CAA 2009 Williamsburg

Automatic Point-cloud Surveys in Prehistoric Site Documentation and Modelling

Mercedes Farjas[1], Francisco J. García-Lázaro[1], Julio Zancajo[2], Teresa Mostaza[2]

[1] Universidad Politécnica de Madrid (Spain)

[2] Universidad de Salamanca (Spain)

Abstract

This paper describes research related to multi-scale measurement and documenting of any spatial objects or spatially-linked information, covering, but not limited to:

- Cultural artifacts
- Prehistoric sites
- Archaeological Landscapes

The aim is providing the practitioners of Human Sciences with quality-controlled metric and geometric descriptions of any material elements concerning their disciplines. The starting point of this paper is a brief reference to some previous works participated by any of the authors, and several geodetic, cartographic and GIS works, together with 3D modelling of graves and petroglyphs. Some study cases out of the authors´ current research are then presented, describing and evaluating methodologies applied in each work. In most of these study cases research and education were combined, the works having been done by students directed by the research authors, using the new teaching methods like project-based learning, in the frame of Intensive Program activities included in the ERASMUS Program.

Key words*: 3D scanner, modelling, site documentation, point clouds surveys*

1 Introduction

It has been said that investigation begins when one has doubts on a certain issue and is impelled to search for a means of satisfying them. This was, in fact, how we began our archaeological projects, by questioning site and artefact documentation methodologies when participating in periodical archaeological campaigns.

In the present work we examine our experiences in the use of laser scanner technologies, briefly summarise the first projects carried out with them and then draw some initial conclusions on their viability and advantages.

We first became acquainted with laser scanners through the Leica company, which put one at our disposal for a data acquisition test. The modelling subject chosen was the statue of Cibeles in Madrid and the project was duly carried out after obtaining the necessary licences. The experience was briefly analysed in the journal of the Colegio Oficial de Ingenieros Técnicos y Topografía[1] .

The images thus obtained were quite surprising and, impressed by the device's capacity for data capture, to further analyse its possibilities for data handling we decided to carry out a series of

[1] Mercedes Farjas and Carmen Sardiña, "Novedades Técnicas: Presentación del equipo Cyrax 2500 de Leica Geosystem", *Topografía y Cartografía* 116 (2003): 70-71.

projects that were part of the requirements for the final year of the Topographical Engineering degree.

One of the first of these was the 3D modelling of a replica of the statue of a Xian warrior[2]. The model was obtained to an accuracy of within 1 cm. Specially interesting in this work were the targets for the subsequent merging of the different point clouds obtained from the surveys. Using our knowledge of photogrammetry we carried out several tests and had to adapt the shapes and colours to the new data acquisition system. Of the principal characteristics, we found that the targets:

- Did not necessarily have to be points, but could also be objects which could later be treated by mathematical analysis of their surface geometry. Ideally, geometries should be regular to allow their centres to be found by minimum square adjustment of the captured points.
- Shapes did not necessarily have to be on a small scale. In fact, the larger the size the easier it was to identify in the digital model and there was no loss of precision.
- Targets gave worse results than 3D geometric objects.
- Of the flat shapes tested, excellent results were obtained with coins
- Spheres were the ideal 3D shapes.
- Colour was another variable that had to be taken into account in the siting of the targets.

We then applied laser scanner technology to objects belonging to the national heritage and compared the results with those obtained by photogrammetry, publishing the results of the first analyses[3]. A partial summary of these projects was presented in Farjas, M. & García Lázaro F.J. 2008.

We undertook the modelling of the Abrigo de Buendía prehistoric site[4], and then used the same methodology for the laser scanning survey of Los Zarpazos in the Atapuerca archaeological site (Burgos, Spain). This last project was used to test the capacity of laser scanning to reproduce natural spaces in three dimensions, with the later addition of data from a short range scanner.

In both projects the general procedure consisted of:

- Pre-editing of the data capture. If the scan was too dense, re-sampling or segmentation was carried out.
- Registration of each point cloud in the chosen project reference system, generally local or global.
- Elimination of unwanted or erroneous points.
- Three-dimensional modelling.

The final results consisted of 3D models of the site, orthophotos, cartographies and videos. The figure below (see fig. 1) shows the model obtained at Atapuerca[5].

[2] D. Gutiérrez and J. A. Santamaría, "Estudio comparativo de precisiones entre un levantamiento topográfico clásico de precisión y un levantamiento con sistema láser escáner 3D: El Guerrero de Xi'an" (Dss Project, Universidad Politécnica de Madrid, Madrid, 2006).

[3] Mercedes Farjas and Anton Bravo, "Tecnologías de representación 3D en los procesos de documentación del patrimonio pétreo" in Ciencia, Tecnología y Sociedad para una Conservación Sostenible del Patrimonio Pétreo, ed. Restauradores Sin Fronteras (Madrid, 2007): 47-57.

[4] D. Alós and R. Minzateanu, "Proyecto e implantación de una red básica para dar cobertura al yacimiento del refugio paleolítico el abrigo de Buendía situado en Castejón (Cuenca). Obtención de cartografía y de un modelo tridimensional del refugio". (Dss Project, Universidad Politécnica de Madrid, Madrid, 2006).

[5] S. Vazquez, "Levantamiento mediante Láser Escáner 3D de la zona de Los Zarpazos en el yacimiento arqueológico de Atapuerca (Burgos)". (Dss Project, Universidad Politécnica de Madrid, Madrid, 2008)

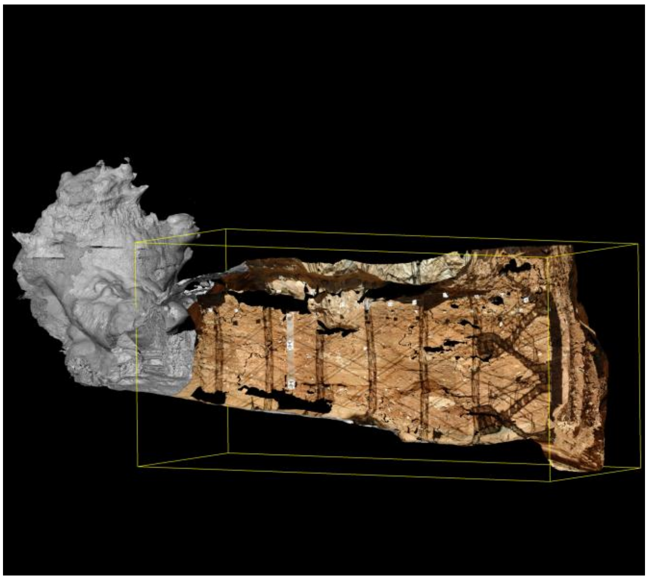

Figure 1. Visualisation of the Galería digital model and untextured Zarpazos model.

After the processing the data acquired by laser scanner, orthophotos can be obtained from the 3D point clouds. As these already contain the radiometric information, the process is a direct orthogonal projection of the point clouds onto a reference system defined by the user. The system does not necessarily have to be parallel to the scans, but can be whichever is best adapted to the zone geometry.

The orthophoto can then be exported to a CAD document for cartographic editing (see fig. 1). The figure below shows the cartography of the Atapuerca site.

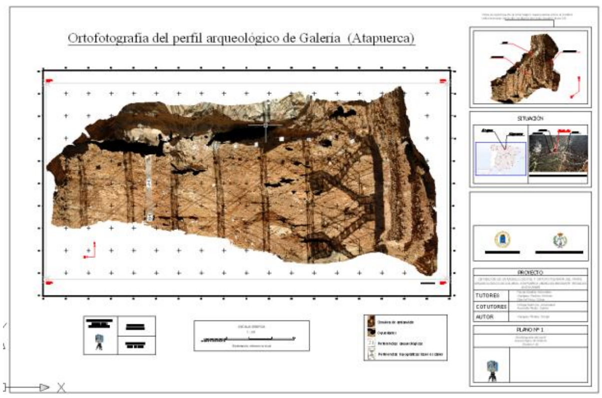

Figure 2. Orthophoto of the Galería (Atapuerca, Spain).

We experimented with different methodologies for the registration of artefacts[6]. In Atapuerca a short-range Konica Minolta laser scanner was used to include scratch marks made by tigers in the model and a prehistoric stone tablet was also modelled.

In the following section we describe two of our projects: one is the survey carried out by long-range scanner at the Cueva Blanca archaeological site and the second is the mapping of an artefact (the Guilanya Stone) by short-range laser scanner. The descriptions are followed by an assessment of the usefulness of these technologies in archaeological surveys.

2 Long-range laser scanner systems: survey of the Abrigo de Cueva Blanca[7].

The objective of this project was the modelling of the Abrigo de Cueva Blanca site and its surroundings by laser scanner. The site is in Hellín, Albacete Province, Spain.

This site was chosen due to its recently discovered wall paintings, which had not been examined by prehistorians or archaeologists. The project was carried out in collaboration with the Prehistory Department of the Spanish Open University (UNED) and the HafenCity University of Hamburg, Germany.

The site is 35 m long and a width that varies between 5 and 8.5 m. (see fig. 3). Numerous stone remains and, to a lesser extent, ceramic remains can be seen on the surface of the site and are clear indications of a prehistoric dwelling place, probably from Neolithic times to the Bronze Age.

---

[6] Mercedes Farjas, *El registro en los objetos arqueológicos: Métrica y Divulgación* (Madrid: Ed. Reyferr, 2007).

[7] J. López, "Levantamiento mediante laser escaner 3D del abrigo de Cueva Blanca, Hellín (Albacete)". (Dss Project, Universidad Politécnica de Madrid, Madrid, 2008).

The wall paintings consist of various animal and human figures in different tones of red pigment. The most interesting group (see fig. 4). is situated on the eastern side, faces west and measures 4 m long by 2.4 m high.

Figure 3. Wall painting at the Abrigo de Cueva Blanca site.

Figure 4. The best preserved group of paintings.

A Leica total station TC-705 was used to construct the grid of the area surrounding the site. To map the points of the site itself two scanner systems were used, a Trimble GS 200 and a Z+F Imager 5006 (see fig. 5), both of which belonged to the HafenCity University of Hamburg.

Figure 5. Equipment and photographs of the spheres, generator and targets used.

The 3D GS200 system uses a pulsed Nd: YAG laser emitted in the visible spectrum range at a wave length of $\lambda = 532$ nm (green). Pulse energy is $E = 0.06$ μJ for a duration of 600 ps. The system can produce up to 5000 pulses per second, i.e it has a maximum repetition frequency of 5000 Hz.

The Z+F Imager 5006 works by bouncing a laser beam off the centre of a rotating mirror which rotates the beam vertically to scan the surrounding area. Angular encoders measure mirror rotation and the horizontal rotation of the equipment. The measuring system is based on phase difference technology and emits various waves at different longitudes. The biggest advantage of the optical triangulation method is its high point capture speed, up to 500,000 per second, compared to the 4,000 per second of the time of flight method.

The project work phases were composed of.

- Data acquisition
- Information processing

- Visualisation of the results

The Z+F Imager 5006 can work from a PC or from a small lateral user interface, the second option being chosen in this case to simplify the process. After scanning the results were visualised in a PC. Besides registering points, the scanner captures other data, such as intensity, reflectance and RGB components. This additional information is pre-processed in a program provided by Z+F, which also exports the scans.

The GS 200 was operated via computer with the help of the auxiliary Trimble RealWorks software, which was also used to handle data processing for the entire project.

Each scanner was placed in different locations. The longer range Trimble GS 200 carried out three surveys, one from directly in front and two others from each side. The following parameters were defined:

- Maximum distance: 50m
- Resolution: 1.4mm

The Imager 5006 carried out five surveys from different stations on the site. Scanner resolution was then changed and two further surveys were performed for detailed registration of the wall paintings. Scanner parameters for scans 1 to 5 were.

- Maximum distance: 50m
- Resolution: 1mm

In scans 6 and 7 the parameters were modified to:

- Maximum distance: 10m
- Resolution: 0.5mm

The number of points captured in each survey and scan is shown in the table below (see table 1). A total of over 50 million points were captured in a single day.

		Points	Total points
GS200	Station 1	2 465 483	6 452 151
	Station 2	1 977 931	
	Station 3	2 008 737	
Imager 5006	Station 1	3 000 776	45 505 869
	Station 2	2 778 051	
	Station 3	3 106 332	
	Station 4	3 769 191	
	Station 5	3 358 215	
	Station 6*	12 547 883	
	Station 7*	16 945 421	
	TOTAL PROJECT POINTS		51 958 020

Table 1. Number of points registered

All the scanner data were transferred to the computer files. Post-processing of data is carried out to reduce the size of the captured information, position the data, eliminate noise and select the data required for modelling.

After registering the scans from all the stations they were merged into a single model. The scanner registers the position of the captured points and situates them in relation to the position of the centre of the laser scanner itself. With each new survey we create a new coordinate reference system, which is different for every scan captured.

To obtain a uniform reference system, similarity transformation is applied to the common points of the different scans. This transformation is different for each of the cloud points captured by the different scans. Before application, a scanner reference system must be defined for use in all scans. All scans are then automatically registered in the same local reference system.

The Imager 5006 scanner cannot automatically recognise targets, so that scans were merged by manually choosing common points and identifying the targets located around the site. When this process has been completed in all point clouds the program automatically locates the common points in the different scans and merges all the models.

The zone containing the wall paintings was scanned only by the Imager 5006 at a resolution of 1 mm. Since this area was comparatively small, approximately 9 square metres, there were not enough targets available to provide automatic merging, so that the reference points were obtained manually using the features visible on the rock face.

When all the points have been entered in the scanner's reference system, they are converted to a previously established topographical terrain reference system. This mesh was used to give coordinates to the spheres and targets placed around the site.

As in the above-described scan merging stage, as both systems share common points a 3D transformation can be carried out to transform the global point cloud contained in the scanner reference system to the local topographical mesh established for the project.

The point cloud was then divided into segments to facilitate the elimination of unwanted points and data handling and to make the most of the available computer capacity (see fig. 6).

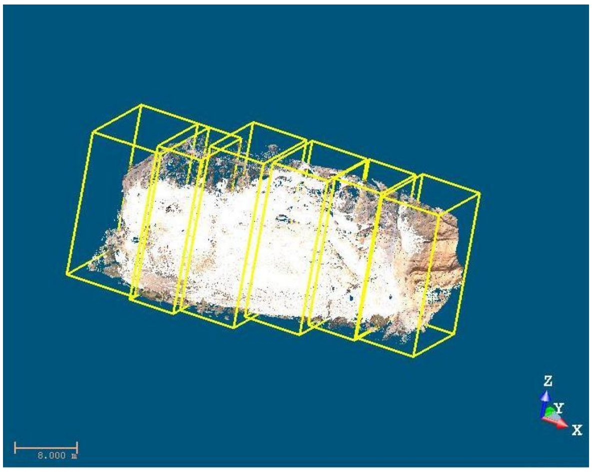

Figure 6. Segmentation process of the point cloud.

The next phase consists of cloud sampling, which is important for the validity of the final results and consists of the elimination of noisy or unwanted points. This step has the advantage that points can be eliminated automatically, thus reducing file size, improving visibility and handling and reducing computer operating times. If the process is carried out in automatic mode, particular care should be taken not to remove information that could subsequently be required for the final product.

In this project, the topographical and spatial filters were the most frequently used to eliminate vegetation, facilitate computation and homogenise the figures. Intensity-based sampling was little used since in our opinion it did not give satisfactory results. Scan-based sampling was used to some extent, but only eliminated a very small proportion of the total points.

When the point cloud has been registered, georeferenced and cleaned of noise and unwanted points, useful results can then be obtained. The most interesting of these may be obtained from the results of colour assignation, the 3D site model, texture matching and orthoimages.

COLOUR ASSIGNATION

Colour assignation is a previous step to obtaining results from the point cloud and can be carried out in various ways. One of these consists of incorporating a camera into the scanner to register point colours, as can be done in the case of the Trimble GS 200. Photos of the zone can also be taken with a conventional digital camera for later application to the point cloud.

In our case, when the data from the two systems had been joined we decided to incorporate colour data from the photographs taken of the site, since, although the data obtained from the GS 200 included colour information, the data from the Imager 5006 did not, and the images thus varied widely in quality and were difficult to visualise. For this process we had to identify common points in the 3D point cloud and in the photos, for which the targets, pronounced hollows and natural features were used. The internal and external camera orientation parameters were also considered, although they did not provide very useful results. The process was finalised when the two-dimensional position defined by the parameters obtained from all the identified points in the 3D point cloud coincided with the point identified in the photo.

When the inverse spatial intersection has been resolved, the program re-samples the entire point cloud registering the colour value (RGB) taken from the pixel nearest to the corresponding position (x, y) in the photo (nearest neighbour interpolation). This radiometric information is then stored to provide more realistic visualisation. The figures below illustrate different stages of the colour assignation process of the 3D point cloud (see fig. 7).

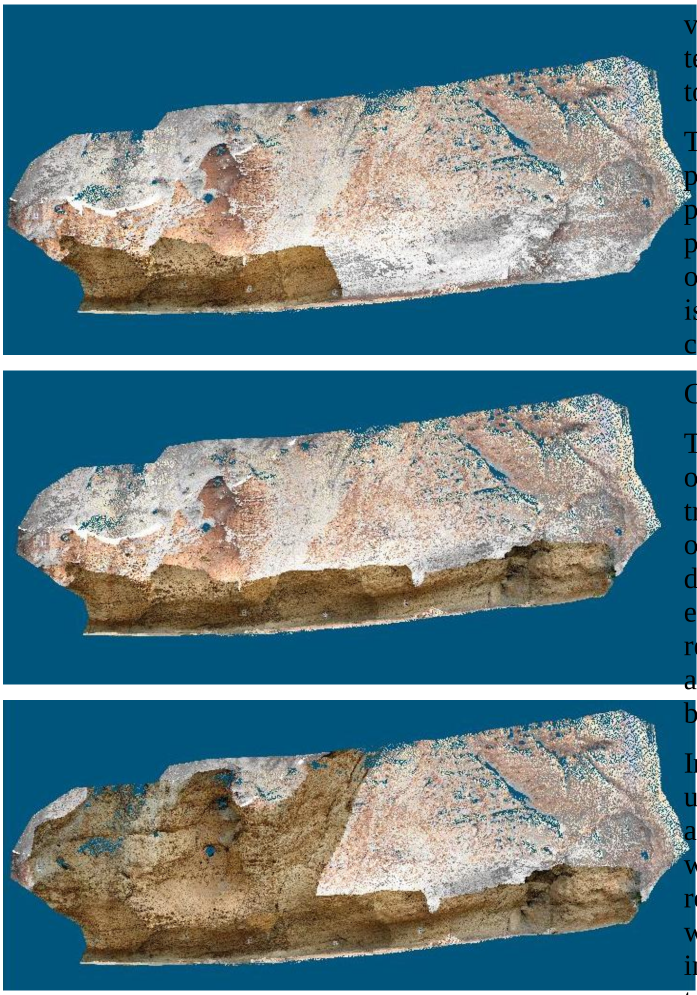

Figure 7 Colour assignation process of the point cloud.

CREATION OF THE 3D MODEL

The creation of a 3D model of the site is the step previous to texture matching. The first stage of the modelling process is the spatial filtering of the point cloud to reduce the number of points and reduce computer operations. The model is then created in RealWorks software using the projection best suited to the purpose. However, as the surface of the site was highly irregular, no projection was in fact used as the site geometry was too complex. The digital model was edited by the TIN (triangular irregular network) method in all the zones containing points. Such programs normally use a Delaunay triangulation algorithm, by which the surface is divided into a series of triangles whose vertices are formed by the 3D points of known coordinates. When it has been considered valid for the project the next stage is to apply texturing to the grid in order to give greater realism to the digital model.

The texture used was taken from the different site photographs which had been matched with the point cloud in the previous colour assignation process. When the image has been superimposed on the surfaces the texture can be applied and what is known as a "realistic image" is obtained, in our case an image of the Abrigo de Cueva Blanca.

CREATION OF THE ORTHOPHOTOS

The textured grid can be used to produce orthophotos. An orthophoto is a digital image transformed from a perspective projection to a an orthogonal projection, eliminating any image displacement due to inclination and the orographic effect of the photographed surface. It should be remembered that an orthoimage can be considered as a plan or map on which a non-specialist should be able to measure angles, distances and areas.

Input data for the generation of orthoimages usually consist of a digital model and the appropriately oriented site photographs, from which the radiometric values of the pixels in the resulting image are calculated. In this project, as we already had available points with radiometric information (RGB), the process was only applied to the orthogonal projection. The orthophoto has the following characteristics:

- Size: 4375x1625 (pixel)
- Size of area: 37x13 (m)
- Scale: 1/100
- Nº of bands: 3 (RGB)
- Resolution (píxel size): 8mm

Due to the archaeological interest of the rock paintings, two high resolution scans were made of this zone in order to obtain an orthophoto. The difference between this image and that of the complete site was that the rock occupied by the paintings had no clearly identifiable georeference points due to its small size and was not included in the site's topographical reference system (see fig.

8). However, as in the case of the orthophoto of the entire site, the orthophoto of the paintings included all the metric properties.

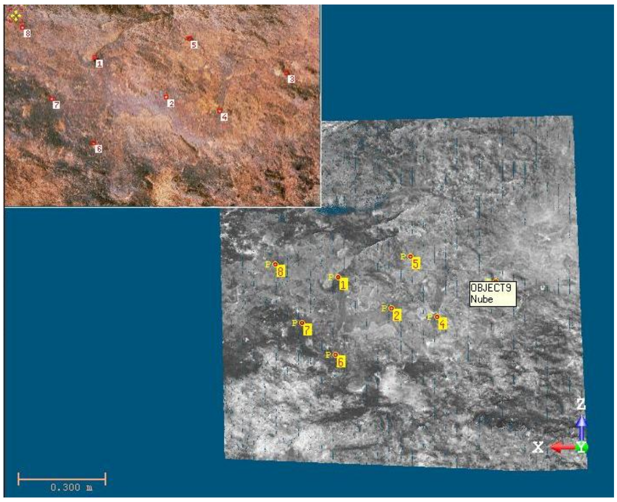

Figure 8 Identification of common points in the photograph and point cloud.

The characteristics of the orthophoto of the wall paintings are as follows (see fig. 9):

- Size: 840x653 (pixel)
- Size of area: 568.8x442.2 (mm)
- Scale: 1/20
- Nº of bands: 3 (RGB)
- Resolution (píxel size): 0.7mm

Figure 9 Orthophoto of the best preserved of the paintings.

CREATION OF THE "REALISTIC IMAGE"

After establishing the grid and validating it for use in the project, texturing had to be applied to the digital model In order to obtain a lifelike image of the Abrigo de Cava Blanca site. The texture used in this case was that of the orthophoto that had been produced in the previous stages, since it had the same projection plane as that chosen for making the grid. A video of the site was also produced at this stage, as this can easily be carried out by one of the data handling software options.

Finally, to determine whether the objectives of the project had been accomplished, an assessment was made of the quality of the results obtained. The precision of the site modelling points and orthophotos was examined and was seen to be within 10 mm. The compatibility between the two laser scanner systems was also satisfactory as the merging of the point clouds obtained from each one was successfully carried out in the site modelling, as shown by the standard deviations of the different fits.

3 Short-range laser scanner systems: 3D Imaging of the Guilanya Stone[8]

Short range optical laser (also known as proximity laser) triangulation techniques are widely used in industrial applications to model component parts to a precision within 1 mm. These triangulation light block systems provide enhanced imaging of objects in greater detail and at a higher registration speed than long-range systems, which also lose radiation distance to the object and have a reduced visual field. Short range 3D scanners are recommended for maximum imaging precision, as is required for the reconstruction of industrial parts or archaeological artefacts.

[8] D. Jiménez-Riesco,"Representación Tridimensional de los "Grabados de Guilanya" mediante laser escaner 3D. Museo de Solsona (Lerida)" (Dss Project, Universidad Politécnica de Madrid, Madrid, 2008)

The Kónica-Minolta VIVID 9i scanner (see fig. 10) used in this project, provided by the ICOM 3D company, is a non-contact laser beam triangulation scanner. It was designed to operate indoors powered by an electrical supply network, so that an auxiliary power supply (battery) is essential for the register.

Figure 10 Minolta Vivid 9i laser scanner.

The accuracy of short range laser scanners is in inverse proportion to the triangulation distance. Intersection uncertainty increases with distance and a precision of 0.05 mm is guaranteed at distances below 3.5 m. The application used for the capture was the Kónica-Minolta Polygon Editing Tool (PET) software, which provides for the adjustment of scan parameters, as well as different scan, visualisation and registration options.

The options available include:

- Control of distance from the target by an "autofocus" system for each scan.
- Automatic calibration when changing lenses.
- Visualisation of the registered image to check quality of the results.
- Colour correction, gap filling and noise filters.
- Synchronisation of scan with target rotation.
- Alignment of registered scans with semi-automatic block point cloud adjustment to identify common points in overlap zones.
- Precision analysis in block point fitting. Goodness of fit can be verified by visualising standard deviations.
- Compatible with standard laser scanner software (Rapid Form, Polyworks).

Rapid Form 2006 was used for post-processing. This software works in a similar way to graphic design programs such as AutoCAD or MicroStation and gives excellent results in processing, cleaning and improving the quality of 3D scans.

Project phases included. Data acquisition, post-processing and visualisation of results.

Before scanning the artefact, its dimensions were noted to determine the number of scans necessary to cover its entire surface at maximum precision. The material and morphology of the stone meant that data acquisition would be a simple process. As the precision had to be very high the following registration parameters were established:

- Mean target distance: 0.921m.
- Homogeneous 0.39m grid with spatial resolution.
- Very short capture time of 2.5 seconds per scan. Data acquisition was accomplished in 20 minutes.

The proximity scanner was stationed at a distance of approximately 0.9 m for each scan. The Konica Minolta scanner was not specifically referenced to known coordinates but worked with a relative coordinate system .

The artefact was registered correctly in nine transversal and longitudinal scan mosaics which were block adjusted. A spatial resolution of the order of 0.39 mm was achieved between points on the merged grid. Each scan was fitted to the previous one by choosing common points in the transverse and longitudinal overlaps. Finally, the nine scans were merged into one to an accuracy within 20 microns.

To guarantee a good result, the grid quality was checked visually in the zones of special interest. The final grid was regular with uniform tessellation. Raw data registered by the VIVID 9i produced a project point cloud with a total of 1,474,946 points.

The reference system trihedron was defined by choosing an origin and the best-fitting plane of the stone. The z axis of the direct trihedron was situated orthogonally to the plane of the stone, so that it could be treated as if it were a fragment of the earth's surface and a digital elevation model could be generated.

Post processing phases:

a) Noise elimination

The point cloud had first to be inspected visually to detect any possible defects or noise that would impair the quality of the model. Minimum cleaning was performed, with few filtering operations and very little information had to be eliminated so that few details of interest were lost. The quality of the registration was such that the point cloud needed very little geometric correction during processing.

b) Data Filtering

The minimum of filtering processes were used on the short range register and the digital model was created after importing the data captured in Rapidform.

The following steps were carried out:

1. "Filter Noise" to eliminate unwanted points. Only 246 points were eliminated and the number of points remaining was 474,690.
2. "Filter Redundancy" to improve consistency of the register at a relative point accuracy of 0.5 mm.
3. Triangulate Surface 3D". Triangulation of the digital model to obtain maximum model quality.

c) Construction of the solid model

In order to triangulate dense point clouds, the applications use powerful algorithms that allow the surface of the object to be defined. When they possess complex geometries, they are triangulated in 3D without using a projection. If the object can be adapted to a specific geometry (plane, cylinder, sphere, cone) the triangulation can be fitted to this geometry to obtain a reference pattern and thus save processing time. In the case of the stone, we modelled the volume without a projection. As a great number of points were involved, the process took 15 minutes, but larger volumes could take much longer according to the computer memory available. The optimised model was exported to a VRML file, which can be used to visualise the result of the digital model from a computer.

After the correct treatment of the triangulation, the final result is in the form of a solid three-dimensional model in a reference system that defines the geometry of the object modelled.

d) Texture matching the geometry

The images of the Guilanya stone were obtained by a Canon Ixus (7.1 MP) compact digital camera, which provides good quality photos. Digital photos should be processed with filters (Photoshop) to improve global radiometric and colour quality before texture matching. When the work involves a mosaic of different orthophotos, block homogenisation of the results by filters is essential to permit histogram equalisation in the overlap zones. The Guilanya stone was textured by fitting a single image to the model, which produced a photorealistic geometric document of the archaeological artefact which could be visualised on a computer screen.

The metric document thus obtained is in the form of a scaled orthoprojection of the textured image. Differential rectification of the image, as in the process described for the preceding project, consisted of straightening and scaling the small geometrical units (pixels) textured in the model. This provided an orthogonal image projected onto a plane at the desired resolution. In this way the defects due to relief and camera axis inclination were eliminated from the textured image and the central projection became orthogonal. This new photographic document is known as an "orthophoto" and is as exact as a map with regard to distance and direction measurements.

e) Inspection tools: model quality.

To check the quality of the digital model, laser scanner applications have potent statistical tools to assess the goodness of the model constructed by comparing the register with the digital model. Standard deviations can be analysed globally or locally by projection planes (X, Y, Z) that bisect the digital model. A maximum tolerance can be established for defect correction. There are also other options that allow studies to be made of the model curvature and the incidence of the laser on the target.

Rapidform 2006 software was used to analyse scan results and the following processes were included:

- Model curvature analysis.
- Laser beam incidence angle analysis.

These types of analysis provide the grounds for determining whether the digital model generated complies geometrically with the precision requirements in the reconstruction or 3D modelling of an object. In this case, the curvature analysis of the digital model allowed us to determine whether the fine engravings on the stone had been preserved on the model.

f) Results

The orthoimages were imported in TIFF format as external raster reference in AutoCAD. This generated two outputs:

- An authentically coloured orthoimage.
- An image in grayscale.

The option that provided the clearest details of the engravings was the shaded grayscale image. Furthermore, as this image was not in colour, it was possible to adjust the contour lines representing the micro-survey of the object.

4 Conclusions

Various projects have been described as case studies of the use of short and long range laser technology. The work carried out is focussed on a methodological comparison of new systems of data acquisition with traditional photogrammetry and the latest versions with correlation options presently available. In general, we would recommend that before undertaking a project with laser scanner systems the objectives should be evaluated so as to form a basis for a decision on the best data acquisition method that meets the needs of the project.

After carrying out this study of the techniques involved in 3D laser scanner modelling of archaeological sites and artefacts, we consider that their advantages and disadvantages can be summarised as follows:

- Advantages:
  - Fast data acquisition: laser scanners can save a great deal of time.
  - The high number of points that can be captured: millions can be captured in a single day. The zone under study can be defined in much greater detail than is possible with classical topography procedures.
  - Precision: laser systems guarantee the accuracy of the point cloud scans, ranging from several millimetres in long range systems to under one millimetre in short range. This produces high quality models with well defined details.
  - Laser scanners can provide greater detail: dark zones can be scanned.
  - Scans can be joined together: the system works with object coordinates similar to that of photogrammetric processes.
  - Image acquisition in real time: some laser scanners incorporate a video camera that can be operated during scanning.
  - Different products can be obtained (orthophotos, curvature, etc.): the associated software offer a wide range of final products.
  - Visualisation of results in real time: during data acquisition the software permits scans to be visualised on a PC for validation.
- Disadvantages:
  - High cost of laser scanner systems: as the technology is still being developed prices are

high and purchase involves a considerable investment.
- The cost of software: prices are in line with the present high cost of scanners.
- The equipment must be handled with great care: the laser system is delicate and is sensitive to rough handling.
- The systems are bulky and difficult to transport.
- The technique still has not been widely accepted: as it is still under development, many archaeologists are reluctant to use it.
- Much auxiliary equipment is required (spheres, generators, etc.): some systems have a high power consumption and may need generators to function satisfactorily.
- The technique needs the support of powerful computers: in many cases, satisfactory results depend on computer operations being available.
- Longer processing time: although field work is greatly reduced, computation time can be lengthy.
- Not compatible with other programs: as the technology is still being developed, each manufacturer makes his own software algorithms, which complicates the interpretation of results and interaction with other programs.
- Data processing requires that operators must be specially trained in the technique.

Bibliography

Barber, "Towards A Standard Specification For Terrestrial Laser Scanning In Cultural" ISPRS(International Society for Photogrammetry and Remote Sensing Estambul, 2004). Commission V, WG V/2

Demir, "Laser Scanning For Terrestrial Photogrammetry, Alternative System Or Combined With Traditional System?", ISPRS(International Society for Photogrammetry and Remote Sensing, Estambul, 2004). Commission V, WG V/2.

Farjas, Mercedes. "Las Ciencias cartográficas en la arqueología: la búsqueda de la métrica en los modelos de divulgación científica". *DATUM XXI* 3 (2003): 4-12.

Farjas, Mercedes. *El registro en los objetos arqueológicos: Métrica y Divulgación*. Madrid: ed. Reyferr, 2007.

Farjas, Mercedes and García-Lázaro, Francisco J. *Modelización tridimensional y sistemas láser escáner 3D aplicados al Patrimonio Histórico*. Madrid: ed. La Ergástula, 2008.

Fryer, John; Mitchell, Harvey and Chandler, Jim. "The Power of Photogrammetry". ASM. Internet, http://www.asmmag.com/news/491 (accessed March 3, 2008).

Llanos Viña, Alfredo and García-Lázaro, Francisco J. "Photogrammetric Surveying of the Cave Pictographs of Altamira". *Jenaer Rundschau* 4 (1983): 193-197 and 206.

S. Bracci S., Falletti F., Matteini M., y Scopigno R. *Explorando David: diagnóstico y estado de la conservación.* Italia: Giunti Press, 2004.