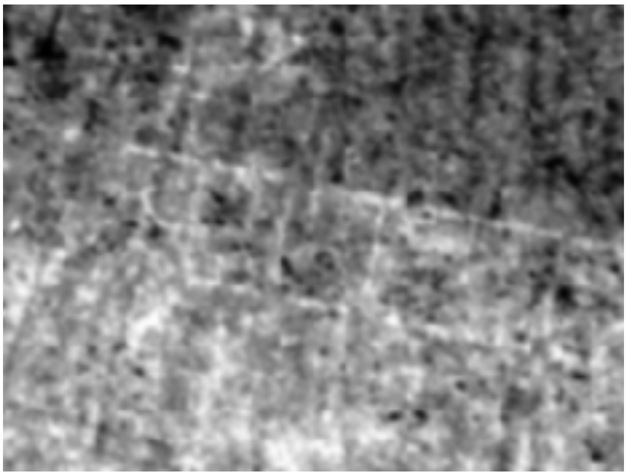

Figure 10. Stretched image; the histogram stretching is of Gaussian type.

3.1.2 Low pass filter

Low pass filtering preserves the low frequency components of an image, which smoothes it. ENVI's default low pass filter contains the same weights in each kernel element, replacing the central pixel value with an average of the surrounding values. The default kernel size is 3 x 3.

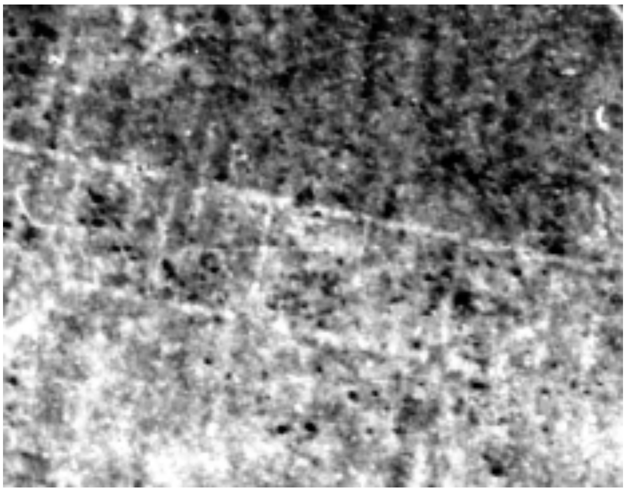

Figure 11. Low pass filtered image.

3.2 Feature extraction

At the state of the art, automatic feature extraction for archaeological purposes is possible in some simple case only. Observing Clunia photograms we note archaeological evidences, but also recent features, complex texture, etc. All these information is degraded in the image mainly by noise and shadows, and only human perception can interpret so complex cases.
In the present job, photo-interpretation is supported by DTM analysis and image enhancement. The elevation model and the enhanced orthorectified image can also be integrated in a 3D model. The photo-interpreter works using well known and consolidated instruments in a new way; this is specially true for archaeologists.
The final 3D model and the enhanced image make it possible to observe archaeological evidences never seen before. Discussion about this evidence is necessary for archaeologists to establish the possible function of buildings, city shape, limits and access, etc.
The methodology described in this paper, has been tested in the central zone of Clunia plateau, and we can present only some preliminary results.
Fig. 12 represents the features extracted from the enhanced image.

Figure 12. Features visible in the central zone of Clunia plateau.

4. CONCLUSIONS

The goal of our research is to demonstrate that micro-relief analysis and image enhancement can improve photo-interpretation results in archaeological feature extraction. We have examined the case of the city of Clunia, to solve some questions about urban organization and building localization. A test area was choseen in the central zone of Clunia plateau, where was possible to verify on site some extracted feature.
Micro-relief analysis of the zone between *Casa de Taracena* and the termas *De Los Arcos* has confirmed the building alignment traces identified in 1995. We also found a second building alignment that is an extension of the structures near *Las Paredejas*. Between these two alignments we can make the hypothesis of a second forum.
It will be interesting to extend the research to micro-reliefs SW from the Claudian forum. Some traces are visible on site, but not as well as in air photography. A study of peripheral zones can give information about fortifications and access to Clunia.
Image enhancement has revealed new archaeological evidence, as well has confirming what was known. We have now a better knowledge of Clunia's urban layout, but the new evidence needs to be verified on site.

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