LASER SCANNING AND PHOTOGRAMMETRY FOR THE DOCUMENTATION OF A LARGE STATUE - EXPERIENCES IN THE COMBINED USE

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ABSTRACT:

Cultural heritage applications involve measurements at different possible scales. While photogrammetry and metric surveying techniques can be suitable for archaeological sites and buildings, they present certain disadvantages for smaller and more complex objects such as statues. Laser scanning technology with its automated data capture capabilities is bringing new perspectives and can satisfy most requirements of this type of applications. This paper describes a practical example based on the combined use of digital photogrammetry and laser scanning techniques with an aim to create a geometrically accurate 3D model of the ancient statue of Hermes of Praxiteles, which is housed in the archaeological museum of Olympia in Greece. A comparative evaluation of the two techniques in the data capture and modelling of the statue is discussed and typical results of the models are presented.

1. INTRODUCTION

Throughout 20th century, photogrammetry has almost been the exclusive technique implemented for the geometric recording and documentation of large monuments and complex irregular structures, such as statues. Sensitive and fragile objects, consisting of a variety of surfaces usually with many curves and holes, could be restituted in analog or digital 3D form through photographic imaging as a non-contact method. However, the restrictions of stereoscopic photography in combination with the complexity of the object, poses several limitations for the detailed recording of objects, which in an indirect way can also affect the obtained accuracy.

The recent advances in terrestrial 3D laser scanning have indicated that this technique has the potential to serve as a powerful tool for architectural and archaeological recording. The advantages manifest specifically for the recording of complex objects, such as sculptures and statues. Examples of applications using laser scanning techniques with encouraging results are found in Adolfsson (1997), Beraldin et al. (2000), Levoy et al. (2000), Rocchini et al. (2001), Henz (2002). Terrestrial scanners may be categorized into two groups:

- Triangulation scanners, which consist of a laser and a CCD housed in a single unit. The CCD is used to record the displacement of a stripe of laser light projected onto an object. Usually the scanner to object distance is less than 2m (close-range scanners). This type of scanners has geometrical resolution and accuracy better than 1mm.
- Time of flight scanners (terrestrial LIDAR), which use a pulsed laser to measure the range to a point on an object's surface. There are several manufacturers who currently provide scanners of this type, like Cyra Technologies, Callidus Precision systems, MENSI, Riegl Laser Measurement Systems, Zolleral Froehlich etc, which have range distance between 2-100 m and resolution of few mm (Kern, 2001). These systems do not provide satisfactory accuracies for applications requiring recording of complex monuments. In addition, the speed of data acquisition is much slower compared to the triangulation scanners.

The development of varying types of scanners cannot imply that the 3D documentation of sizeable and complex objects, such as large statues, has become trivial or that scanning can replace all other imaging techniques. On the contrary, there are several technical difficulties associated with the use of scanning, such as data management due to the huge quantities of data generated on-site, and requirements for sophisticated processing capable of performing registration and merging of large numbers of scans. Furthermore, the type and format of the products generated by scanning techniques, such as point clouds, triangle meshes and 3D models, are different to those usually expected or are familiar with by the end users like architects, archaeologists or conservators.

Figure 1. The Hermes statue as is exhibited in the museum

In applications which require recording of large objects, usually the integrated or combined use of laser scanning with photogrammetric methods can give better results than the sole implementation of each one technique. This paper discusses the combined use of photogrammetric and laser scanning methods for the creation of an accurate 3D solid model of a complex large statue. The ancient statue made by Praxiteles presents the mythical god Hermes and is housed in the archaeological museum in Ancient Olympia in Greece (Figure 1). Data collection and processing aspects for each methodology are described and results are given to highlight the advantages that are available to end users through the combined use of the two technologies.

2. THE HERMES OF PRAXITELES PROJECT

The main objective of the "Hermes Project", which was funded by the Hellenic Ministry of Culture, was the construction of a seismic isolation retrofitting assembly for the statue. This is because the region whereby the archaeological museum of Ancient Olympia is located and houses the statue, is subject to high seismic activity. The assembly is designed to minimize the ground accelerations and to nullify the possibility of causing damage to the statue due to any possible earthquakes. For this purpose, an accurate 3D model of the statue was required. The project was commissioned to a team of researchers from the Schools of Civil Engineering and Rural and Surveying Engineering of the National Technical University of Athens, in Greece.

The Hermes statue is considered a masterpiece of sculpture art of the classic antiquity era. It is dated circa 343 BC and is made of Parian marble. It is believed to be the only original work still existing by the famous sculpture Praxiteles. The statue was dedicated to the sacred Altis from the Eleians and the Arcadians to commemorate their peace treaty. The statue shows Hermes holding in his left arm the infant Dionysos while in his raised right hand he probably held a bunch of grapes. Hermes looks sluggish but manly, resting in the trunk of a tree. His hair are mixed up and come in contrast with his skin, which looks tender and smooth (Figure 1). The statue's height is 2.13m, and is standing on a marble base of dimensions 1.25 in height and 1.26 m by 0.84m horizontally.

For the creation of the statue's 3D model, it was decided to perform a complete close range stereoscopic photographic documentation as well as an independent scanning using a terrestrial triangulation laser scanner. The use of two independent techniques allows evaluation of the reliability of each and the attained precision in restitution of the object's size and shape.

3. DATA COLLECTION

The data acquisition from both methods, due to the size of the sculpture and the fact that the object was impossible to move, required the use of scaffolding with appropriate levels, so that access to all parts of the statue could be facilitated. The width of the scaffolding was broad enough to enable unobstructed movement of the instruments and operators within necessary distances between the camera or scanner and the object.

Special attention was paid to the stability of the construction, so that vibrations during data capturing mainly caused by the operator would be minimised. This is important, because motions during data capture may introduce noise to scanned images and displacements of the control points at the photo images. Figure 2 depicts the wooden construction specifically built for this project.

Figure 2. Special scaffolding was constructed for the data collection

The scaffolding had basically two levels:

- A first level of 1.25m height from the ground, which surrounded the sculpture with a width of 1.20m and at distance of 0.30m from the perimeter of the sculpture's base. This level was used during the photo acquisition of the whole body of the sculpture and the scanning of the lower body part.
- A second level of 3.90m height from the ground, which was effectively above the sculpture with a width of 1.00m. In addition, a gap of dimensions 0.80x0.50m was purposely constructed to enable access for the photo acquisition of the upper parts of the sculpture, heads and hands of Hermes and infant Dionysos (Figure 3).
- An alternative location of the second level at height of 2.70m from the ground, which encircled the statue's upper body in order to allow details of the upper parts of the object being captured (Figure 4).

Figure 3. The central photo of the strip taken from the top

Data acquisition for the base of the sculpture was performed last in sequence, from the ground level when all levels of scaffolding were removed.

Figure 4. The upper scaffolding level was used for scanning

3.1 Topographic Survey

In order to realise a stereoscopic restitution of the Hermes statue, it was necessary to define a set of control points with coordinates inserted in a local reference system. A classical topographic survey by intersection method was performed using a Leica TCR307 total station (accuracy of angular measurements 1” and ±2mm±2ppm in distance). The total station has also the capability to work in a reflectorless mode with a degradation in the distance measurements. A traverse of six points on the ground floor and eight targets evenly distributed around the walls of the room where the statue is housed, were measured with a redundant number of readings. This ground control system was used to determine the reference system of the control points of the photo stereopairs (described in §3.2). An arbitrary system of coordinates has been adopted with the Z-axis having its origin at point 01 and abscissa axis formed by ground point 01 and wall point 2 (Figure 5). The 3D least squares adjustment resulted to point accuracy within 3mm at 95% confidence level. The coordinate system defined with this procedure gave also the georeference of the 3D model obtained with the laser scanning data.

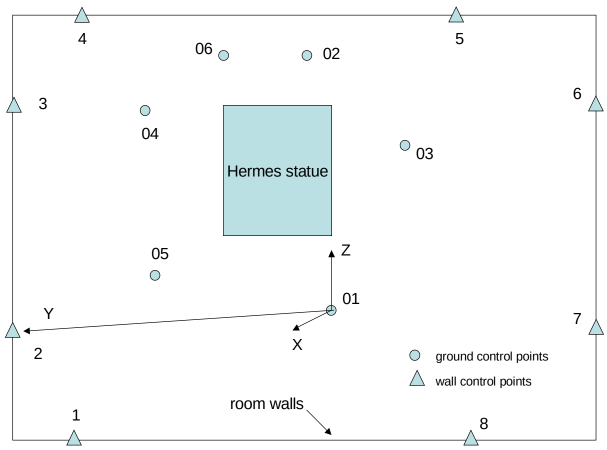

Figure 5. Schematic of the control network (not to scale)

3.2 Photogrammetric Data Collection

The photogrammetric images were taken independent of laser scanning data collection. From each location, photographs were taken by two cameras:

- An analog semi-metric camera, Hasselbland C/M 500, format 5.5x5.5 cm^2 and focal length c = 50mm. The mean distance from the object was about 1.60m so that the scale of the photos should be about 1:30 (final accuracy specifications for the coordinates of the detail points was 0.8mm<1mm)
- A digital camera, Sony DSC-F707 with 2560x1920 pixels (5 Mpixel with pixel size about 4μm) and zoom capability x5. The photos were taken always with the minimum zoom, with c=9.7mm given by the manufacturer, and the output was in a TIF format. The mean distance from the object was 1.80m, so that agreement could exist with the imaged scenes of the analog and digital photos.

The dual photography was performed exclusively for research purposes, so that a comparison of the results of such a complex object derived from photos of different type cameras could be studied. It should be noted that none of the two cameras is metric and their inner orientation data through a laboratory calibration are not known.

With each camera, 43 photos were taken in total, which create 22 stereopairs, that is:

- 8 photos, one stereopair for each of the four sides of the base of the sculpture
- 32 photos for the body of the sculpture. The sculpture was divided for practical reasons into two parts, lower and upper. One stereopair (2 photos) was taken for each part, along each basic direction (forward, backward, left and right) and one stereopair (2 photos) along each diagonal direction. In total, 2 photos were taken for 8 directions at 2 parts, thus 32 photos. Figures 6a and 6b show the left and right images of the stereopair, taken along the direction forward-right diagonal for the upper part of the statue. The details of the body of infant Dionyssos, which are not pictured on other stereopairs emphasise the importance for performing such a multiple photographic coverage of the body of the sculpture
- 3 photos, in two stereopairs, for the coverage of the statue from the top (cf. Figure 3).

The most difficult part during the photogrammetric data collection was the establishment of control points, mainly due to the sensitivity of the object being captured. There were several methods tested prior to photogrammetric collection, with the assumption that any physical contact with the sculpture was not allowed. The most appropriate method proved to be the projection through a video projector of a laptop computer screen showing a predesigned grid of $1x1cm^2$ that was covering the surface of the sculpture from each location of the photographic shooting. Simultaneously, the coordinates of selected nods of the grid were measured from a pair of stations that were established close to the sculpture. This method was nevertheless, rejected by the authorities of the museum. It was considered that this technique possibly causes damage to the surface of the marble by producing spots due to continuous exposure to the projector’s light for the duration of few minutes.

The most efficient method finally implemented, was the placement of 6-12 predefined targets (square black and white) on light wooden frames or sticks that were placed adjacent to the part of the statue to be photographed. There was an effort to locate the wooden sticks in such a way so that the attached

(a) left image (b) right image

Figure 6. Stereopair of the upper part along the diagonal direction of the statue base

targets would be in varying distances from the camera, following in effect the relief of the sculpture. For each stereopair, different locations were selected for the sticks. The sticks were fixed stable on the scaffolding levels of the wooden framework and the XYZ coordinates of each control point were measured using a total station with an accuracy of 4mm. In addition, the coordinates of natural points on the surface of the sculpture, that were selected very carefully to be used as control points, were measured. Yet, very few of them were used for the orientations of the stereopairs due to the difficulty of their positioning with adequate accuracy and reliability on the photos. Figures 3 and 6 show examples of the predefined control points, while Figure 6 shows seven selected natural control points marked in red (small circle) on the digital image.

3.3 Laser Scanner Data Collection

The laser data capture was performed by Archaeoptics Ltd. using a Minolta VI-900 laser scanner (http://www.minolta-3d.com), which is a laser light-stripe triangulation ranger-finder. The scanner provides colour data with a CCD resolution of 640x480 pixel per colour and has three interchangeable lenses of f = 25.5mm, 14.5mm and 8.0mm respectively. The highest resolution the scanner can provide is 170μm and its precision is ±0.008mm. The scanning procedure is safe for the sculpture, since the 690nm red semiconductor laser beam moves continuously during scanning for extremely small duration. After setting up the scan, the actual process takes about 3 seconds to acquire roughly 300,000 points.

The scanning procedure requires an operator who interactively moves the scan head to set each new scanning window. The window is constrained by both the field of view of the lens being currently used and any occlusions of the laser or the camera mounted on the front of the scanner. The scanner has the ability to acquire RGB data which was used only for determining material changes and breaklines in the statue. The duration of the Hermes scanning was 2 days during which 649 overlapping scans (20-30% overlap of adjacent scans) were acquired at a distance of about 1m from the statue and at 0.5mm resolution with an accuracy of 0.25mm, in order to record details smaller than 1mm without the dataset becoming completely unmanageable in size. Each scan comprised the scan metadata, that is laser power used, focal length etc, the raw 3D coordinates of the range grid, intensity and per-vertex colour information. In total more than 269 million triangles were created. The raw data required around 10Gb of space uncompressed (Tsakiri et al, 2003).

4. DATA PROCESSING

The data derived from both methods were edited independently, so that a 3D model as complete as possible would be acquired from each one. At a second stage, the data from both methods will be used in an integrated mode so that the best result would be achieved.

4.1 Photogrammetric Procedure

The process described in this paper refers to photogrammetric images derived from the digital camera. The analogue images are processed independently and a comparison considering the accuracy and the quality of the results from each type of image is the focus of a future study.

The first stage in processing refers to the calibration of the SONY digital camera for taking photos from a distance of 1.80m with the lens at the minimum zoom. A 3D close-range test field of 6x6x3 m^3 was used, which is established at the metrology room of the School of Rural and Surveying Engineering of NTUA and is measured with an accuracy of 2mm. The test field consists of approximately 130 targets in total, placed on stable metallic columns and a metallic board attached onto a wall. Part of this test field was photographed from six different positions and orientation angles. A simultaneous adjustment was made for the data of each photo, the exterior orientation and the focal length, principal points' coordinates and the two coefficients of the radial distortion, by measuring 22-30 control points, through in-house processing software (Tournas, 2003). The results with their respective standard deviations, which are notably low, were estimated as:

$c = 2\,913 \pm 4$ pixel,

$x_o = -22 \pm 6$ pixel, $y_o = 3 \pm 2$ pixel.

Figure 7. A 3D view of the TIN, density 1-2cm

The next stage included orientation of all stereopairs and DTM extraction at the SSK Z/I Imaging digital photogrammetric workstation. Several attempts were made for performing triangulation adjustment, absolute or relative, of all the stereopairs at each part (upper and lower) of the sculpture's body. Yet, the fact that the pre-signed control points were different at each stereopair in addition to the difficulty in recognising the natural control points from various views, did not allow estimation of the parameters with sufficient accuracy (rms of resulted coordinates was less than 8mm). So, each one of the 22 stereopairs was oriented separately. The DTM extraction was made manually, with point density of 1-2 cm at the scale of the sculpture, since the automatic procedure fully failed in most cases, and a large number of breaklines was restituted. The outline of the surface was made with irregular TIN net (Figure 7).

The merging process of all stereopairs was performed through characteristic tie points or natural control points, taking advantage of the relatively large overlapping of the stereopairs. Merging was not always easy to accomplish and finally systematic errors were introduced, as was confirmed by the comparison between the unified model with the equivalent derived through the laser scanning data. Also, despite the multiple photographic coverage of the sculpture there were some parts of the object which were not covered stereoscopically (for example, part of Hermes' right ear).

4.2 Laser Scanning Data Processing

Editing of the acquired laser data comprises mainly the tasks of aligning and merging the scans. Alignment is a critical process to perform in order to bring all the scans of the statue to a common coordinate system. The registration of all scanned images was performed by applying the Triangle Mesh Registration, a variant of the Iterative Closet Point algorithm (ICP), which does not need targets in order to achieve high accuracy registrations. During the merging process, integration of the registered sets of surface measurements into a single 3D model was carried out using a hybrid approach of mesh integration with volumetric hole-filling. For these tasks, in-house software developed by Archaeoptics Ltd. was used (Tsakiri et al., 2003). Figure 8 shows two 3D views of the produced merged model of the statue. It is noted that these models are georeferenced to the same system as the photogrammetric models.

Figure 8. Typical 3D views of the merged model of the statue

4.3 Combined Use

The common products of digital photogrammetric procedures are vector (line drawings, DTM) and raster (orthoimages) data which are produced with high accuracy. On the other hand, the emergence of laser scanning has benefited cultural heritage applications in that is a fully automated process, but without necessarily having directly out the above products. However, the cloud points form at once a 1:1 scaled 3D geometric model of the object compared to the initial scaled model produced by photogrammetry. It is therefore un uncomplicated task to obtain, in a time-efficient manner, all the products such as profiles and sections, lines and polylines, etc expected by the end-users, in addition to solid 3D model production in a variety of formats (many of them acceptable from CAD environments). Once the 3D models of objects are developed, the user can easily perform some basic interpretation using a variety of freeware viewers (e.g. 3D-Exploration of Right Hemisphere, SpinFire Professional, etc) which include easy-to-use tools that allow creation of sections with levels at any inclination and measurement of distances on the object. Figure 9 gives an example (not to scale) of such an editing of the Hermes 3D solid model.

Through the combined use of photogrammetric and scanning data, the geometry of any kind of object can be fully captured since the limitations of the objects that are self-covered (concave) are somehow narrowed with the availability of more data coverage. Moreover, new products can be available, such as the production of '3D orthophotos', which is the orthoprojection of photos onto a unified dense DTM of the whole object derived from laser scanner data (Lingua and Rinaudo, 2001).

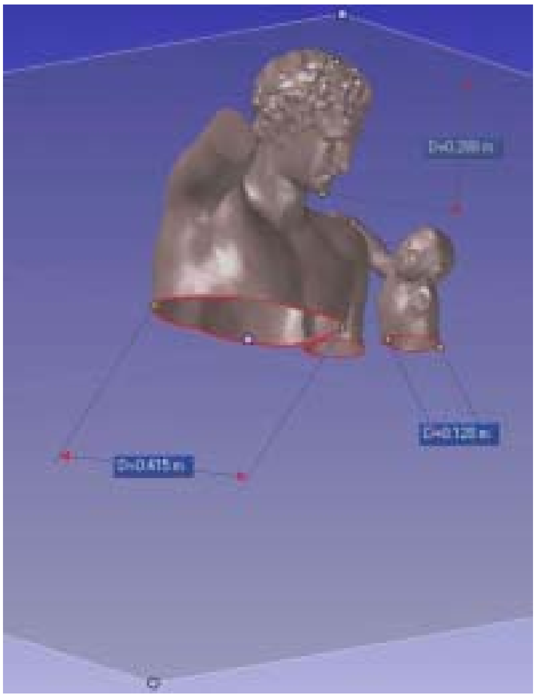

Figure 9. Basic interpretation of laser scanner products is easily performed in freely-available viewers

In this project, various combinations of photogrammetric and scanning data of the sculpture of Hermes have been attempted. The most important are:

- testing the compatibility of the two data sets by transferring dense (every 1cm on the statue scale) horizontal sections derived from the merged data of the photogrammetric restitutions, onto the 3D solid model derived from the scans. This procedure has indicated the existence of systematic errors among the photogrammetric models, that were properly corrected
- orthophoto production (of parts) of the statue using the TIN net derived from the scanned data and breaklines photogrammetrically produced.

5. CONCLUDING REMARKS

Photogrammetry is an elegant measurement method traditionally used in cultural heritage applications. The shortfalls of this method, mainly associated with limited geometry of areas in the shadow of the object, are more prominent when the object is a large complex statue, such as the one described in this paper. The recent emergence of terrestrial laser scanning has shown that has the potential to be of major value to the cultural heritage recording professionals. While data collection in this project using the two methods indicated a small gain in time over laser scanning (two days scanning versus three days for photo images), the main advantage is the fully automated data capturing process using terrestrial laser scanning. Furthermore, this technique does not require the relatively strong restrictions to be fulfilled by the stereoscopic images, such as having the two different bundles to cover the same body parts and the rays to homologous points to intersect at good angles.

While both photogrammetric and laser scanning techniques can deliver similar type of products the end users are accustomed to have, such as line drawings, DTM etc., the interest mainly lies in the supplementary role these types of data can have in 3D model creation. In this project independent 3D models of the Hermes statue have been created to allow evaluation studies being performed. Future work currently concentrates into matching and integrating local detailed scanned areas into a global model defined by photogrammetry using fairly automated operations.

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