

IMAGE-BASED RECONSTRUCTION AND MODELING OF THE GREAT BUDDHA STATUE IN BAMIIYAN, AFGHANISTAN

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ABSTRACT:

In the valley of Bamiyan, Afghanistan, ca 2000 years ago, two big standing Buddha statues were carved out of the sedimentary rock of the region. They were 53 and 35 meters high and the Great one figured as the tallest representations of a standing Buddha. In March 2001 the Taleban militia demolished the colossal statues, as they were considered an insult to Islam. After the destruction, a consortium was established to rebuild the Great Buddha of Bamiyan at original shape, size and place. Our group did the computer reconstruction of the statue, which can serve as basis for the physical reconstruction. In this paper we report the results of the 3D reconstruction of the Great Buddha, using different types of imagery in parallel and performing automatic and manual procedures.

KEYWORDS: Cultural Heritage, Orientation, Matching, 3D Reconstruction, Surface modeling, Visualization, Photo-realism

1. INTRODUCTION

In the great valley of Bamiyan, 200 km north-east of Kabul, Afghanistan, two big standing Buddha statues were carved out of the sedimentary rock of the region, at 2500 meters of altitude. The Emperor Kanishka ordered their construction around the second century AD. Some descendants of Greek artists who went to Afghanistan with Alexander the Great started the construction that lasted till the fourth century AD. The town of Bamiyan, situated in the middle of the Silk Route, was one of the major Buddhist centres from the second century up to the time that Islam entered the valley in the ninth century. The larger statue was 53 metres high while the smaller Buddha measured 35 m. They were cut from the sandstone cliffs and they were covered with mud and straw mixture to model the expression of the face, the hands and the folds of the robe. To simulate these folds of the dress, cords were draped down onto the body and were attached with wooden pegs. The lower parts of their arms were constructed on wooden armatures while the upper parts of the faces were made as wooden masks. The two giants were painted in gold and other colours and they were decorated with dazzling ornaments. They are considered the first series of colossal cult images in Buddhist art.

The two statues were demolished on March 2001 by the Taleban, using mortars, dynamite, anti-aircraft weapons and rockets. The Buddhists, the world community, ONU and UNESCO failed to convince the Taleban to leave such works of cultural heritage.

After the destruction, a consortium was established with the goal to rebuild the Great Buddha of Bamiyan at original shape, size and place. This initiative is lead by the global heritage Internet society New7Wonders [www.new7wonders.com], with its founder Bernard Weber and the Afghanistan Institute & Museum, Bubendorf (Switzerland), with its director Paul Bucherer. Our group has volunteered to perform the required computer reconstruction, which can serve as basis for the physical reconstruction.

In this paper we present the results of the computer reconstruction of the Great Buddha of Bamiyan. The computer reconstruction is done using three different types of imagery in parallel and performed with automatic and manual procedures.

Only the manual results will serve as basis for the possible future physical reconstruction.

2. AVAILABLE IMAGES OF THE GREAT BUDDHA

Our work is based on the use of three different types of imagery in parallel [Gruen et al., 2002, Gruen et al., 2003]:

1. A set of images acquired from the Internet ("Internet images");
2. A set of tourist-type images acquired by Harald Baumgartner, who visited the valley of Bamiyan between 1965 and 1969 ("Tourist images");
3. Three metric images acquired in 1970 by Prof. Kostka, Technical University of Graz [Kostka, 1974].

Originally our interest in the reconstruction of the statue was a purely scientific one. We planned to investigate how such an object could be reconstructed fully automatically using just amateur images taken from the Internet. Then, after learning about the efforts to actually rebuild the Great Buddha we decided to get involved in the project beyond a purely scientific approach and to contribute as much as we could with our technology to the success of the work.

3. PHOTOGRAMMETRIC PROCESSING

The reconstruction process consists of phototriangulation (calibration, orientation and bundle adjustment), image coordinate measurement (automatic matching or manual procedure), point cloud and surface generation, texture mapping and visualization. A contour plot of the big statue, done by Prof. Kostka [Kostka, 1974], is also available (20 cm isolines, scale 1:100). From this plot some control points could be measured and used for the phototriangulation.

3.1 The Internet Images

The main scientific challenge here lies in the facts that no typical photogrammetric information about these images is available and that existing automated image analysis techniques will most probably fail because of the different acquisition time, different illumination conditions and different image scales. After the establishment of an adjusted image block

(Figure 1, right) [Gruen et al., 2002], the 3D reconstruction of the statue was performed with a multi-photo geometrically constrained (MPGC) least squares matching software package developed at our Institute [Gruen et al., 2003]. The automatic surface reconstruction works in fully automated mode and a point cloud of ca 6000 points is obtained. Some holes are present in the results (Figure 1, left) because of surface changes due to the different time of image acquisition and to the low texture in some areas.

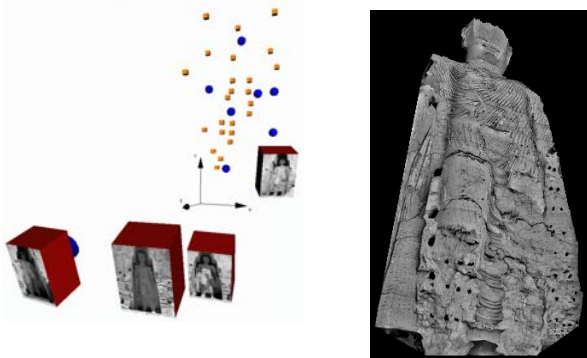


Figure 1: A view on the recovered camera poses of the Internet images with tie and control points (left). The reconstructed texturized 3D model (right).

3.2 The tourist images

Also for this data set, the main challenge is the facts that no typical photogrammetric information is available and also the different illumination conditions between the images. After the establishment of an adjusted image block (Figure 2, left) [Gruen et al., 2003], a MPGC least square matching algorithm was applied to the images [Gruen et al., 2003]. As result, 5585 points are obtained and after manual editing of blunders, a textured model is generated (Figure 2, right). The relatively low image resolution of the tourist data set results in a coarse but quite complete 3D model.

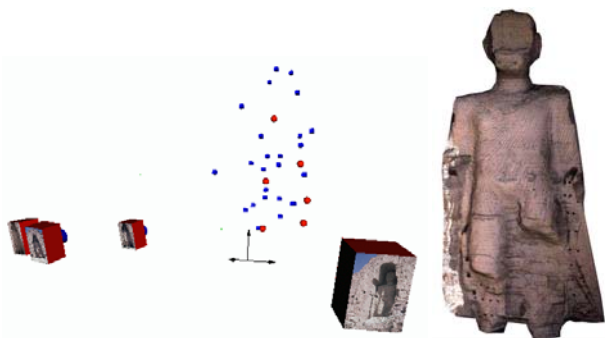


Figure 2: Recovered camera poses of the tourist images (left) and 3D texturized model of the statue (right).

3.3 The metric images

Using the information in [Kostka, 1974] and some control points measured on the contour plot, we achieved the first approximations of the exterior and interior parameters. The final orientation of the images is achieved using a bundle adjustment [Gruen et al., 2002]. Then automated and manual procedures are applied to reconstruct the 3D model of the statue.

3.3.1 Automatic Measurements

The 3D model of the Buddha statue was generated with Virtuozo digital photogrammetric systems [Virtuozo NT, 1999] and with our self-developed matching software [Gruen et al., 2003].

The matching method used by Virtuozo is a global image matching technique based on a relaxation algorithm. In our application, two images of the metric data set were used to reconstruct the 3D model. A regular image grid with 9 pixels spacing was matched using a patch size of 9×9 pixels and 4 pyramid levels. As result, a point cloud of ca 178 000 points is obtained (Figure 3).

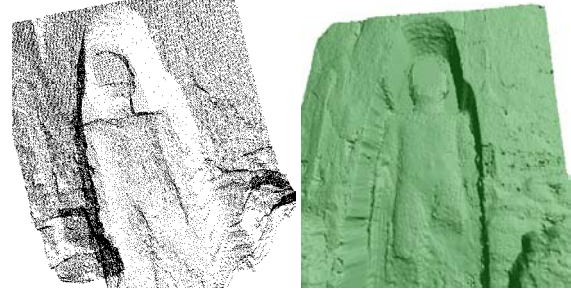


Figure 3: Left: 3D point cloud generated with Virtuozo matching on the metric images (ca 178 000 points). Right: the surface generated from the measured point cloud.

Due to the smoothness constraint and grid-point based matching, the very small features of the dress were filtered or skipped. Therefore these important small features had to be measured manually. Afterwards, the central image was projected on the generated surface and the texturized 3D model is shown in Figure 4.



Figure 4: Texturized model of the Bamiyan Buddha.

Then we tested our matching algorithm on the three metric images [Gruen et al., 2003]. The MPGC matching algorithm resulted in fairly reliable and precise results: 49 333 points (without the surrounding rocks) and 73 640 points (with part of the surrounding rocks) were obtained. The recovered point cloud data as well as the texturized 3D model are shown in Figure 5.

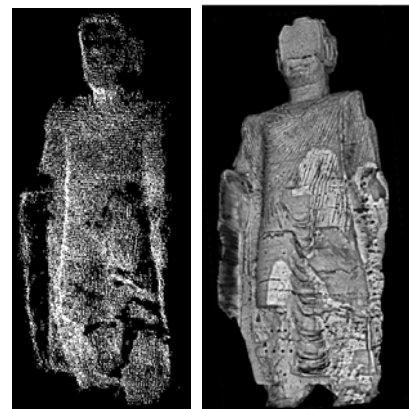


Figure 5: Point cloud of the statue obtained with our matching algorithm (left). Final texturized model (right).

3.3.2 Manual Measurements

The dress of the Buddha is rich of folds, which are between 5 and 10 cm in width and only precise manual measurements could reconstruct the exact shape and curvature of the dress. Therefore the metric images are imported to the Virtuoso stereo digitize module [Virtuoso NT, 1999] and manual stereoscopic measurements are performed, including also part of the surrounding rock. With the manual measurement a point cloud of ca 76 000 points is obtained and the folds on the dress are now well visible (Figure 6). The following surface generation was performed with 2.5D Delauney triangulation by dividing the point cloud in different parts. A mesh for each single point cloud is created and then all the surfaces are merged together with Geomagic Studio [http://www.geomagic.com]. The final 3D model is presented in Figure 7.

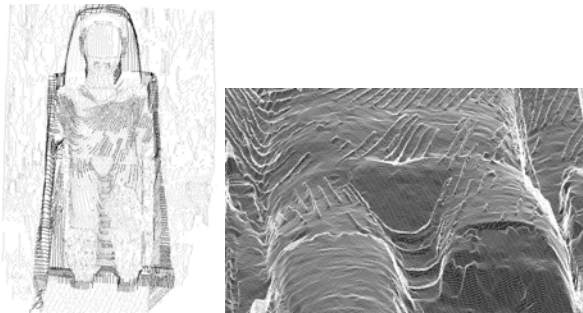


Figure 6: The point cloud of the manual measurement (left). The main edges and the structures of the folds, measured as breaklines, are well visible, in particular when visualized in wireframe mode (right).

4. PHYSICAL RECONSTRUCTION

The 3D computer model that we reconstructed with the manual measurements is used to generate a first scaled physical model of the Great Buddha (Figure 8). At the Institute of Machine Tools and Production, ETH Zurich, R.Zanini and J.Wirth recreated a 1:200 model statue of the Great Buddha importing the point cloud in a digitally programmed machine tool (Starrag NF100). The machine works on polyurethane boxes and follows milling paths calculated directly from the point cloud. The physical model is created in three steps: (1) a roughing path, (2) a pre-smoothing path and (3) the final smoothing path. The time needed for preparing the production data was about 2 hours while the milling of the part itself was done in about 8 hours.

5. CONCLUSIONS

The computer reconstruction of the Great Buddha of Bamiyan has been performed successfully using digital photogrammetric techniques. We have presented here different versions of the 3D model, based on automated point cloud generation using internet images, tourist images and three metric images and manual measurements using three metric images. While the automated matching methods can provide for dense point clouds when applied to high resolution images, they can fail to model the very fine details of the statue, e.g. the folds of the robe. Therefore, only manual measurements allowed to generate a 3D model accurate and complete enough to serve as the basis for a possible physical reconstruction in situ.

A web site of the work has been established on our server and is available at

<http://www.photogrammetry.ethz.ch/research/bamiyan/> with more technical details, stereo images and animations.

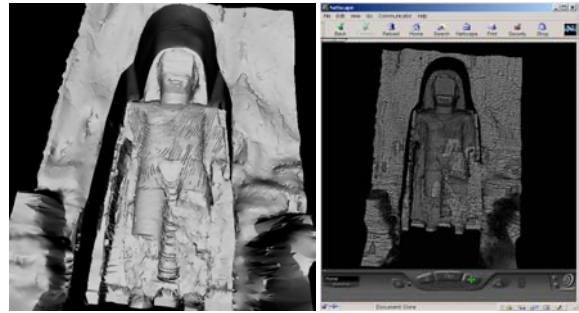


Figure 7: Shaded model of the Buddha (left image) reconstructed with manual measurements on the three metric images. Texturized model visualized with VRML viewer (right image).

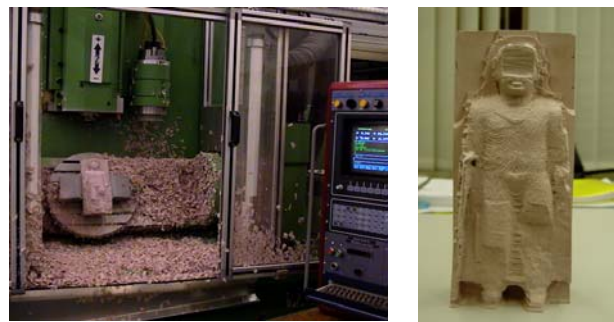


Figure 8: The milling machine used for the physical reconstruction of the Bamiyan Buddha (left) and an image of the model (right).

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