MODELING AND VISUALIZATION OF LANDSCAPE AND OBJECTS USING MULTI-RESOLUTION IMAGE DATA

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ABSTRACT

In this paper we present the photogrammetric modeling and visualization of the UNESCO World Heritage site of Bamiyan, Afghanistan using multi-temporal and multi-resolution images. The final goal of our work is the production of virtual flights over the Bamiyan area, the extraction of cartographic vector features around the village and the documentation of the protected area with a tourist and cultural information system. Each data set was processed with our own photogrammetric software and afterwards the recovered 3D datasets were all merged together. The fusion of the available data is a very complex and critical task, requiring smart algorithms for modeling and visualization. A factor 400 is present between the different resolution levels of the geometry, while, in the texture, we have a factor 1250. Problems with interactive and real-time navigation of large data sets will be also addressed in the paper.

1. INTRODUCTION

The region of Bamiyan, ca 200 km North-West of Kabul, Afghanistan, was one of the major Buddhist centers 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 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 larger standing Buddha was 53 meters high while the smaller one measured 38 m. They were cut from the sandstone cliffs and they were covered with a mud and straw mixture to model fine details such as the expression of the face, the hands and the folds of the robe.

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

The invasion of the Soviet army in December 1979 started 23-years long period of wars and barbary that left Afghanistan as a heavily hurt and damaged country, with little hope for quick infrastructure reconstruction, economic improvements, political stability and social peace. Moreover, at the end of the 1990s the extremist Taleban regime started an internal war against all non-Islamic symbols. This led in March 2001 to the complete destruction of the two big standing Buddha statues of Bamiyan (Figure 2), as well as other smaller statues in the Bamiyan area (Foladi and Kakrak). 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 area contains numerous Buddhist monastic ensembles and sanctuaries, as well as fortified edifices from the Islamic period. The site symbolizes the hope of the international community that extreme acts of intolerance, such as the deliberate destruction of the Buddhas, are never repeated again. The whole area is nowadays 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 2: Above: The explosions of March 2001. Below: The empty niches, where the Great (left) and the Small (right) Buddhas once stood, as seen in August 2003 during our field campaign.

In previous papers we have reported about the photogrammetric 3D reconstruction of the Great Buddha [Gruen et al., 2004a, Gruen and Remondino, 2005]. The goal of our current work is the creation of a photo-realistic 3D model of the entire Bamiyan area and a detailed view of the cliff with and without the standing Buddhas. The final products are the generation of virtual flights over the UNESCO World Heritage site and a GIS to be used as the basis for a cultural and tourist information system.

2. TERRAIN MODELING FROM SATELLITE IMAGERY

The computer modeling of large sites has recently received some attention. Many cultural heritage applications require precise 3D reconstruction for documentation and visualization purposes and over the past years it has become increasingly common to use 3D digitization and modeling techniques for these purposes. The motivations are two-fold: (a) the available technologies for data acquisition, processing and visualization are continuously improving and (b) the increasing interest of UNESCO in large sites. UNESCO has in fact started the ëOpen Initiativeí partnership with different space agencies to support, assist and contribute in the monitoring and documentation of World Heritage sites, natural hazards and for sustainable development using satellite data. Nowadays a great array of data acquisition tools is available: satellite images, digital aerial cameras, radar and hyperspectral sensors, GPS/INS positioning systems, aerial and terrestrial laser scanners, terrestrial still-video, video and panoramic cameras. In particular, high-resolution satellite images with a footprint smaller than 5m are becoming increasingly available to the earth observation community and their respective clients for visualization and mapping purposes. The related cameras are all using linear array CCD technology for image sensing. The possibility and need for accurate 3D object reconstruction requires a sophisticated camera model, being able to deal with such sensor geometry. The choice of the imagery mostly depends on the data availability for a specific location and time, the price and the required scale of application. Furthermore, space images are often competing with traditional aerial photos in particular in problematic countries where aerial images are not available or no surveying company is operating. These images are available in different radiometric modes (panchromatic, multispectral) and also in stereo mode.

2.1 3D Modeling of the Bamiyan landscape

For the 3D modeling and visualization of the Bamiyan area, 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. For the project, a B/W stereo pair acquired with the HRG sensor carried on SPOT-5 and a PAN Geo level IKONOS image mosaic over the Bamiyan area were available. The SPOT-5 images were acquired in across-track direction at 2.5m ground resolution while the IKONOS image mosaic (available in B/W and pansharpened) has a ground resolution of 1 m.
The sensor modeling, DTM/DSM and ortho-image generation were performed with our software SAT-PP, developed for the processing of high-resolution satellite imagery [Zhang and Gruen, 2004; Poli et al., 2004; Gruen et al., 2005]. After image orientation a DTM was generated from the SPOT stereo pair using the SATñPP module for DTM/DSM generation. A 20 m raster DTM for the whole area and 5 m raster DTM for the area covered by the IKONOS image were then interpolated from the original matching results (Figure 3), using also some manually measured breaklines near the Buddha cliff.

The visualization of the produced DTM is a very important element, as for the external world it is usually the unique and possible contact with the 3D model. Visualization packages and tools are available in different forms. For DTM visualization (often called ëgeovisualizationí), more than 500 packages are available, while many other developed software packages are not widely known and public. The packages can be classified according to their real-time performances, the rendering quality of geometry and texture, the anti-aliasing function, the input data, the level of detail (LOD) properties, etc. For the photo-realistic visualization of the whole Bamiyan area (49x38 km^2), a 2.5 m resolution B/W ortho-image from SPOT images and a 1m resolution IKONOS pansharpened ortho-image were generated. The SPOT-DTM and the IKONOS-textured 3D model are shown in Figure 3.

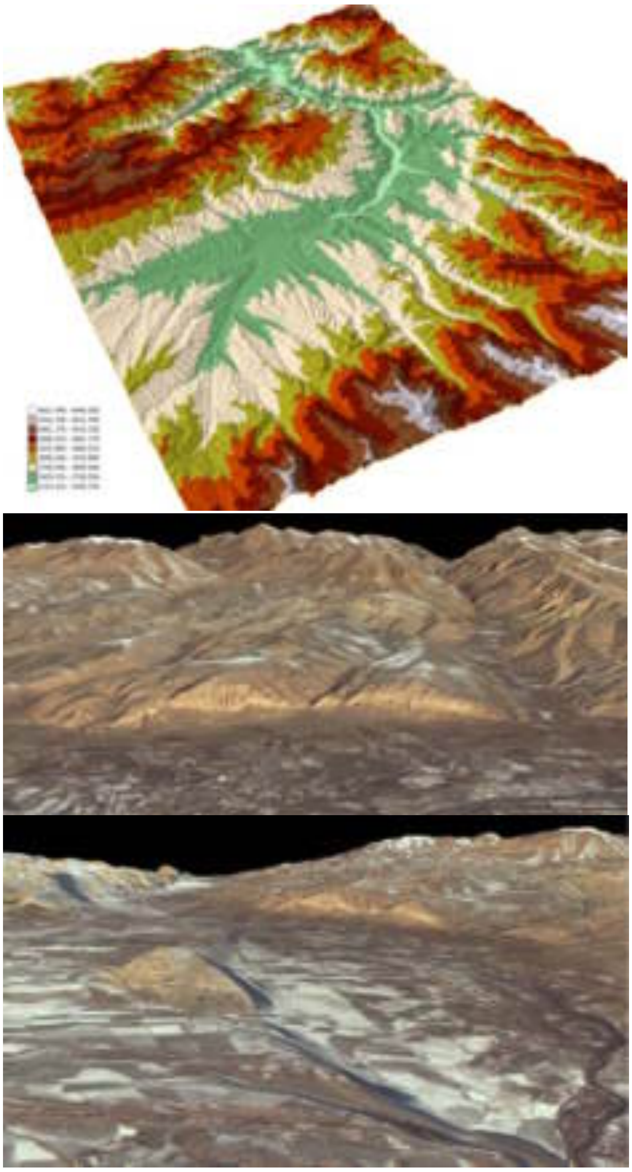

Figure 3: DTM generated from a SPOT-5 stereopair (above) and textured with a pansharpened IKONOS mosaic (center and below).

The recovered DTM was also imported into a GIS software to create an information system of the protected area, which may serve for technical, scientific and tourist purposes in the future [Gruen et al., 2004b].

3. MODELING OF TERRESTRIAL OBJECTS

The 3D computer reconstruction of the Great Buddha statue was performed on different image data-sets and using different algorithms [Gruen et al., 2004a]. Various 3D computer models of different quality, mostly based on automated image measurements were produced. However, in most of the cases, the reconstructed 3D model did not contain essential small features, like the folds of the dress and some important edges of the niche. Therefore, for the generation of a complete and detailed 3D model, manual photogrammetric measurements were indispensable. The final 3D model of the Great Buddha (Figure 8) was used for the generation of different physical models of the statue. Recently, a 1:25 scale model was generated for the Swiss pavillion of the 2005 World Exhibition in Aichi, Japan.

For the reconstruction and modeling of the Bamiyan cliff (Figure 4), a series of terrestrial images acquired with an analogue Rollei 6006 camera was used. The niche is approximately 1 km long and 100 m high. A geodetic network of 10 stations was used to measure with a total station 30 control points distributed along the rock cliff.

Figure 4: 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 were digitized at 20 micron resolution and then oriented with a photogrammetric bundle-adjustment (Figure 5). The surface measurements were performed manually on stereo-pairs in order to get all the small details that an automated procedure would smooth out. The recovered point cloud was triangulated, edited and finally textured, as shown in Figure 7.

Because of the network configuration and the complex shape of the rock facade, the recovered geometric model is not really 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.

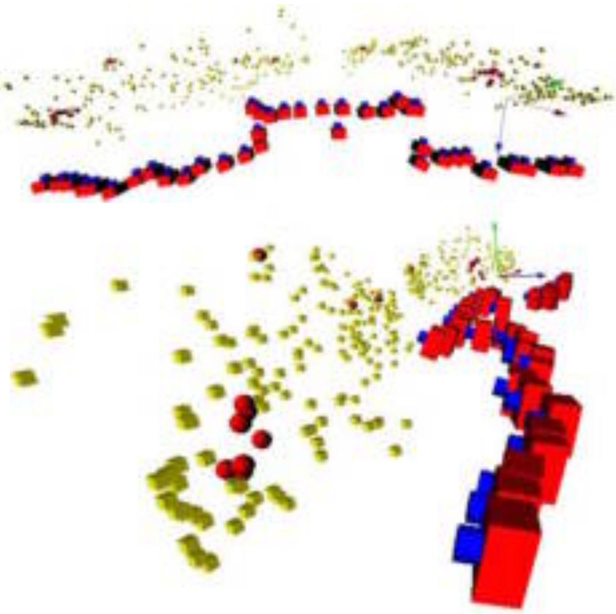

Figure 5: Recovered 39 camera poses of the Rollei images used for the modeling of the rock cliff. The spheres represent the used control points; the cubes are tie points.

The two empty Buddha niches (Figure 2) 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. They are in a fragile state of conservation and there are risks of imminent collapse. The two objects were modeled using digital images acquired with a Sony Cybershot F707. The image size is 1920x2560 pixels while the pixel size is ca 3.4 μm.

For the Big Buddha niche (approximately 60 m height and 25 m wide), five images were used. The camera parameters were recovered with a bundle adjustment and the final average standard deviations of the object coordinates were σ_x = 0.014 m, σ_y = 0.017 m, σ_z = 0.021 m (depth). Manual measurements were afterwards performed to precisely recover the full object. Thus a point cloud of ca 12 000 points was generated, using horizontal profiles and breaklines for the main edges. The recovered camera poses and the measured points are displayed in Figure 6.

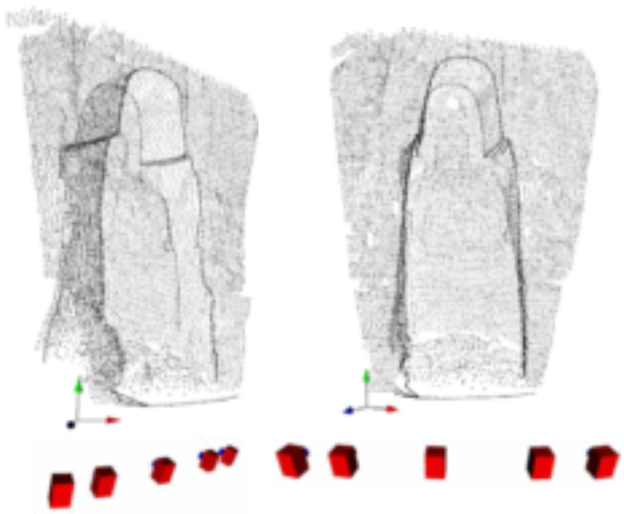

Figure 6: Recovered positions of the cameras and the measured points for the modeling of the empty niche of the Great Buddha.

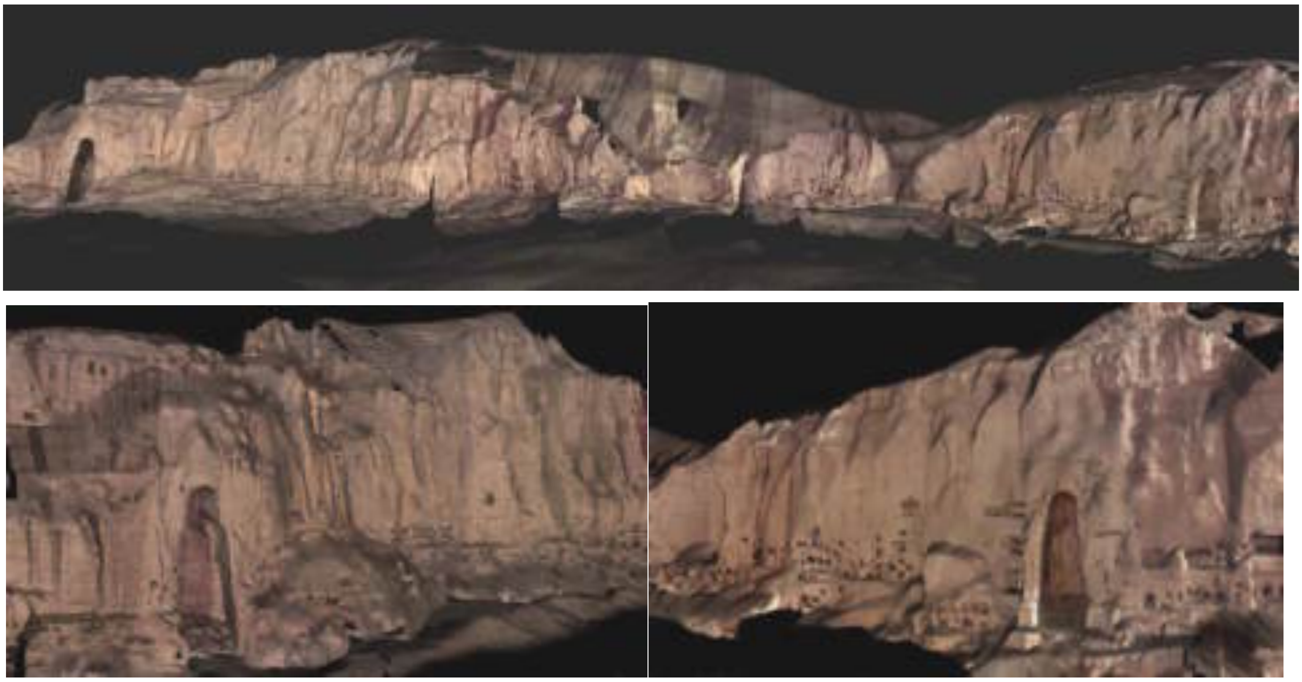

Figure 7: Highly detailed 3D model of the Bamiyan cliff (above) with two closer views of the empty niches (below).

Figure 8: 3D model of the Great Buddha of Bamiyan and its actual empty niche. The modeled frescos are visible in the upper right image.

After surface generation the 3D model was textured for photo-realistic visualization (Figure 8).
The niches of the Bamiyan Buddha statues were rich with paintings, which have been partly destroyed earlier in history and ultimately during the explosions. The best way of proper documentation and visualization of this lost art is the generation of an accurate and photo-realistic image-based 3D model. In particular, the ceiling part of the Big Buddha niche (approximately 15 m of diameter and 16 m depth) was rich with mural paintings in different colours, representing Buddha-like figures, bright-coloured persons, ornaments, flowers and hanging curtains. Using available images that tourists acquired in the 60ís and 70ís, we were able to create different mosaics of the paintings and to use them for the photo-realistic texture mapping of the 3D model [Remondino and Niederoest, 2004] (Figure 8, upper right).
Having the 3D model of the Great Buddha and its actual empty niche, the volume of the material that was destroyed during the demolition was computed: the leftover rubble at the bottom of the empty niche amounts to ca 60% of the original statue. This gives a clear hint that the leftovers are not sufficient to be used for a physical reconstruction (e.g. by anastylosis).

4. INTEGRATION OF MULTI-RESOLUTION IMAGE-BASED DATA

The interactive visualization of massive textured 3D models is a complex and challenging problem. In many projects the size of geometry and texture available data easily exceeds the capabilities of current hardware. Therefore there is a need for rendering techniques able to maximize the available amount of visible data with an optimal use of the rendering power, while maintaining smooth motion during the interactive navigations. The correct visualization of large data sets requires a view-dependent adaptation of the model resolution and an efficient occlusion culling. Therefore different dynamic multi-resolution approaches have been proposed, based on the idea of constructing a smaller and adaptively approximated representation of the visible 3D data and render only them instead of the complete model. Towards this goal [Borgeat et al., 2005] developed a new technique for fast, view-dependent and real time visualization of large multi-resolution geometric and textured 3D models. The approach uses geomorphing to smoothly interpolate between geometric patches generating a hierarchical LOD structure and maintaining seamless continuity between neighbouring patches of the model. Generally all the developed approaches are very time consuming and processor intensive. In fact the task of extracting the adequate representation out of a 3D model and send it to the graphics hardware is usually the main problem during the visualization of huge data.
The Bamiyan project is a combination of multi-resolution and multi-temporal photogrammetric data, as described in the paper and summarized in Table 1. The geometric resolution of the recovered 3D data spans from 20 m (SPOT-5) to 5 cm (Buddha model) while the texture information is between 2.5 m (SPOT-5) and 2 mm (fresco) resolution. Thus a factor of 400 exists between the different geometry resolutions, while there is a factor of 1250 in the texture data. The whole triangulated surface model covers an area of ca 49x38 sqkm and contains approximately 35 million triangles, while the texture occupies ca 2 GB. The fusion of this kind of multi-resolution and multi-temporal data for visualization purposes is a very complex and critical task. Currently no commercial software is able to handle all this data at the same time, mainly for these reasons:
- the data is a combination of 2.5 and 3D geometry, limiting the use of packages for geodata visualization, usually very powerful for large textured terrain models;
- the amount of data is too big for graphical rendering packages, generally able to handle textured 3D data well.
- The high-resolution texture information exceeds the memory capacity of most current graphic cards.

New approaches and algorithms for an efficient and versatile visualization of the data are therefore required, and together with the constantly improving hardware technologies we will see solutions to this problem in the near future.

5. CONCLUSIONS

In this work we have shown the modeling of the World Heritage site of Bamiyan, Afghanistan. The project is a completely image-based 3D modeling application that combines multi-resolution geometry and multi-temporal high-resolution images. The different types of images have been used to produce a detailed terrain model as well as 3D models of the empty niches and the rock cliff where the two Buddha statues once stood.
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.
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. But the combination of all the image-based models of Bamiyan constitutes a huge quantity of 3D textured information that requires efficient and versatile rendering techniques for visualization.

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Table 1: Multi-resolution data (geometry and images) used in the Bamiyan project.

Source of data		Year	Image resolution	Geometry resolution and number of triangles	Texture resolution
Satellite images	SPOT 5 - HRG	2003	-	20 m (11.3 M)	2.5 m
	IKONOS	2001	-	5 m (19.2)	1 m
Terrestrial images	Rollei	2003	20 micron	1 m (2.5 M)	50 cm
	Sony	2003	4 micron	50 cm (0.7 M)	10 cm
	[Kostka, 1974]	1970	10 micron	5 cm (0.3 M)	1 cm
	Frescos	60ís & 70ís	20 micron	N.A.	2 mm