3D MODELING AND VISUALIZATION OF LARGE CULTURAL HERITAGE SITES AT VERY HIGH RESOLUTION: THE BAMIYAN VALLEY AND ITS STANDING BUDDHAS

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ABSTRACT

In this paper we present the modeling and visualization of the cultural heritage area of Bamiyan, Afghanistan. The region is situated ca 200 km north-west of Kabul and it was one of the major Buddhist centres until the ninth century AD. The two standing Buddhas belonged to some of the most famous Buddhist monuments world-wide. In 2001 they were destroyed through an act of vandalism by the Taleban militia. In our previous reports we have already presented the 3D computer reconstruction of the Great Buddha while in this contribution we will describe the terrain modeling of the surrounding area from satellite images, the 3D reconstruction of the entire rock cliff of Bamiyan and the modeling of the two empty niches where the Buddha statues once stood.

1. INTRODUCTION

The region of Bamiyan, ca 200 km North-West of Kabul, Afghanistan, was one of the major Buddhist centres from the second century AD up to the time when Islam entered the area in the ninth century. For centuries, Bamiyan lay in the heart of the famous Silk Road, offering rest to caravans carrying goods across the area between China and Western Empires. Strategically situated in a central location for travellers from North to South and East to West, Bamiyan was a common meeting place for many ancient cultures. In the region, many Buddha statues and a hundreds of caves were carved out of the sedimentary rock. In particular, near the village of Bamiyan, at 2600 meters altitude, there were three big statues of Buddha carved out of a vertical cliff (Figure 1). The famous standing Buddha statues, as well as other small statues in Foladi and Kakrak have been destroyed by the Taleban militia in March 2001 (Figure 2, left).

In 2003, the World Heritage Committee has decided to include the cultural landscape and archaeological remains of the Bamiyan valley in the UNESCO World Heritage List [http://whc.unesco.org/]. The whole area is in a fragile state of conservation as it has suffered from abandonment, military actions and explosions. The major dangers are the risk of imminent collapse of the Buddha niches with the remaining fragments of the statues, further deterioration of still existing mural paintings in the caves, looting and illicit excavation.

Figure 1: Panorama of the Bamiyan cliff with the three Buddha statues prior to demolition.

In our previous reports we have already presented the 3D computer reconstruction of the Great Buddha of Bamiyan (Figure 2, right, Gruen et al., 2002, 2003). In this article we describe the 3D modeling procedures for (1) the terrain of the whole Bamiyan area, (2) the entire rock cliff of Bamiyan and (3) the two empty niches where the Buddha statues once stood. For the modeling of the cliff and the niches, images and geodetic measurements acquired during a field campaign in August 2003 were used.

Figure 2: The explosion of March 2001 that destroyed the Great Buddha statue in Bamiyan (left). The 3D computer model of the figure, as reconstructed from existing images (right, Gruen et al., 2002, 2003).

The final goal is the generation of virtual flights over the UNESCO cultural heritage site. This includes a comparison of the previous situation with our high-resolution 3D models and the current situation with the empty niches.

A photo-realistic 3D digital model of the entire Bamiyan area and a detailed view of the cliff with and without the standing Buddhas will be presented.

2. TERRAIN MODELING FROM SATELLITE IMAGERY

For the 3D modeling and visualization of the area of interest, an accurate DTM is required. We had the contours of Russian map 1:50 000 digitised, but when we tried to map an IKONOS image onto the derived DTM we realised that its quality was not sufficient. Aerial images were not available to us and the idea to acquire them was unrealistic, due to the absence of any surveying company operating in that area. So space-based

image acquisition and processing resulted as the only alternative to the aerial photos or any other surveying method. Nowadays space images are competing successfully with traditional aerial photos, for the purpose of DTM generation or terrain study in such problematic countries, as Afghanistan is. Also the resolution and availability of world-wide scenes taken from satellite platforms are constantly increasing. Those scenes are available in different radiometric modes (panchromatic, multispectral) and also in stereo mode.

2.1 The satellite images

The HRG sensor carried on SPOT-5 since May 2002 was suitable for our tasks [Spot Image]. The sensor can acquire stereo images in across-track direction at 2.5m ground resolution in panchromatic mode. The time difference between two successive acquisitions in stereo mode of the same area depends on the incidence angle, with a minimum of one day difference. The satellite flies at a mean height of 832 km, along a quasi-polar and sun-synchronous orbit.

Due to the scientific, social and cultural interest of the project, a B/W stereo pair over Bamiyan was provided at special conditions by the ISIS Program [ISIS]. The two scenes have been acquired on 18th December and 19th December 2003, at 10:40 a.m. and 10:20 a.m. local time respectively. The scenes are 24000 x 24000 pixels large and cover a mountainous area of approximately 60x60 km, centered at (34∫50ë N, 68∫ 7` E) and (34∫50ë N, 67∫ 48` E). The cloud cover was zero and the ground resolution is 2.5 m.

Furthermore, a B/W Geo level IKONOS image mosaic over the Bamiyan area was provided by Space Imaging [Space Imaging] (Figure 3). The scene was acquired on 15th December 2001 and covers an area of 13x20 km, centered at (34∫46í N, 67∫49í E). The image size is 13957 x 21118 pixels and the ground resolution is 1m.

Figure 3: The two empty Buddha niches as observed by IKONOS (courtesy of Space Imaging, Inc.). Left: Great Buddha. Right: Small Buddha.

2.2 GPS measurements

For the georeferencing of the satellite images, seven GPS points were measured (Figure 4) during our field campaign in August 2003. Two Trimble GEO Explorer receivers logging carrier phase data (C/A code) were used; one receiver was set as ëmasterí (fix position) and the other served as ëroverí. The points were identified on the IKONOS image and then measured in C/A mode.

After the data collection, the observations were post-processed to generate more accurate positions. It was not possible to perform absolute differential corrections as the closest master station was ca 1500 km away. Table 1 summarises the GPS measurements.

Table 1: GPS measurements and related parameters.

No. of Points	Average satellites	Average PDOP	Horiz. Accuracy	Vert. Accuracy
7	6	2.78	0.11 m	0.3 m

Figure 4: The distribution of the GPS ground control points on the IKONOS image mosaic. In the centre the master station position.

2.3 Scenes orientation and DTM generation

The DTM was generated from level 1A scenes (radiometrically but not geometrically corrected) using SATñPP (SATellite Precision Positioning) software developed at our Institute. SAT-PP includes different modules for the precise processing of high-resolution satellite image data and allows image pre-processing, orientation, matching, DTM/DSM generation and object extraction. For more details, see [Zhang, Gruen, 2004; Poli et al., 2004]. The IKONOS mosaic orientation was based on a 2D affine transformation. On the other hand, the SPOT scenes orientation was based on a rational function model. Using the camera model, the calibration data and the ephemeris contained in the metadata file, the software estimates the RPC (Rational Polynomial Coefficients) for each image and applies a block adjustment in order to remove systematic errors in the sensor external and internal orientation. The scenes' orientation was performed with the help of the GCPs measured with GPS. Table 2 shows the image orientation results.

Table 2: Image orientation results.

Source	RMSE East (m)	RMSE North (m)	RMSE Height (m)
IKONOS	0.56	0.48	-
SPOT Image Pair	1.22	2.01	1.50

The oriented SPOT stereo pair was then subjected to the automated DTM/DSM generation, using the module of SAT-PP. A 20 m raster DTM for the whole area and 5 m raster DTM for the area covered by the IKONOS image were interpolated from the original matching results, using also some manually measured breaklines near the Buddha cliff (Figure 5). The matching algorithm combines the matching results of feature points, grid points and edges. It is a modified version of MPGC (Multi Photo Geometrically Constrained) matching algorithm [Gruen, 1985; Zhang, Gruen, 2004] and can achieve sub-pixel accuracy for all the matched features.

Figure 5: The recovered DTM of the Bamiyan area displayed in colour coding mode (left). The two overlaid DTMs (right).

Finally, for the visualization of the whole Bamiyan area, a 2.5 m resolution ortho-image from SPOT images and a 1 m resolution ortho-image from the IKONOS image were generated. The textured 3D models are presented in Figure 6.
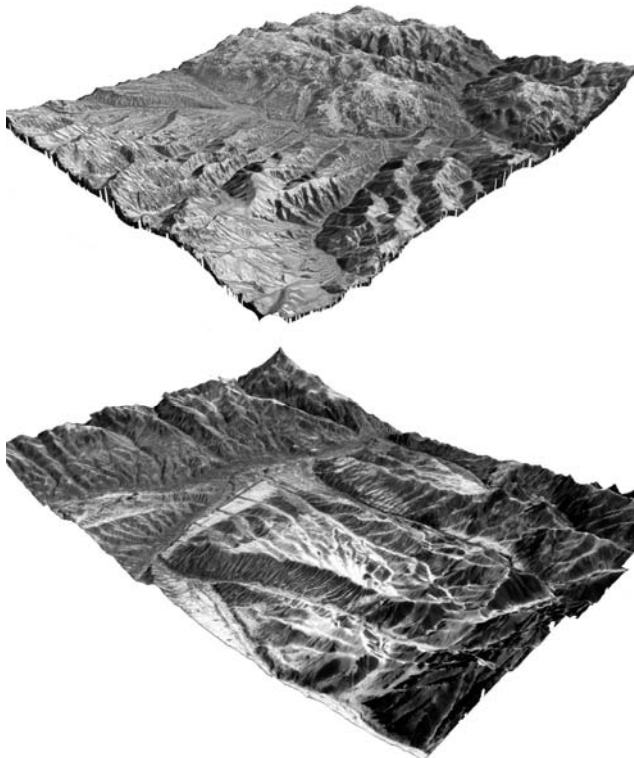

Figure 6: The DTM of the Bamiyan area generated from satellite images and textured with a SPOT5 (above) and an IKONOS ortho-image (below).

In Figure 7 two closer views on the 3D IKONOS textured model of the Bamiyan cliff and the old Bamiyan city (the pyramid-type hill to the left) are presented.
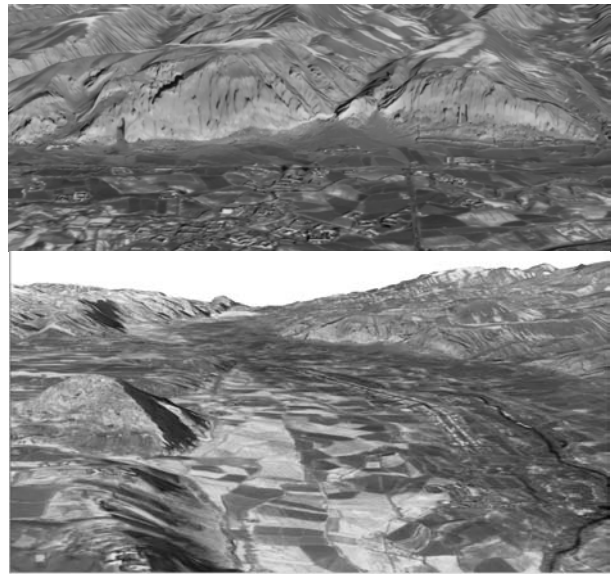

Figure 7: Zoom into the 3D Bamiyan terrain model. The rock cliff with the two empty niches (above). A view of the Bamiyan area: on the left the hill (Shar-i Ghulghulah) where the old city was located while in the centre the new ébazaarí is visible (below).

3. MODELING OF THE ROCK CLIFF OF BAMIYAN

For the reconstruction and modeling of the Bamiyan cliff (Figure 8), a series of terrestrial images acquired with an analogue Rollei 6006 camera was used. Furthermore, a geodetic network of 10 stations was used to measure, with a total station, 30 control points distributed all along the rock cliff.

Figure 8: The Bamiyan cliff, approximately 1 km long and 100 m high (above). The cliff as seen from the empty niche of the Small Buddha (below).

The images of the rock facade were acquired along a strip. 39 images were oriented with a self-calibrating bundle adjustment, measuring the tie points in the Analytical Plotter (Figure 9). The average precision of the object points is σ_x= 0.15 m, σ_y= 0.11 m, σ_z= 0.23 m with a standard deviation of unit weight a posteriori at 0.013 mm.
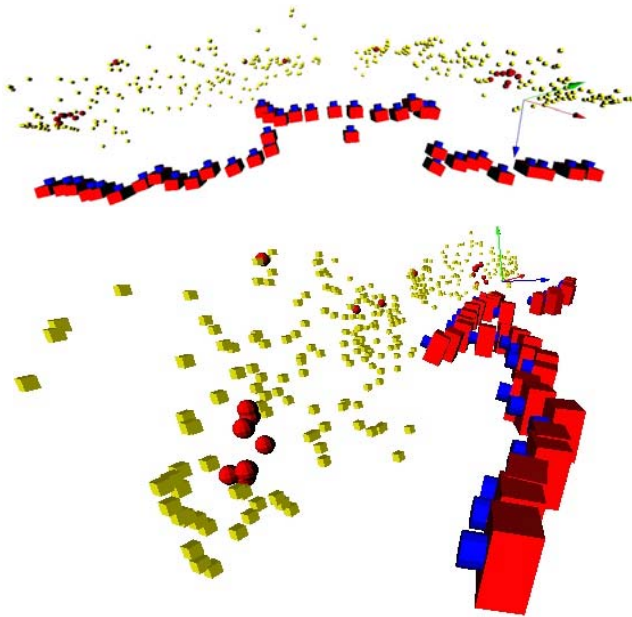
Figure 9: The recovered camera poses of the Rollei images used for the modeling of the rock cliff. The spheres represent the used control points. Top: a view from the top of the strip. Bottom: a view from the side of the empty niche of the Great Buddha.

Because of some software problems with the Analytical Plotter we could not perform stereo measurements with the instrument. Therefore the images were scanned at 20 micron resolution and the modeling of the cliff surface was done by measuring the points with the commercial software Photomodeler. Then a mesh with a 2.5D Delaunay triangulation was generated and a textured model of the cliff was produced (Figure 10).
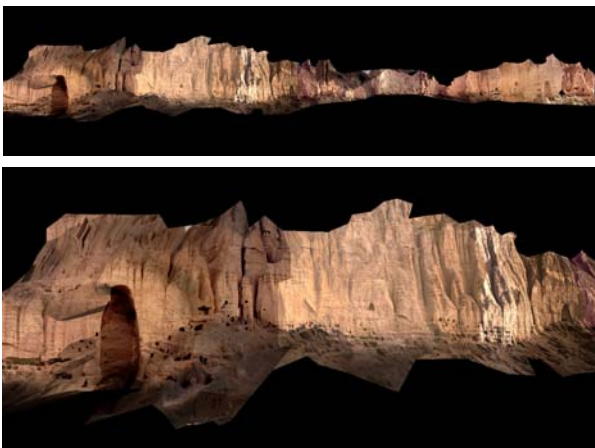

Figure 10: Two different views onto the 3D textured model of the Bamiyan rock cliff.

Because of the network configuration and the complex shape of the rock facade, the recovered geometric model is not complete, in particular in the upper part. In some areas it is not possible to find corresponding features, because of occlusions, different lighting conditions and shadows. This is not such a big problem, because the cliff model is not meant to be used alone, but in a next step it will be integrated into the DTM of the larger environment.

4. MODELING OF THE TWO EMPTY NICHES

The modeling of the two empty Buddha niches was performed using digital images acquired with a Sony Cybershot F707. The image size is 1920x2560 pixels while the pixel size is ca 3.4 µm.

Both niches are now a ìnational monument with unique importance to humankindî and are safeguarded by UNESCO, the Japanese Government and the Afghan Ministry of Information and Culture (Figure 11).

Figure 11: The sign in front of the empty cave of the Great Buddha that declares it a protected national monument.

4.1 The empty niche of the Great Buddha

For the 3D computer reconstruction 5 images were used (Figure 12). The camera parameters were recovered with a self-calibrating bundle adjustment, measuring the tie points semi-automatically by means of Least Squares Matching (LSM) [Gruen, 1985]. The final average standard deviations of the object coordinates are $\sigma_x = 0.014$ m, $\sigma_y = 0.017$ m, $\sigma_z = 0.021$ m.

Figure 12: The empty niche where the Big Buddha once stood, as seen in August 2003.

Afterwards, distortion-free images were generated and imported into the VirtuoZo stereo digitize module [VirtuoZo NT, 1999]. Three stereo-models were set up and points were measured along horizontal profiles, while the main edges were measured as breaklines. Thus a point cloud of ca 12 000 points was generated. The recovered camera poses and the measured points are displayed in Figure 13.
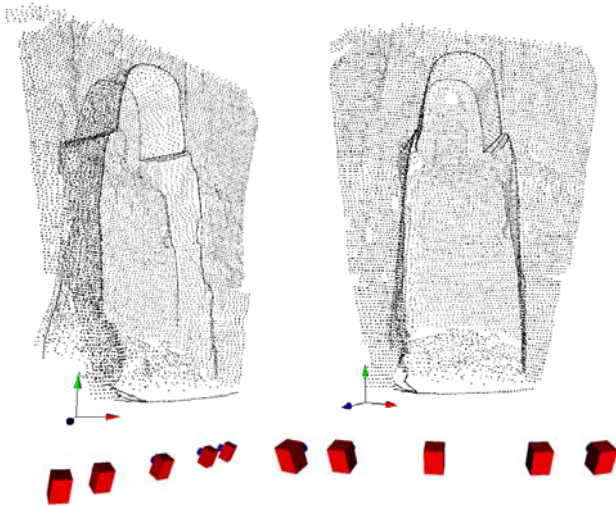
Figure 13: The recovered positions of the cameras and the measured points for the modeling of the empty niche of the Great Buddha.

The surface generation was then performed with a 2.5 Delaunay method, dividing the measured point cloud into separate parts. A mesh was created for each single point cloud and then all the surfaces were merged together with Geomagic Studio [Raindrop]. The final model of the empty niche is displayed in Figure 14.
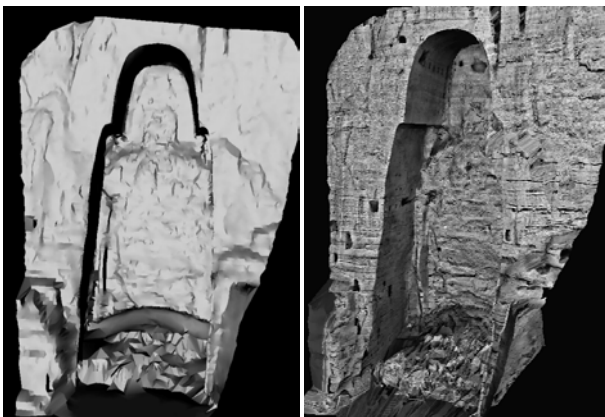

Figure 14: 3D model of the empty niche of the Great Buddha, visualized in shaded (left) and textured mode (right).

The recovered 3D model of the empty niche allows the comparison between the actual situation and the previous one, before the destruction (Figure 15 and 16).

Figure 15: The niche of the Great Buddha: a comparison between an image of the 1970ís and the actual situation.
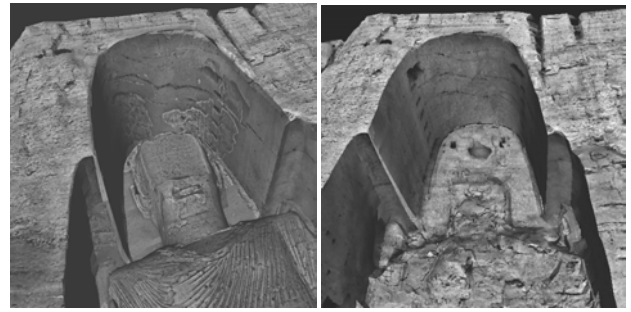

Figure 16: The reconstructed 3D models of the Great Buddha and the actual empty niche. An image of the full 3D model of the Great Buddha is shown in Figure 2.

4.2 The empty niche of the Small Buddha

The modeling of the empty niche of the Small Buddha was performed using 9 images (Figure 17)

Figure 17: The empty niche of the Small Buddha.

The necessary tie points were measured semi-automatically with LSM and then imported in a self-calibrating bundle adjustment. The final average standard deviations of the object coordinates are $\sigma_x = 0.015$ m, $\sigma_y = 0.019$ m, $\sigma_z = 0.022$ m.
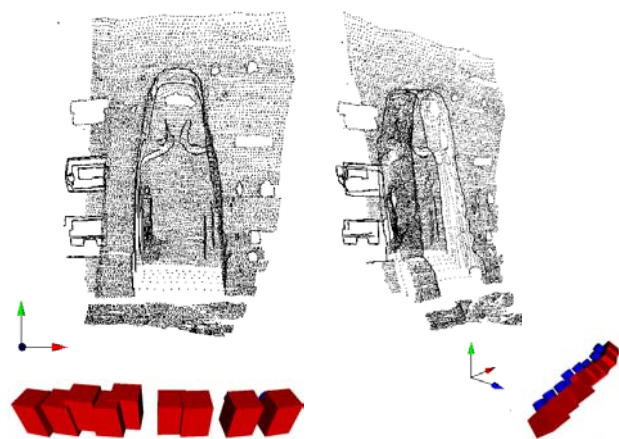

Figure 18: The camera poses and the manually measured points for the modeling of the empty niche of the Small Buddha.

Afterwards manual measurements were performed in VirtuoZo on the distortion-free images and a cloud of approximately 17 000 points was recovered (Figure 18).
For the mesh generation, we had to split the point cloud in different parts, to be able to perform 2.5 Delaunay triangulation.

After the surface generation, a textured model was produced, as shown in Figure 19.
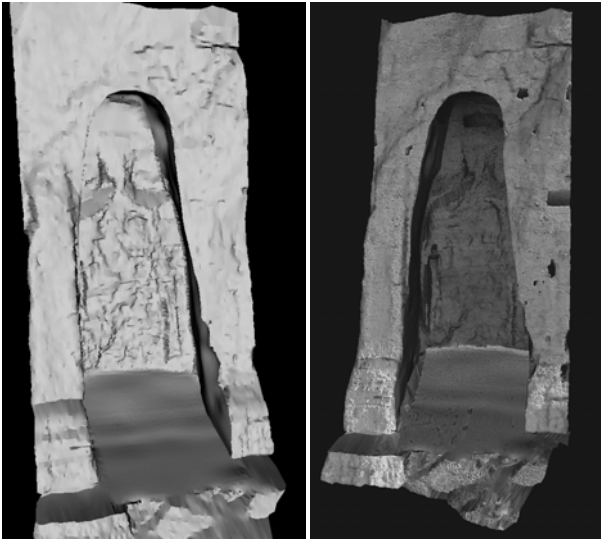

Figure 19: 3D model of the empty niche of the Small Buddha, visualized in shaded (left) and textured mode (centre and right).

5. CONCLUSIONS

In this work we have shown the modeling of the whole cultural heritage site of Bamiyan, Afghanistan. We have used different types of images and produced a detailed terrain model as well as 3D models of the two empty niches and the rock cliff where the two Buddha statues once stood. The 3D reconstruction of the Small Buddha statue is currently underway.

The satellite images were the only possibility for the mapping of the heritage area because of their instant availability and high resolution.

Manual measurements were necessary to reconstruct all those small features that an automatic procedure would miss. The big operational problem was actually the 3D surface modeling of the cliff and the Buddhas. We are still not satisfied with commercial modeling software and we spent more time on modeling than on measurement. In order to have a smooth production process one should adapt the measurement procedure to the capabilities of the 3D modeller.

The photo-realistic 3D digital models of the entire Bamiyan area and the detailed view of the cliff with and without the standing Buddhas will be used for visualization and animation.

We also can now compute the volume of the material that was destroyed during the demolition. This will give clear hints as to whether the leftovers will suffice to be used for physical reconstruction. Results from these considerations will help to decide about the best reconstruction.

In addition, the DTM will now be imported into a GIS software to create a complete information system of the protected area, which may serve for technical, scientific and touristic purposes in the future.

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