LASER SCANNING ISSUES FOR THE GEOMETRICAL RECORDING OF A COMPLEX STATUE

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ABSTRACT
Recent advances in laser scanning technology allow for fast and efficient 3D documentation of cultural heritage artefacts and statues. The advantages are more evident when the objects are of large size and comprise complex surfaces and fine details. There is therefore, a need to addressing clearly all the practical difficulties and issues that one has to consider when using this technology for the documentation of large archaeological statues. This paper describes a number of specific issues, from data capturing procedures to data management and processing, raised in a project aimed in producing a geometrically accurate 3D model of the ancient statue of Hermes by Praxiteles. Finally, results from the 3D solid model of the statue are also provided.

1 INTRODUCTION

The accurate geometric documentation of complex irregular structures of large size can be a challenging task even for close range imaging techniques. The shape of this type of objects is uneven comprising a variety of surfaces usually with many curves and holes. Typical examples of such objects are large statues, which usually have recesses and other fine details carved by the sculptor using chisels and drill. In addition to capturing geometrically correct shape, it is often required in cultural heritage applications to capture colour. This parameter constitutes a useful piece of scientific information, especially for older statues which are covered with a complex brew of marble veining, dirt, materials used during restoration and mainly discoloration and other effects of weathering.

The documentation of archaeological artefacts located in non-laboratory environment such as museums, presents further challenges, mainly because the statues are permanently housed and the conditions during the data capture procedure cannot be easily altered, for example the lighting of room or the limited space around the statue. For statues of long height, data capture for the top parts of the object can be problematic for practical reasons, which include restricted working space and use of mobile workbenches. An overriding concern during data capture of large fragile objects is the safety of the statues. The techniques that can be employed should involve non-contact methods (ie avoidance of setting targets on the surface of the statue) and measuring systems that can control the levels of light and heat as these can potentially damage the artwork.

Further to data capture, the processing of the data in order to create an accurate 3D solid model of the captured object for purposes such as digital documentation, moulding or even rapid prototyping, can be an extremely difficult task because of the management of large volumes of data.

Recent advances in laser scanning technology allow for fast and efficient 3D documentation of cultural heritage artefacts and statues. A great advantage of the technique relies in that is entirely a non-contact method thus allowing for the fine geometric details of sculptured and irregular surfaces to be more easily captured when compared to close-range photogrammetric methods. Clearly, the combined use of both techniques offers many advantages (eg Bitelli et al. 2002; Henz 2002), however in many applications, such as in metric cultural heritage documentation of sensitive complex statues, laser scanning is preferred to record data economically and with high accuracy. There is therefore a need to addressing all the practical difficulties and issues about the data collection and processing that one has to consider when using this technology for the documentation of large archaeological statues.

Since a significant proportion in the world's museums heritage collections are large complex statues, this paper aims to discuss the issues from data capturing procedures to data management and processing for the creation of the final model of such an ancient complex and fragile object using a high resolution terrestrial laser scanner. A description on the various stages of the data collection and processing to create an accurate 3D solid model of the statue of Hermes by Praxiteles is given and results of the digital 3D model of the statue are also considered.

2 DATA COLLECTION

The aim of the project was to acquire a geometrically accurate 3D model of the Hermes statue, which is housed at the archaeological museum in Ancient Olympia in Greece. The area is subject to high seismic activity and the archaeological artefacts of the museum are therefore prone to vibrations generated by the earthquakes. To minimise the ground accelerations and improve the likelihood of reducing damage of sensitive structures, such as the statue of Hermes, it was decided by the museum authority to construct a seismic isolation retrofitting assembly. The assembly is designed to enhance the statue's safety without impairing its appearance and this process required an accurate 3D model of the statue.

The Hermes statue, dated to 343 BC, is made from Parian marble and is considered a masterpiece of ancient Greek art. It is the only original work of Praxiteles that has survived and was found at Olympia, intact on his base, several metres under the ground. It was dedicated to the sacred Altis from the Eleians and Arcadians to commemorate their peace treaty. Later it was moved to the temple of Hera, where it was found in 1877 AD. The statue shows Hermes (Fig. 4) holding in his left arm the infant Dionysos while in his raised right hand he probably held a bunch of grapes, dangling it before the childgod, who stretches out his small hand to grasp the sacred fruit. The statue of 2.13m height is standing on a marble base of dimensions 1.25m in height and 1.26m by 0.84m horizontally.

The 3D laser scanner implemented for the data capture is a Minolta VI-900 (http://www.minolta-3d.com), which is a state-of-the-art system, and is typically tripod-mounted for maximum ease of use. The highest resolution the scanner can provide is 0.17mm (170 microns). It is a laser light-stripe triangulation rangefinder of short range, with typical distances from the object being in the order of 0.6-1.2m. It also provides colour data and the quoted precision is ± 0.008mm for the fine operating mode.

In the ensuing discussion, the practical aspects need to be considered when data collection is performed from a large fragile statue using a short-range laser scanner instrument are addressed.

2.1 Mounting of scanner

Statues have surfaces that point in all directions with many horizontal crevices, such as the folds in carved drapery. Therefore, the scanner needs to have flexibility and be able to scan surfaces of any orientation. Also, the top parts of the statue, such as the head and upper body parts require a configuration whereby the scanner is mounted on a level above the tallest part of the statue to facilitate data capture from all directions. Scaffolding around the statue (Fig. 1) with appropriate levels to allow scanning of the tops of the statue and the difficult regions, which are hidden or occluded by parts of the statue, was constructed. It is important to note the stability of the scaffolding during data capture so that vibrations of the system, mainly caused by the operator, are minimised.

Fig. 1. Scaffolding levels to secure access and stability of laser scanner

An overriding concern during data capture is to avoid harming the statue by accidental collisions between the scanner and the statue, as well as being tangled by the instrumentation cabling. The wide scaffolding, which was used in this project and consisted of wooden floors with a width of 1m around the statue and at a distance of 0.2m from the outline of its basis, prevented such problems. When the levels of scaffolding are not wide enough, accidents may be caused by tripod leg deployment during scanner repositioning. It is therefore necessary to have a "scan plan" that minimises the number of scanner positions and thereby reduces the potential for colliding with the statue.

The Minolta scanner's motion platform is a customised heavy-duty camera tripod head that allows the scanner to be reoriented through pan, tilt and translate motions enabling difficult to reach areas to be scanned. This also minimises the number of repositions of the scanner platform as many scans can be taken from the same physical position by simply reorienting the scanner on the tripod head.

2.2 Scanning procedure

Using the Minolta VI-900 scanner, 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 either the laser or the line-of-sight camera both mounted on the front of the scanner. After setting up the scan, the actual process takes three seconds to acquire roughly 300,000 points. RGB colour data at a per-vertex level is acquired immediately after the scan is complete via the camera used for triangulation. The RGB data for the Hermes statue was not required to be photo-realistic, merely diagnostic for determining material changes and breaklines in the statue.

However, any tremors either caused by the pressing of the scanner "Release" button or through movement of the scaffolding may introduce folds in the range data. Such an example is shown in Fig. 2, which depicts "rippling" on the statue's chest due to tremors in the scanner platform.

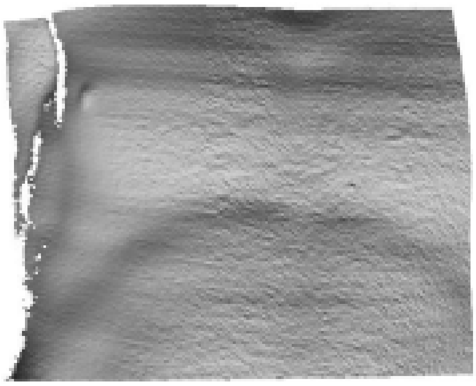

Fig. 2. “Rippling” on the chest due to tremors in the scanner platform

All scans for the Hermes statue were obtained at a distance of about 1m from the statue and at 0.5mm resolution with an accuracy of 0.25mm. This resolution was decided upon in order to achieve the goal of recording the intricate details like chisel marks smaller than a millimetre and any changes of material but without the dataset becoming completely unmanageable in size.

Clearly, for capturing complex surfaces, a large number of scan images are needed to cover the object. The number of scans required depends on the shape of object, amount of self-occlusion, the object size and the desired resolution of the source dataset.

The duration of the Hermes scanning was two days, during which multiple overlapping scans were obtained. The overlap of adjacent scans was about 20%-30%, which not only enables registration to work more efficiently but also helps quantify any distortive effects on accuracy the underlying matrix was causing.

Regarding safety of the statue from the scanning process as a non-contact method, laser triangulation does not cause harm because only light touches the object. The scanning beam was a 690nm red semiconductor laser and it moved continuously during scanning. The difficulty of scanning under field (non-laboratory) conditions cannot be underestimated considering also the fact that the data capture was performed during restricted time periods following the museum’s operating hours.

2.3 Marble surface

The type of material of the object to be scanned may significantly affect the captured laser data. The underlying hypothesis of active optical geometric measurements is that the imaged surface is opaque and diffusely reflecting. The marble, which is the material used for the Hermes statue, is composed of densely packed transparent crystals causing it to exhibit subsurface scattering. Marble departs from this hypothesis and exhibits two important properties of translucency and non-homogeneity (Godin et al. 2001). These properties generate two key effects on the geometric measurement and result in a bias in the distance measurement and an increase in noise level when compared to a reference opaque surface.

Fig. 3. The right knee. Beneath the knee is Plaster, above is Parian Marble. The contrast in noise levels is quite marked

Specifically, the shiny marble, by causing some increase in the subsurface scattering, may result in degradation of the quality of the range data and disturb the way that the models are rendered. Levoy et al. (2000) state that their assumption on treating the diffuse reflectance as ideal Lambertian when scanning marble statues was possibly not correct because the computed reflectances from each scanned surface did not agree since the laser observations included noise and other errors. In scanning the Hermes marble statue, it was noticed that the reflected spot was shifted away from the laser source and also the spot varied in shape across the surfaces of the statue due to the random crystalline structure of the marble leading to noise in the depth values. In fact, the surface made of plaster, which is located at the right knee of Hermes, did not exhibit the same reflectance effect compared to the polished marble surfaces, as seen in Fig. 3. For this reason, a number of data test collections from the statue were performed in order to assess the material properties and eliminate the noise in the final model.

2.4 Data management

The datasets produced by short range, high resolution laser scanners during the scanning process can quickly become impossible to handle and unmanageable for post-processing. There are many different techniques on storing datasets, with most commonly being the storage as point clouds, polygon meshes or range images. Individual meshing or automatic triangulation are often applied on the whole point cloud to create models but extremely high performance from a PC is required to achieve acceptable speed when executing such calculations. On the other hand, range images are more efficient and commonly used in computer graphics because the scanned surfaces are stored as encoded range images (Pulli 1999).

In this project, the simplest and most accessible for the Hermes raw dataset technique was implemented; a simple conversion of the proprietary Minolta format data to ASCII PLY files which were then compressed with *gzip*. Each scan comprising the scan metadata, such as laser power used, focal length and so on, the raw 3D coordinates of the range grid and per-vertex colour information. This technique, although not the most efficient in terms of storage space, does virtually guarantee the readability and completeness of the archived raw datasets in the future.

In scanning the Hermes statue, 649 scans were acquired resulting in 143,652,299 range samples and 269,178,117 triangles. In total, the raw data requires around 10Gb of space uncompressed, 4Gb compressed. Therefore, it was felt unnecessary to use a more involved data management system.

3 PROCESSING ASPECTS

The post-processing of the acquired laser data comprises mainly the tasks of aligning and merging the scans to produce the 3D solid model of the structure.

3.1 Alignment

Alignment of scans is performed in order to bring the hundreds of scans of a statue, acquired from different locations, to a common coordinate system. Unlike photogrammetric methods, which make use of reflective targets or pre-signed points as control points, registration of scanned images requires a different approach. There are a variety of techniques used, with the most common being the iterated-closest-points (ICP) algorithm (eg Besl and McKay 1992) which finds matching points on two meshes, computes the rigid transformation that minimises the squared distances of these point pairs and iterates until some convergence criterion is met. Modifications to the original ICP algorithm have been made to improve the rate of convergence and register partially overlapping sets of points (eg Chen and Medioni 1992; Zhang 1994). For complex objects such as statues, an extended ICP algorithm to minimise the sum of squared distances for all views simultaneously using multiple range images is preferred to ensure an even distribution of registration errors between overlapping views.

To produce the final Hermes model, sophisticated in-house software by Archaeoptics Ltd., was used to perform the alignment of all the scans, including a global alignment phase, as well as the integration of each scan into the final model and subsequent hole-filling and mesh repair. The full global alignment of all 649 scans took about 100 hours to perform using a fairly standard PC (2GHz Pentium IV, 1Gb RAM).

3.2 Merging

The goal of merging is to integrate registered sets of surface measurements into a single 3D surface model. The generic problem of surface reconstruction is to estimate a manifold surface that approximates the unknown object surface from a set of sampled 3D points, without making any assumptions about the surface shape. The two approaches reported most frequently for fusion of multiple overlapping surface measurements into a single surface model are mesh integration (Turk and Levoy 1994) and volumetric fusion (Curless and Levoy 1996).

In the case of Hermes, merging of scans was undertaken by in-house software by Archaeoptics Ltd. using a hybrid approach of mesh integration with volumetric hole-filling. It was decided that the resampling undertaken during volumetric fusion would get away from “what the scanner saw” and, unless resampled at a computationally crippling level, would lose much of the surface detail we wished to retain. Therefore, we used an in-house mesh integration technique which accurately fuses overlapping scans together.

However, the final stage of processing, hole-filling and mesh repair, is difficult when merely relying on the mesh data itself. This is typically due to holes being non-simple and most often non-planar either due to poor triangulation choices as input to the fusion algorithms, or poor quality output from the fusion process. To efficiently handle holes with extremely ill-defined boundaries and holes that might span areas of high curvature, we use a variant of the volumetric diffusion method (Davis 2002). This technique ensures efficient and effective automatic hole-filling at both a geometric level and at an aesthetic level. A merged model of the Hermes statue using the above approach is shown in Fig. 4.

Fig. 4. A merged model of Hermes statue

4 CONCLUDING REMARKS

Documentation of cultural heritage artefacts using laser scanning is one of the most active areas for the use of this technology, with the construction of 3D digital models as one of its principal objectives. With a significant proportion of museum artefacts made of marble and having complex surfaces, it is important to deal with specific aspects of acquiring, aligning, merging and viewing scanned data.

The Hermes project was performed using an “off-the-shelf”, high resolution, laser triangulation scanner which proved more than sufficient in capturing details smaller than one millimetre. Data capture comprised of 649 scans because there was an overlap averaging around 30% in each scan to avoid holes and missing data due to occlusions. Handling the massive amounts of data in a time-efficient manner is an extremely important problem that is faced only with this type of scanned objects.

Although laser scanning is a preferred method to record data economically and efficiently in order to create 3D models of complex statues, it is important to emphasise the need of using alternatives methods such as photogrammetry to capture data, which can provide control and ensure that the models are geometrically correct. During the Hermes project photogrammetric recording was also performed and a comparison of the models between the two techniques will be made.

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