COMPARISON AND EVALUATION OF LASER SCANNING AND PHOTOGRAMMETRY AND THEIR COMBINED USE FOR DIGITAL RECORDING OF CULTURAL HERITAGE

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ABSTRACT:

Three-dimensional (3D) scanning and modeling of sites and artifacts of cultural heritage have increased remarkably in recent years. A wide variety of objects, e.g., small pieces of pottery, statues, buildings, and large areas of archaeological sites, have been scanned and modeled for such purposes as preservation, reconstruction, study, and museum exhibitions. Due to the range in size of the objects to be scanned and differences in the objectives for scanning and modeling, many approaches and options have been tested and used. As a result, it is clear that there is no single method that is applicable to recording every subject of cultural heritage and hence there is a strong demand for a hybrid method that exploits several technologies. Laser scanning can produce the dense 3D point-cloud data that is required to create high-resolution geometric models, although the quality of color information is sometimes lower than required. Another technology, digital photogrammetry, can produce high-resolution textures, if the original images have sufficient pixels, and 3D models. There is no doubt that these two technologies can supplement each other in creating high-quality 3D recordings and presentations. In this paper, we report a comparison and evaluation of laser scanning and photogrammetry and their combined use to digitally record cultural heritage objects from the point of view of producing accurate and expressive models and efficient data processing. The data used here was obtained from our experimental 3D measurement of Byzantine ruins on Gemiler Island, off the southwest coast of Turkey, in 2002.

1. INTRODUCTION

The development of three-dimensional (3D) laser scanners has brought a whole new landscape to the recording, preservation, and study of historical and cultural heritage. Laser scanners can automatically digitize the 3D coordinates of the complex shape of an object. This makes it easy to create a detailed 3D model of the object from a 3D point cloud. One of the drawbacks of laser scanners is that color images of an object cannot be obtained or, if it is possible, the quality of the color images is worse than that of the photographs. To record the true color of an object more precisely, photographs must be taken.

Terrestrial photogrammetry using digital cameras, which can also be used for measuring objects three-dimensionally, has come into practical use owing to the increased number of pixels available with digital cameras and the growing CPU power of personal computers. The biggest advantage of this technology is that we can obtain accurate 3D coordinates of objects and create 3D models from two or more overlapping photographs, while at the same time we can use it to record and represent the appearance of objects. To record historical and archaeological sites digitally, the most practical and effective approach is to combine 3D laser scanning and digital photogrammetry (El-Hakim 200; Beraldin 2002). However, we need to develop guidelines based on an evaluation of each method in terms of

accuracy, efficiency, presentation ability, etc., so that we can select the most appropriate method according to on-site conditions and recording requirements.

In this paper, we report a comparison and evaluation of laser scanning and photogrammetry and their combined use for digitally recording cultural heritage objects from the point of view of the accuracy and expressiveness of the models and efficiency in data processing. Data used here was obtained from our experimental 3D measurement of Byzantine ruins on Gemiler Island, off the southwest coast of Turkey, in 2002. A laser scanner (LPM-25HA, Riegl) and a 16 million mega-pixel digital camera (DCS Pro Back, Kodak) were used to measure the ruins of two basilicas. To process the 3D images and create 3D polygonal models, we used InnovMetric Polyworks, and to analyze photographs we used Topcon's digital photogrammetry system, PI-3000.

2. BYZANTINE RUINS ON GEMILER ISLAND

Gemiler Island is located off the Lycian coast of southwestern Turkey and faces the Mediterranean Sea. A wide variety of buildings from a bygone medieval city are scattered throughout the island, i.e., the maritime city seems to be completely preserved. The site has been studied by the Research Group for

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Byzantine Lycia, a Japanese joint research project whose members include art historians, archaeologists, architectural historians, a photographer, and students. They started excavating Church III, one of the four basilicas on the island, in 1995 after several years dedicated to surface exploration. Over 10 years of research has revealed that the city was built in the late 5th to early 6th centuries, i.e., during the early Byzantine era, and the close relationship between the island and St. Nicholas (Tsuji, 1995; Research Group for Byzantine Lycia, 1998; 2002).

Of the four basilicas on the island, the so-called Church II and Church III have kept their original form relatively well and hence they were selected as the first targets for 3D recording and modelling in the Gemiler Island project (Kadobayashi et al. 2003). Church II, which stands halfway up the western slope of the island, has three aisles and measures about 20 x 10 x 9 m. The semi-dome of the apse and the north wall are well preserved (Figure 1). Some frescos remain on the walls around the entrance and the windows. A floor mosaic was also found there.

Figure 1. Church II: exterior view (left) and interior view (right)

Church III, located just below the top of the island, and hence easily visible to ships sailing on the Mediterranean, has three aisles and measures approximately 30 x 15 x 9 m. Generally, the south and west of the basilica, i.e. the atrium and west and south wall, are well preserved, whereas the north and east, i.e., the semi-dome of the apse and the east wall, are not. The wooden roofs of both basilicas have completely perished (Figure 2).

Figure 2. Church III: west wall and nave (left) and apse and nave (right)

3. DATA COLLECTION

In 2002, we conducted 3D measurement of the two basilicas. In addition to the laser scanning, which was the main task, surveying using a total station and RTK-GPS, and taking photographs with digital cameras were carried out (Kadobayashi et al. 2003). In total, we spent 11 days at the site.

3.1 Laser Scanning

We selected a Riegl LPM-25HA to scan the two basilicas due to its battery-driven capability, portability, and accuracy in meeting our requirements. Although the basilicas are relatively large, the architectural historian required a sampling step of 1 cm or less, assuming that the plans would have been drawn to a scale of 1:100. Table 1 summarizes the specification of the laser scanner.

SPECIFICATION	VALUE
Measurement range	2 – 60m
Measurement accuracy	± 8 mm
Measurement rate	1000 points/sec.
Measurement resolution	1 mm
Measuring beam diameter	15 mm @ 10 m 20 mm @ 20 m 60 mm @ 60 m
Laser wavelength	near infrared
Horizontal scanning range	± 180°
Vertical scanning range	± 150°
Positioning accuracy	± 0.009°
Angle readout accuracy	± 0.009°
Scanning speed	36°/sec.
Scanner size	25 x 30 x 32 cm
Scanner weight	9.5 kg

Table 1. LPM25HA laser scanner specifications

We located the scanner at 29 points and scanned 55 images of Church III. The number of measured points was approximately 34 million and the total data amounted to about 470 MB including the RGB value of each point. At Church II, we located the scanner at five locations and scanned seven images, totaling about 5 million points and amounting to 70 MB. It took about 55 hours to scan Church III and 7 hours to scan Church II.

The sampling step was altered from 0.06 to 0.15 gon according to the importance and condition of the target, though due to limited work time, most targets were scanned with a sampling step of 0.1 gon. When the sampling step was 0.06 gon and the target was 10 m away, the sampling step on the target was about 1 cm, while it was about 1.6 cm when the sampling step was 0.1 gon.

3.2 Photo Shoot

The Riegl LPM-25HA is capable of capturing RGB color, but it was considered unlikely that the quality would be good enough for our applications. In addition, it was not able to scan the details of the mosaic flooring and hence we needed another method to record these.

A DCS Pro Back from Kodak with a Distagon 50-mm F4 FLE lens, mounted on a Hasselblad 555ELD, was used to record high-resolution images that were intended to be used to provide texture data for the 3D models. It has a CCD that is 36.86 x 36.86 mm and produces 4072 x 4072 pixel images. Around 1300 images were taken at Church II and Church III.

We took these photos in such a way that adjacent pictures would overlap. As far as possible, we also tried to take them from an orthogonal position in relation to targets such as walls, though this was sometimes impossible when photographing floors since scaffolding was required. In these cases,

photographs were taken from a slanted angle. All of the photographs were taken as single, not stereo images since we had just one set of the DCS Pro Back.

4. DATA PROCESSING

4.1 3D Models from Point Clouds

To align and merge the multiple 3D images to produce 3D polygonal models, Polyworks from InnovMetric was used. First, the images were translated from a local coordinate system to a global coordinate system based on the coordinates of the reference points included in the images using the function provided by LPMSCAN (software from Riegl) to control the scanner. The coordinates of the reference points were obtained from a conventional topographic survey. Secondly, the translated images were imported into Polyworks and then merged into one polygonal model. The size of the polygonal model of Church II in the POL format was about 2,560,000 polygons. The file size was approximately 70 MB. This would be even larger if the model was saved in VRML format.

Since the size of the point-cloud data for the 3D model of Church III was huge, we first partitioned the church into several sections, i.e., the apse, the south wall, and other areas, and then created a 3D model corresponding to each section. These separate models were then merged into one. Some section models were based on the original point-cloud data and others used the reduced data. The total size of the 3D polygonal model of Church III was approximately 6,300,000 polygons in the POL format. The file was about 174 MB in size.

Figure 3. 3D model of Church II: close-up of apse

Figures 3 and 4 show 3D models of Church II and Church III, respectively. Note that these models have no texture, but color information is attached to the vertices. This appearance is due to vertex color, i.e. color captured by the LPM-25HA scanner, and considerably differs from the original color.
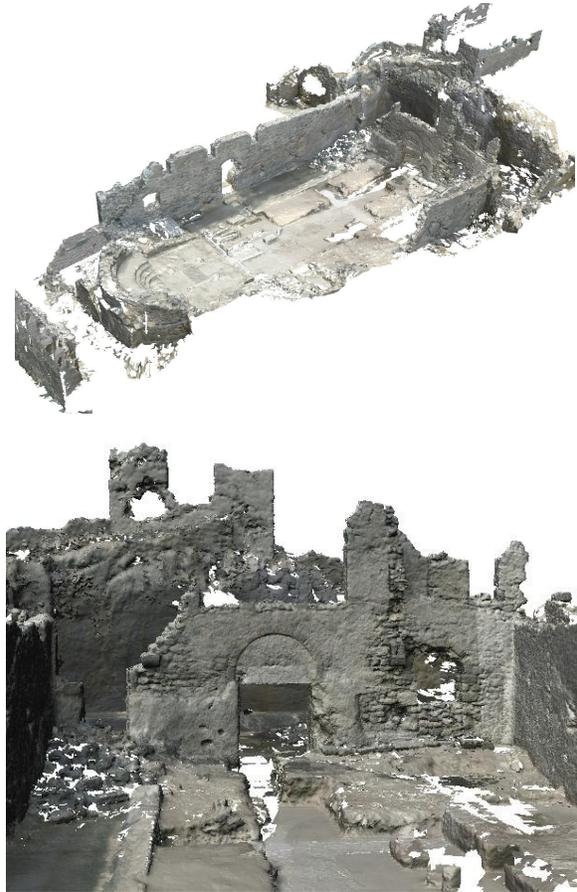
Figure 4. 3D model of Church III: bird's eye-view (above) and close-up of west wall (below)

4.2 Point Cloud with Color Information from Photographs

Usually, RGB images captured by laser scanners are not as high a quality as required for many applications, and even worse, some scanners cannot acquire color images. Therefore, other methods of enhancing representations of the appearance of a scanning target are needed. One popular technique is texture mapping and another is the use of point clouds with color per vertex.

Point-based rendering and modelling are currently important research topics in computer graphics (Pauly et al. 2003; Zwicker et al. 2001; Rusinkiewicz et al. 2000). This is because laser scanning technology is making it easier to obtain dense point clouds. Hence, the size of the polygon models being output has become larger and larger. However, the tools and infrastructure for handling large 3D polygonal models are not yet sufficiently developed. Rendering and modeling using point clouds is attractive since it reduce the data size drastically compared to polygonal models and would therefore be suitable for use on the Internet.

We tried to improve the quality of the color information included in the 3D images scanned by the LPM-25HA laser scanner with the high-resolution images taken by the DCS Pro Back. Each image was analyzed using a corresponding 3D image. The user specified more than six matching points in both a photograph and a 3D image so that the photograph was given

x,y,z coordinates for the reference points. Matching and analyzing were done using software we developed. Figure 5 shows the original RGB color of a 3D image and Figure 6 shows the partially improved 3D image. As a comparison shows, the results were reasonably good.

Although the result was quite good, it is important to note that there is not just one photograph corresponding to a 3D image since a laser scanner can scan a very wide area at once. For example, the LPM-25HA laser scanner can cover 360° horizontally. Color adjustment between several photographs is thus required. If the target is an object that can be placed in a room or the interior of a historical building, it is easier to control the illumination during shooting. However, if the target is located outside, as in our case, it is difficult to control the lighting conditions and the laborious task of adjusting the color is required.

Figure 5. Original RGB information included in the 3D laser data

Figure 6. Improved RGB information (top-right side)

4.3 3D Models with Texture Mapping

To increase the quality of their appearance, we added texture to the polygonal models. The texture images were created from high-resolution image data taken by the DCS Pro Back. For texture mapping, PI-3000, a digital photogrammetry software from Topcon (kochi et al. 2003), was used due to its outstanding features such as follows:

1. It can process pictures taken by a standard digital camera.
2. It runs on a note PC
3. It can calculate Digital Surface Models (DSM's) fully automatically

In addition, it does not require a fixed base or other set up conditions if users do not need sub millimeter accuracies. This was very important for our case since the pictures were not taken by a specific setup condition prepared beforehand.

As there was a huge number of points, reduced point-cloud data for Church II in ASCII text format was imported into PI-3000. A photograph was chosen and also imported into PI-3000 and analyzed using bundle adjustment. To align the 3D polygon model and texture images, three reference points, with global coordinates obtained from a topographical survey, were used. Figure 7 shows the textured 3D model of Church II. To indicate the completeness of the matching, the point cloud is shown on the right.
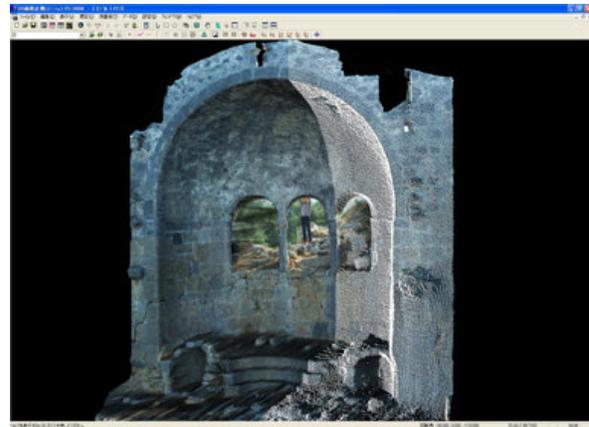
Figure 7. Textured 3D model of Church II

4.4 3D Models from Digital Photographs

We attempted to create 3D models from digital photographs using PI-3000. To model the semi-dome and apse of Church II three-dimensionally, two pictures were selected. These pictures were taken at a distance of 16 m and the baseline length between them was 6 m. The focal length was 52 mm. The theoretical resolution was therefore 3 mm for XY and 8 mm for Z. Note that these images were not taken by a specialist in photogrammetry. They were more like tourist photographs except that a high-end camera was used.

A TIN model has been automatically created and the number of produced points was about 260,000. The resolution is 2 mm. The result is shown in Figure 8. As can be seen, the small details are well modelled. There is a crack on the wall (see Figure 8 above) that is 1-cm wide for the most part. The actual resolution in this case is thought to be less than 5 mm. Figure 9 illustrates different views of the same model. The shape of the semi-dome is well modelled, although it is difficult to model shapes such as a dome, as in this case, using conventional photogrammetry.
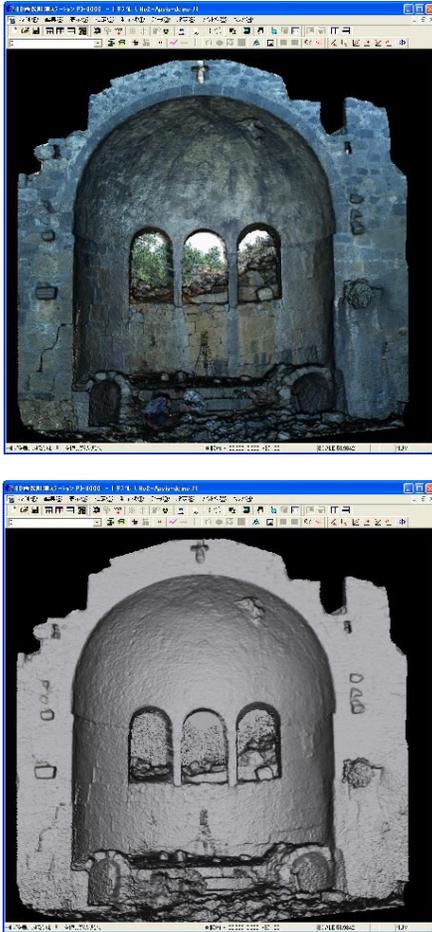
Figure 8. 3D model produced from two pictures using PI-3000: with texture (above) and without texture (below)
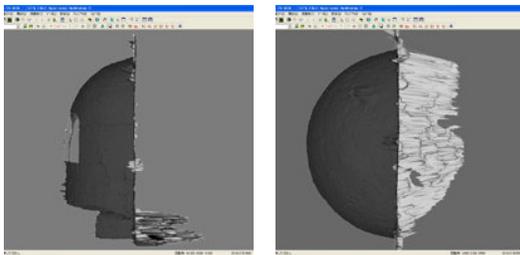
Figure 9. Different view of the 3D model produced from two images

To evaluate its accuracy, the 3D model was compared with elevations drawn by members of the Research Group of Byzantine Lycia. It took 800 man-hours at the site to carry out measurements using a non-prism total station and levelling string, and 300 man-hours to draw seven elevations in the office. In contrast, our method required one day at the site to take photographs and measure reference points, and one day to analyze data and construct the 3D model in the office. The post-process time would be shorter, maybe one or two hours, if the digital photograph were taken based on the predefined set up condition since it took 30 minutes for stereo matching on a PC with a Pentium IV 2.66GHz CPU. When compared with the

elevation, the model was accurate to within 1 cm as shown in Figure 10. The result was satisfactory in terms of efficiency and accuracy.

Figure 10. 3D model of Church II with overlay of elevation

4.5 Orthophotograph of Floor Mosaic

There are still wide areas of mosaic on the floor of Church III. The mosaic is composed of tesserae, small pieces of colored stone that measure approximately 1 x 1 x 1 cm. Since the LPM-25HA cannot scan the shape nor capture the color of the mosaic floor, we were unable to model the details of the floor (see Figure 4). As a result we attempted to use digital photogrammetry to make an orthophotograph and 3D models of the floor mosaic.

Due to difficulty with scaffolding, we were not able to take pictures from just above the floor and hence the photographs were taken from a slanted angle. A total of 25 photographs were taken, which covered about a 5 x 1.5 m area of the floor mosaic. Four reference points, with coordinates measured using the RTK-GPS, were used. It took about two hours for stereo matching producing 700,000 points. Totally it took 3 to 4 days due to the difficulties in selecting stereo pairs from pictures taken from a slanted angle. An orthophoto created using PI-3000 is shown in Figure 11 (left); Figure 11 (right) shows the photo with an overlay of the drawing. The overlapping accuracy was within 1 cm.

Whether or not the drawing is a benchmark is arguable since there is a possibility that the drawing contained large errors as a result of the recording method. Researchers put a vinyl sheet on the floor and traced the pattern of the mosaic. Back at the office, the vinyl sheet was then spread out on the ground and photographed from a rooftop so that the sheet would be covered by a single image. The photo was projected on to a wall on which a section paper was hanging and lines were drawn on it following the projected pattern of the mosaic. The drawings therefore have both lens and projection distortion. Taking this

into account, the orthophotograph we created is a more accurate recording.

Figure 11. Orthophotograph of cloor moaic (left) and that with overlay of drawing (right)

We also examined the possiblilty of creating a 3D model from the orthophotographs of the floor mosaic. Another area, depicting a tree and two birds, was selected for this attempt (see Figure 12, left). Most of the tesserae of the leaves and the bird on the left are missing and that portion is concave. Using PI-3000 made it possible to model the details, (see Figure 12, right), while a 3D model based on point-cloud data was not able to model it. The resolution of the model is 1 mm.

Figure 12. Floor mosaic: 2D image (left) and 3D model (right)

5. CONCLUSIONS

We discussed several methods of creating high-quality 3D models of cultural heritage objects. Unfortunately, no one method can be applied to every situation and we need to select the most appropriate method or combine several methods. There are no strict guidelines for this selection. Instead, practical experience and accumulated know-how is required to enable everyone involved in researching and preserving cultural heritage to record objects three-dimensionally, reconstruct them as computer graphics model, and utilize the models for their various purposes.

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