CAPTURING THE PAST AND PRESENT: TOOLS AND METHODOLOGIES FOR 3D MODELING OF SMALL OBJECTS

Charalampos Georgiadis [1], Petros Patias [1], Georgios Stylianou [2]

1 Aristotle University of Thessaloniki, Department of Rural and Surveying engineering, P.O box 473 GR-541 24 Thessaloniki, Greece.
2 European University Cyprus 6, Diogenes Str. Engomi P.O. Box 22006, 1516 Nicosia, Cyprus

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ABSTRACT:

Emerging technologies in hardware and software in the field of laser scanning are creating new horizons in 3d modeling of artifacts. We are now capable of producing accurate models with hundreds of thousands triangles and photorealistic textures, so a new question arises, what is the optimum number of triangles and also the best tool to use for the production of these 3d models. Another aspect is how we can make these models available with the usage of free viewers which have the ability to handle large numbers of triangles and also have the capability for basic measurements and different representations of the model. The selection of the appropriate method for the 3d modelling and the representation lies in the complexity of the object, and the accuracy of the final model we want. In our study we present models of different small objects, either archaeological artifacts, or exhibits of modern art. These models were created using different techniques, photogrammetry and laser scanning. Depending on the modelled object we used different laser scanners, which we thought were appropriate for the task depending on the complexity and the size of the modelled object. Although a fine model was initially produced for each object, the final model was generalized to fit the needs at hand. The purpose of this paper is to present different methodologies for the creation of such 3d models, and propose a guideline for the usage of the appropriate methods and tools for the production of the model and also for its representation. In order to facilitate our methods we are giving examples of modelled objects, and we describe the methodology for their creation.

1. INTRODUCTION

Modelling 3 dimensional objects is a rigorous and time consuming process. A lot of different approaches exist spanning from photogrammetric techniques to laser scanning methods. (Sotoodeh S. et all, 2004) applied photogrammetric techniques using a structured light system and digital frame cameras to reconstructed 300 year old wooden globe, (Duran Z, U. Aydar, 2004) also used a structured light system and traditional photogrammetric techniques to model the Nippur Cubit Rod. (Remodino F and F. Menna, 2004) present examples of close range photogrammetry applications in different kinds of archaeological objects. While (Hanke K. et all, 2004) demonstrate the usage of laser scanners in the modelling of archaeological finds.

In our study we modelled a series of different objects spanning from contemporary art objects to archaeological finds of pre history. These objects differed in shape, complexity and size. Our goal was to find the optimum modelling technique in order to produce the most detailed models while consuming the least amount of time. In order to achieve this goal the first step was to classify the objects in different categories depending on their size and complexity.

For simple objects with well defined edges and simple surfaces we used photogrammetric techniques independently of the object size.

For objects of high complexity we used a series of laser scanners, depending on the object's size and material. In our study we have used three different laser scanners. For small objects (such as soda can or shoe box size objects we used the Next Engine scanner), for larger objects (such as small statues) we used the Konica Minolta laser scanner and finally for larger objects (large statues, approximately 3 m in height) we used the Optech ILRIS 3d scanner.

One of the difficulties when dealing with laser scanner data in the amount of measured points and the number of the final number of triangles of the model. Depending on the usage of the model there is a trade-off between model detail and size of the model, so we have to carefully decide about the number of the scans and the overlapping regions of the objects and also for the scan's resolution. In some cases we need different level of details for the same objects so we have to scan in the highest resolution and generalize the model for other applications.

When we model objects with photogrammetric techniques our only decision lies in the number of photos to cover the object and the type of control we are going to use. For low accuracy projects one or two distances along the objects are enough to produce a model; in cases we need high accuracy we used an exterior orientation device. In our study we used the photomodeler software to produce 3d textured models. The modelling was done manually by constructing triangles.

2. 3-D CAPTURE AND MODELLING TOOLS

In this section we are going to demonstrate some examples of 3d models created using different laser scanners and techniques depending on the size and complexity of the object. For the object's modelling with photogrammetric techniques we used a Canon 400D camera with two different lenses (20, and 28mm). The Canon 400D camera has a resolution of 3888x2592 pixles, and a pixel size of 5.7 microns. For the laser scanning modelling we used a Konica Minolta 9i, an Optech ILRIS 3d and a NextEngine lasers canner. The Konica Minolta 9i laser scanner has a range of 0.6 to 2.5 meters, with an accuracy of 0.05 mm and a resolution of 640x480 points. The Optech ILRIS 3D laser scanner has a range of 3-1000 m, an accuracy of 10mm and user defined resolution with minimum a spot step of 0.0015^o. The NextEngine scanner has a resolution of 400 DPI, an accuracy of 127 microns and a range of 15-50 cm.

2.1 Objects of simple complexity

In the following section we are going to demonstrate some examples of the 3d modelling using photogrammetric techniques in simple complexity objects. We are going to explore examples of objects we used an exterior orientation device and others we just used some distances along the objects. We are going to discuss the number of photos, the number of triangles of the final model and the total time needed to complete the final model.

The first object we are going to demonstrate is an object with simple plane surfaces. For this model we used an exterior orientation device. We can see an aspect for this object in Figure (1). For the modelling of the object we used 7 images. The images were taken with the digital SLR Canon 400D camera, using a calibrated 28mm lens. The calibration was performed using the Photomodeler calibration module. The final model was constructed using approximately 100 triangles, while point RMS was 2 mm. For the project's orientation 24 control points and 65 tie points were used. The total processing time for the whole project including the data collection phase, was approximately 6 hours. The final model was exported in 3D Studio Max format, and some corrections were performed in 3D studio Max environment. Finally the model was exported in both VRML and 3D pdf format. So we can see that modelling a simple object can be done manually with the least possible effort, high accuracy and in the same time produce light models that are very easily handled by modern computers.

Figure 1. Simple complexity object with Exterior Orientation Device

The second example consists of a very simple object, which resembles a cube Figure (2). For this model we used measured distances on the cube's sides as control information. For the modeling of the object we used 8 different images. The images were taken with a Canon 400D camera using a calibrated 20mm lens. The final model was created using approximately 45 triangles, while point RMS was 3 mm. The total processing time for this model was about 4 hours. While the final 3d model was very light in both VRML and PDF formats.

Figure 2. Cube shaped low complexity object

2.2 Small objects of high complexity

For the modelling of small high complexity objects we used two different laser scanners the Konica Minolta 9i and the NextEngine scanner. We used the Konica Minolta scanner to scan modern art exhibits of a museum. We can see a series of examples using this scanner. The processing of the laser scans was done using the Geomagic Studio 10 software, while the final models were exported in both VRML and 3d-pdf formats. The first object is a small sculpture Figure (3).The main goal of this application was to produce 3d models for web access of the e-museum website of the Macedonian Museum of Contemporary Arts. In order to model this object we performed 15 different scans and acquired a total of 760.208 points. The final model was created with 474.250 triangles. The size of the object was approximately 16x16x8 cm. The colour taken from the laser's camera was used to texture the final model, as the object was monochrome.

Figure 3. Small Contemporary Art Exhibit

In Figure (4) we can see a snapshot of the final model.

Figure 4. 3-Dimensional model of a small statue

Due to the nature of the application, web shared 3d models, the model was generalized in order to produce a lighter version of the initial full model. We tested four different versions with 3.000, 7.000, 15.000 and 75.000 triangles in two different file formats 3d-pdf and VRML. We finally decided that the 75.000 version was the suitable one for our application, because the file size (1.172 KB) for the 3d-pdf format was considerably low compared to the lower detail versions, while the VRML format size (with the textures) was 8,477 KB, almost 8 times bigger.

The second object we demonstrate here is a quite large and complex statue approximately (18x160x200cm) Figure (5), which we modelled with the Konica Minolta laser scanner.

Figure 5. 3-Dimensional exhibit

For this object we conducted four different scan sets, we individually scanned the head, the hands, the walking figure and we also performed a total scan of the object in order to join the scan to a full one. As a result we performed 26 different scans totalling in measuring 1.732.025 points. The final model had 1.202.164 triangles. In that model we also used texturing colour information from the laser scanner camera. Finally we created three different versions of the model with 25k, 50k and 75k triangles and we choose the 75k version in 3d-pdf format, which had size 2.208Kb.

The third object is a 3dimensional painting approximately (50x50x30cm) figure (6). We performed 5 different scans collecting 1.050.327 points and creating a model with 375.373 triangles. The texturing of this model was performed using an external image taken with a Canon 400d camera, and using the Geomagic software to register the image to the model, the textured modelled is shown in Figure (7). Finally the web version of the model was created using 13K triangles resulting in 3d-pdf file with size of 12.140Kb

Figure 6. 3-D Painting

Figure 7. Model of the 3-D Painting

Finally we are going to demonstrate some scans with the Nextengine scanner. We used this scanner to model Cycladic figurines. Our goal in this project was to detect minute details in the figurines so they can provide new information to the archaeologists. The first figurine Figure(8) has an approximate size of (25x40x30mm), and we performed 14 different scans, collecting 1.079.921 triangles, and creating a model with

319.570 triangles. For this model we created full detail VRML and 3d-pdf files. The VRML files with texture information had a size of 84.715Kb, while the 3d-pdf file had a size of 6.203Kb.

Figure 8. 3-D model of a figurine head

The second figurine was a broken face in two pieces approximately (55x40x40mm), we scanned the 2 different pieces and we produced a model with the two combined pieces Figure(9). We performed 29 scans collecting 4.852.916 triangles, and creating a model of 1.367.192 triangles. The final VRML model had a size of 205.010Kb, while the 3d-pdf model had a size of 14.141Kb. The whole process of the figurine models was approximately 12 hours of work, half of them was consumed during the scanning process, in order to scan the object from multiple points of view, while the modelling took another six hours.

Figure 9. 3-D Model of a broken Figurine head

2.3 Large objects of high complexity

The modelling of large objects of high complexity was performed using an Optech ILRIS 3D scanner. We scanned two statues of approximately 3 m height. For the example we demonstrate Figure (10) we performed 7 different scans collecting 4.737.427 points and constructed a model with 600.129 triangles. Each scan was performed with a grid of 5mm. The final web version of the model was consisting of 75.000 triangles.

Figure 10. 3-D model of a large Statue

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3. ANALYSING THE 3D MODELLING METHODS AND TOOLS

For this study we modelled a total of 24 different objects using different techniques and laser scanners. We group our results in four different categories. The first category consists of the objects modelled with photogrammetric techniques using the Photomodeler software and a calibrated Canon 400D digital SLR camera with a series of different lenses. We processed 5 different contemporary art exhibits using photogrammetric techniques. The second group consists of the 11 objects modelled with the Konica Minolta 9i laser scanner. We also modelled 2 objects using the Optech ILRIS 3D scanner. Finally 6 pre history Cycladic figurines were modelled using the NextEngine laser scanner.

3.1 Photogrammetric Modelling

Photogrammetric modelling was performed using the photomodeler software. We used a Canon 400D digital SLR camera, and two different calibrated lens (20mm and 28mm). The calibration was performed using the photomodeler module. We used an exterior orientation device for the modelling of the first object, while for the others we used measured distances in the object to define the scale of the model. In general the RMS errors were between 2.5 and 11 mm. In table (1) we can see some basic statistics for the modelled objects.

# of Photos	Object dimension(cm)	Object complexity	# of Triangles	RMS (mm)	used control
7	167x102x72	Medium	60	2.5	distances
7	49x20x25	Medium	100	2.37	points
8	49x49x49	Low	50	3.14	distances
3	275x290x25	Low	24	11	distances
11	212x212x73	Medium	68	5	distances

Table 1 Statistics for objects modelled with Photomodeler

We can see that using photogrammetric techniques we can model simple objects with very basic measurements, achieving high accuracy, while consuming a small amount of processing time. Although the triangles are manually created in the photomodeler environment the numbers of them in the final model are not that large to discourage someone from using this methodology. In general the processing time for each model was from 3-7 hours depending on the number of the objects' surfaces.

3.2 Scanning small complex objects with the Konica Minolta 9i scanner

Here we present some statistics table 2 for the 11 objects scanned with the Konica Minolta scanner.

# of scans	Object Dimension (cm)	Object complexity	# of triangles	Web version model	Vrml Size(Kb)	3D pdf size (Kb)
3	21x14x1	Middle	184001	13K	13,749	4,353
14	18x13x9	High	451284	451K	54,270	3,346
15	16x16x9	High	474250	75K	8,478	1,172
9	46x26x8	High	593477	100K	12,219	1,432
4	153x132x11	High	945108	250K	81,651	24,206
18	40x30x180	High	729757	50K	11,656	2,565
11	23x5x178	Middle	521948	50K	6,537	1,071
14	32x39x20	High	1607620	75K	66,996	5,451
5	50x50x15	High	374919	13K	50,278	12,140
26	18x160x200	High	1202164	75K	8,894	2,208
17	9x(5x13x17)	High	1156355	175K	38,703	9,953

Table 2 Statistics for objects modelled using the Konica Minolta 9i scanner

As we can see for most of the objects we performed 10-15 scans, while for objects such as 3 dimensional paintings we performed 3-5 scans and for a large statue with 3 different pieces we performed 26 scans. Most of the objects were modelled by measuring around 1000k points, while the final model was constructed using 500k triangles. In our study we only used texturing in specific objects because most of them were uniformly coloured. For the ones that had significant colour information we used texture from images taken with a Canon 400D digital SLR camera and performed the texturing process using Geomagic Studio10. Due to the nature of the application of the project we had to reduce the size of the final models, as result most of the models were generalized and models with 50-75k triangles were produced. In one case we used the full model, and in some other cases we used models in the neighbourhood of 200k triangles. Another aspect of the study is the delivery format we used. As we can see from the table 3d-pdf files are considerably smaller than the VRMl ones. In most of the case 3d-pdf files are 4 times smaller, and in some cases even 12 times smaller. Additionally acrobat reader has the ability to perform some basic measurements, have different types of representation of the model, and it can also produce cross sections of the object. On the other hand it is suitable only for examining the object separately. When using VRML files you have the ability to integrate them in a virtual world and interact with them in a different way. In general the collecting the data and processing the cloud points in order to produce the final models took roughly 6-10 hours for each model depending one the number of scans for each of the object, and also whether or not we used external images for producing a textured model.

3.3 Scanning large complex objects with the Optech IRLS 3D scanner

We used the Optech scanner to model two large statues of approximately 3 meters height. We scanned the objects in using a 5mm grid. In table 3 we can see some of their statistics.

# of scans	Object Dimension (cm)	Object complexity	# of triangles	Web version model	Vrml Size (Kb)	3D pdf size (Kb)
7	33x33x274	High	600129	75K	20,393	2,218
5	37x37x277	High	721262	75K	57,179	3,627

Table 3 Statistics for objects modelled using the Optech ILRIS 3D scanner

Although that the statues had pretty much the same shape we used 7 scans for the one and 5 for the other, while the scanned points were about 4 million points. The final models had roughly the same amount of triangles, while the models used for the web application model had 75K triangles. The final 3d pdf files were considerably smaller then the VRML ones.

3.4 Scanning small complex objects with the NextEngine scanner

Finally we present the statistics for the 6 pre history Cycladic figurines scanned with the NextEngine scanner Table 4. We can see here that for the details need for the specific project we used a large number of scans for each object. This was done because some of the objects had very narrow edges so we had to perform more scan in order to have the desired overlap between scans. Although we collected a large number of points for each object the final models were using a considerably lower number of triangles, also pertaining fine detail on the objects allowing for an extensive study of their surface from specialists. In addition multiple scans were performed in order to reveal aspects of the artifacts that can only been seen from specific points of view.

# of scans	Object Dimension (cm)	Object complexity	# of triangles	Vrml Size(KB)	3D pdf size (Kb)
12	4x2.5x9	High	512784	106,937	3,557
15	4.1x4x9.5	High	625046	95,104	8,851
12	17.5x7x33	High	1262982	15.920	10,326
21	4.5x2x5	High	449312	95,898	10,282
14	3x3x4	High	319570	84,715	6,203
29	4x4x9.5	High	1367192	205,010	14,141

Table 4 Statistics for objects modelled using the NextEngine scanner

4. CONCLUSIONS

In this study we presented work done in two different research projects using a two different modelling techniques photogrammetry and laser scanning. When applying photogrammetric techniques we used the photomodeler software. We produced 3-dimensional models of 5 different objects. The objects we modelled have simple shape and they were combined from simple plane surfaces. In most of the cases we used simple control information (distances measured along the object's edges) and we achieved high accuracy from 0.2-1.1 cm. the models were constructed manually and most of them had roughly 50 triangles thus producing light 3-D models that can easily be distributed along the web. Processing time for the whole application was between 3-7 hours.

For objects of high complexity we used laser scanning techniques. We worked with 3 different laser scanners depending on the size of the objects. For medium size objects we used the Konica Minolta 9i scanner, for large objects we used the Optech ILRIS 3D scanner and for small objects we used the NextEngine scanner. Processing time and the final size of the 3D model depends on the number of the scans which is proportional to the complexity, the size of the object, and the level of detail we want to achieve. For distributing the final model the 3D-pdf file format is the most appropriate, because it keeps the file size small while giving the abilities to perform basic function in the reader environment. Users have the extra abilities to perform measurements, to produce cross sections of the object and to display the model in different ways.

When modelling small objects the selection of the right method and tools is essential in order to optimize the whole process. For simple objects photogrammetry is the right tool. Data collection is not time consuming. For most of our models taking images for the models was completed within 15-30 minutes. The bundle adjustment phase was performed in less than an hour. The only time consuming phase is the creation of the model using triangles, which depends on the complexity of the surface. As result when creating models of simple objects even the modelling stage is not time consuming.

When applying laser scanner techniques the time spent during data collection stage depends on the laser scanner and the amount of detail we want to capture. Data processing is proportional to the number of scans and the coverage of the scans. Choosing the right angles when scanning small objects minimizes the hole filling process in the model creation stage. With the Konica Minolta scanner we can perform fast data acquisition, while the data acquisition time for the other scanners depends on the level of detail. The NextEngine scanner is a very powerful tool when used to scan soda can size objects, giving very detailed 3d models, while using considerably low cost equipment.

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