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EPOCH Showcase 2.4.8: IMAGE-BASED MODELING

ETH Zürich

1. Introduction

The EPOCH showcase 2.4.8. deals with the application of image-based modeling techniques for the documentation of cultural heritage objects, and includes projects that have been conducted at ETH Zurich: the Bamiyan project, the Nasca-Palpa project, the Mount Everest project and the Bayon project. The described projects can serve as examples to clarify the potential of image-based modeling technologies especially for medium and large size sites. The goal of showcase 2.4.8. is to demonstrate the advantages of image-based modeling compared to traditionally applied surveying and modeling techniques in the field of cultural heritage documentation. Hitherto, mostly terrestrial surveying methods (theodolite, GPS, levelling) were applied to generate commonly used products such as 2D maps and CAD models. These techniques usually are highly accurate methods, but require persons and instruments directly at the site and, therefore, cause an impact on the object, which especially in cultural heritage documentation is not intended by the involved scientists. A second problem archaeologists are concerned with, is efficiency. One can observe, that the larger the site and the more objects are to be mapped, the mentioned methods become more and more expensive in terms of persons and time required for the documentation and modeling process. These disadvantages can be bypassed by applying image-based modeling techniques. Thereby, data acquisition and processing can be conducted highly efficient and products are available much faster. In addition to the well-known products such as 2D maps and 3D CAD models, image-based modeling techniques provide the possibility to produce 3D models with a photorealistic texture, enabling the user to virtually navigate through the scene. Thereto, images contain a higher amount of information compared to the selective surveying methods. The same applies to the resolution of the acquired information: the level of generalization can be varied with the available imagery, whereas using traditional surveying methods, the operator has to decide about the level of generalization in the field with the restriction that remeasurements might not be possible. Finally, a successful application of image-based modeling techniques requires knowledge on the user side, but this also applies to other methods. One of the aims of the EPOCH network of excellence is to provide tools for archaeologists and other scientists involved in research on cultural heritage which can be applied by themselves. Nowadays, not only the traditional survey with theodolite and level is widely used, also new and complex technologies like GPS, computer vision technologies, photogrammetry, remote sensing and laser scanning, to mention the most important ones, are deployed more and more. Some of them can easily applied also by non-experts, e.g. GPS, whereas others require high level knowledge, e.g. computer vision or photogrammetry. For this reason, these techniques today are mostly used in joint projects, e.g. our Nasca-Palpa project or the Sagalassos project, where experts in these disciplines utilise archaeological problems for the application and further development of their techniques.

2. Existing techniques

A wide variety of techniques for 2D/3D data acquisition and 3D modeling exist and already is applied for cultural heritage documentation. Usually, the choice of the data acquisition method depends on the object size, cost factor, aimed accuracy and project specific needs and restrictions. The most common techniques can be classified by the object size they are suited for (table 1), additionally the other factors have to be considered when choosing a method by taking the specific project parameters into account.

Method	***Mode***	***Image-based***
Terrestrial survey (medium/large(?) size areas), theodolite, level, tachymeter	-	no
GPS (medium size areas)	-	no
Laserscanning (medium/large(?) size objects), terrestrial and	active	no (intensity values)

airborne		
Radar (large sites), satellite platform	active	no
Photogrammetry/Remote Sensing (large sites), terrestrial, airborne and satellite imagery	passive	yes
Unidirectional methods (shape-from-texture, shape-from-contour, focusing etc.), close-range/small objects	passive	yes
Structured Light, shape-from-shading, active and photometric stereo etc., close-range/small objects	active	yes

Table 1: Overview of different 3D measurement/modeling techniques

Image-based modeling techniques can be applied for almost every object size, from the 3D modeling of small artefacts to the mapping of large archaeological sites. Generally, image-based methods can be classified into active and passive, uni-directional and multi-directional techniques. While active methods make use of controlled energy sources (light, electromagnetic waves) as e.g. structured light or radar, passive methods deal with uncontrolled energy received by the sensor. Mutli-directional acquisition systems use different viewpoints and/or controlled illumination directions, whereas uni-directional systems acquire images along one linear direction in space. This showcase particularly demonstrates the potential of photogrammetry, a passive and multi-directional method proven since years for analog and digital images, still with a potential for development in terms of automation in triangulation, DTM generation, feature extraction and digital sensors.

3. Used techniques in showcase 2.4.8

The showcase 2.4.8, „Image-based Modeling“, contains four different projects dealing with photogrammetric data acquisition. The object size varies from medium (Bayon Buddha statue) to large terrain data stes like Nasca-Palpa or the Bamiyan valley. Although stereo image processing was the basis of data acquisition in all of the four included projects, each of the projects shows its own characteristics concerning the employed image sensor, image processing methods and the resulting products and, finally, the utilisation of data.

A wide variety of image sensors was used in these projects: non-metric CCD cameras (Bayon, Bamiyan), metric terrestrial camera (Bamiyan), analog aerial cameras (Mount Everest, Nasca-Palpa), and satellite imagery from IKONOS and SPOT-5 (Bamiyan).

Generally, the configuration for image acquisition applied in the showcase projects can be divided into 3 classes:

1. Close-range image acquisition using overlapping images covering the whole object. Images taken from positions distributed around the object. Examples are Bayon and Bamiyan (acquisition of the statues). As derived products, 3D models with photorealistic texture at high accuracy were obtained. Metric and non-metric cameras can be used, the method is suited especially for small and medium size objects (figures 1 and 2).

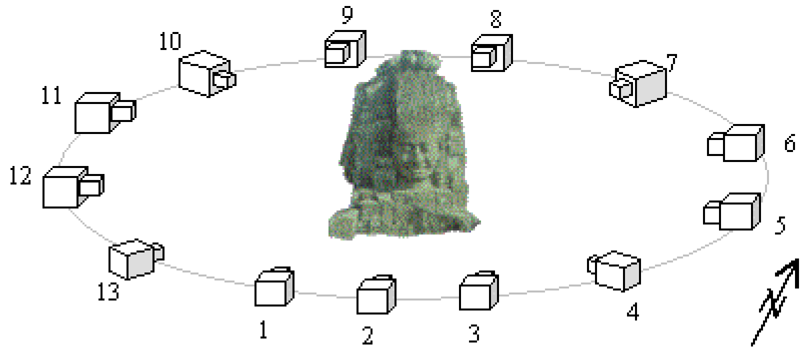


Figure 1: Image acquisition for the Bayon Buddha statue

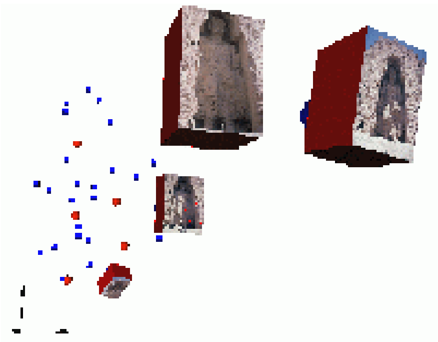


Figure 2: Camera positions for image acquisition of the Bamiyan Buddha statue

2. Aerial photographies taken with special metric, calibrated cameras onboard an airplane. Derived products are orthoimages, digital terrain models and 3D vector data containing topographic elements or, in case of the Nasca-Palpa project, the geoglyphs. Large site mapping and modeling tasks can be solved efficiently using aerial photogrammetry as shown in the Mount Everest and Nasca-Palpa projects (figure 3).

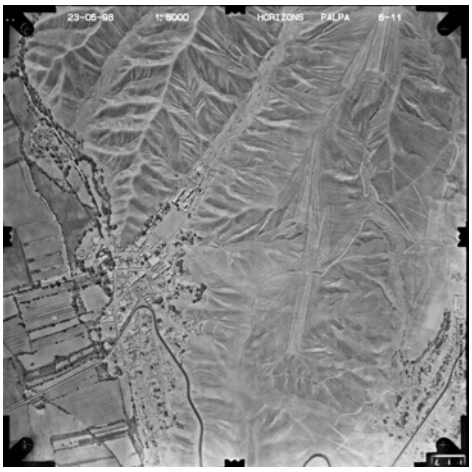


Figure 3: Aerial image of the Cresta de Sacramento (Nasca project). Fiducial marks in the four image corners enable to reestablish the image acquisition geometry

3. Acquisition of satellite imagery using sensors at different resolutions, an example is the DTM and orthoimage generation for the Bamiyan valley (figure 4). Unlike as applying the other 2

classes, the customer has no influ-ence on the image acquisition process, the images are taken systematically according to the satellite's orbit and afterwards distributed commercially.

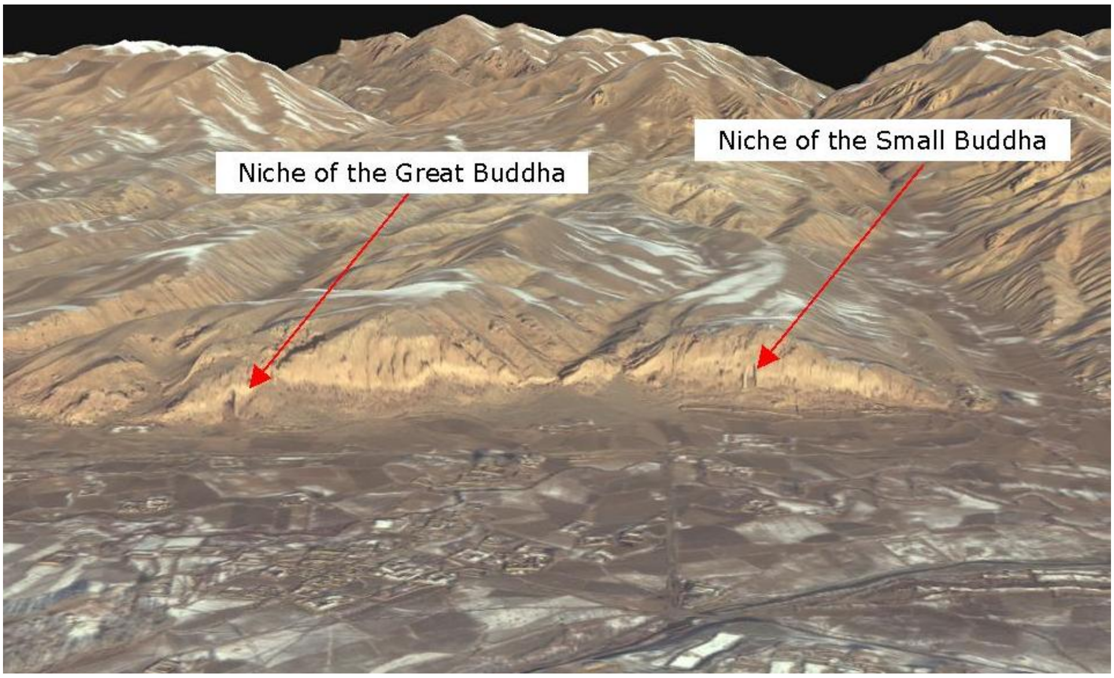


Figure 4: 3D view of the Bamiyan valley, DEM derived from SPOT-5 imagery, textured with IKONOS orthoimage

The image processing steps are identically for all of the three classes, stereo overlapping presumed:

1. The inner orientation up to the time of image acquisiton has to be reestablished for each single image. For this purpose, different methods can be applied, the most common ones are camera calibration data (e.g. for CCD cameras, terrestrial analog cameras) and measuring fiducial marks or Réseau grids (aerial cameras, terrestrial cameras).
2. Image triangulation has to be conducted to link together the single images. A number of corresponding points (at least 5) has to be measured in the images (figure 5). This process can be done manually or automatically using image matching algorithms. To be able to measure directly in object space coordinates, an absolute orientation has to be performed, most commonly by measuring control points in the images which serve as a basis for coordinate transformations to object space coordinates.

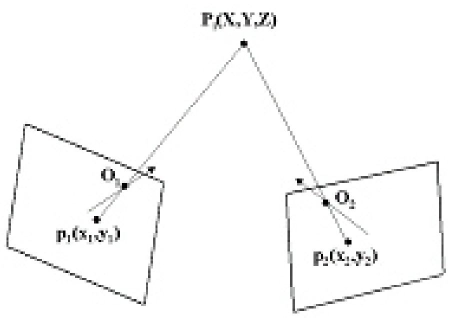


Figure 5: Measurement of homologous points in two (or more) images: One object point P(X,Y,Z) has different image coordinates $p_1(x_1, y_1)$; $p_2(x_2, y_2)$ in images O_1, O_2 taken from different view points (parallax). At least 5 of these points have to be used for the relative orientation of two images.

3. Calculation of the image orientation parameters by bundle adjustment. With the measured image or model coordinates of the tie points and control points, the observation equations can be formulated and the equation system be solved such that the orientation parameters are obtained. The results are absolutely oriented stereo models, in which objects can be measured directly in 3D object space coordinates.

4. Derivation of products. Measuring in the oriented stereo models, digital terrain models (DTM), 3D point clouds and 3D vector data can be produced. DTM generation and point clouds can be performed manually, semi-automated or fully automatically, again based on image matching algorithms. 3D vector data can be measured manually or semi-automatically. After DTM generation, orthoimages can be automatically generated and mosaicked.

5. 3D visualization of the results. The 3D points resulting from step 4 can now be draped with the orthotexture and additionally with the 3D vector data for visualization purposes.

Any of these 5 steps can be applied in the frame of an photogrammetric project, while the steps 1-3 are obligatory. Table 2 gives an overview of the showcase projects and their main parameters.

Project	**Image Data**	**Image Processing**	**Products**
Bayon	Minolta Dynax 500si (analog) 13 colour images 24x36 mm format	Manual measurement on analytical plotter 170 tie points 3 control points	3D point cloud Triangulated surface Photorealistic 3D-model with application of view-dependent texture mapping
Everest	Wild RC-10 aerial camera (analog) 160 B/W images 23x23 cm format	Manual measurement on analytical plotter Orthomosaic on digital workstation	Digital Elevation Model (10m) Orthomosaic (1m) 3D-models in different software environments
Nasca	Zeiss RMK 15/23 aerial camera (analog) ~1000 images b/w and colour 23x23 cm format	Manual measurement on analytical plotter Orthomosaic on digital workstation Investigations on automated image processing for aerial triangulation and DTM generation	Digital Elevation Model (2m) Orthomosaic (0.28m) 3D vector data of geoglyphs and topography 2D map Geodatabase including geometric and archaeological attribute data 3D-model with orthophoto texture and vector layers
Bamiyan	**Buddha niche:** Internet images High resolution metric photographs Touristic images **Bamiyan valley:** SPOT-5 satellite imagery (2.5m) IKONOS satellite imagery (1m)	Automated and manual measurements on a digital workstation using different software packages	3D point cloud High-resolution photorealistic 3D-model of the Buddha statues and niches with orthoimage texture Digital Elevation Model of the Bamiyan area, automatically generated from SPOT-5 images 3D-model of the Bamiyan valley with SPOT-5 DEM and IKONOS texture

Table 2: The main project parameters

4. Analysis of the showcase solutions

The different products, derivable from images, demonstrate the potential of image-based modeling techniques. The advantages have already been mentioned above, therefore, here some aspects about image-based modeling which have to be considered before deciding on the method of choice in a project frame. Firstly, a decision has to be made about the kind of image-based technique to be applied and the deployed sensor according to the required accuracy and the availability. Furthermore, an operator who is skilled in image processing is necessary for a successful accomplishment of a project. Yet another unresolved issue is the publication of products, especially 3D models. Until now, no convincing and secure method suited for common access in a convenient manner does exist. From physical to virtual models, each of them is limited by certain factors. Physical models may become unmanageable regarding their size, while virtual models presume the availability of a computer and data access.

5. Applicability of the showcase solutions

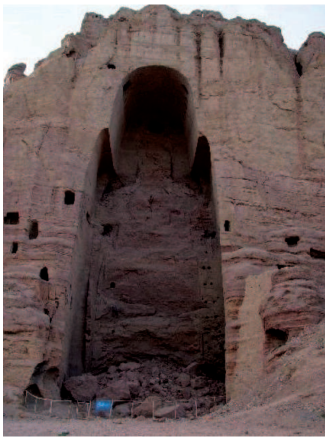
Image-based modeling techniques can be applied to a multiplicity of cultural heritage projects. Objects at any scale, from small and medium size objects, e.g. ceramics and architecture facades, up to large scale terrains, can be documented, measured, modeled and visualized in 3D based on image information. The opportunity to demonstrate a project using 3D visualization to a broad audience can be an impressive means of presentation for different purposes. On the other hand, to provide image-based modeling techniques as a tool for archaeologists and other scientists, most of the existing software systems will have to be simplified concerning their user-friendliness. Another important issue to improve the acceptance of image-based modeling technologies for a wider use is the education of interested researchers on a level that allows them to conduct standard projects efficiently.

Another remarkable fact about image-based methods is that it is the only method which allows for the reconstruction of objects which even do not exist anymore (Bamiyan) or to document objects in an earlier state of preservation (Nasca), as long as adequate images still exist. Furthermore, products, e.g. orthophoto maps, can be derived without a significant loss of information because the image content remains.

As mentioned above and shown in the examples, image-based modeling techniques are well-suited for the processing of large areas as well as small and medium size objects at high resolution. The expenses vary from low-cost image acquisition and processing systems in a range of a few thousand EUR up to specially ordered aerial photoflights and professional photogrammetric workstations. Finally, the persons in charge will have to decide about the best suited method in every individual case. As a result of this showcase, demonstrating the high quality products which can be obtained by image-based modeling at a comparable low effort, we hope to have pointed out its advantages to be considered as a worthwhile alternative.

Image-Based Modeling

Photogrammetry Since many years photogrammetry has been used quite a lot for mapping, recording and documentation of archaeological monuments,



The Bamiyan Buddha before (left) and after (right) the destruction by Talibans

excavation findings and cultural heritage sites. Lately digital techniques for recording, processing and visualization have opened new possibilities for 3D modeling.

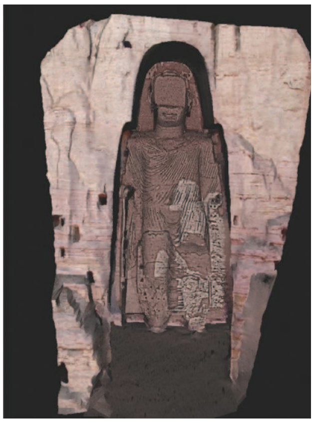
The Bamiyan Buddha The modeling of the cultural heritage area of Bamiyan, Afghanistan, is a good example showing the capabilities and achievements of the photogrammetric modeling techniques and combining large site landscape modeling with highly detailed modeling of local objects (statues). As it is well known, Afghani Talibans demolished the Buddha statues placed in Bamiyan in March 2001, notwithstanding the appeals from all over the world to save such ancient art masterpieces.

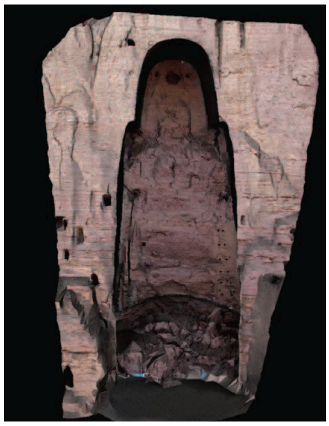
The distruction of the Bamiyan Buddha by Talibans

The demolition was carried on by means of explosives, guns, rockets and mortars in such an accurate way that no physical reconstruction is possible

Image based modeling is a breakthrough technology for the creation of 3D object and scene modeling. Only images are needed to produce the 3D models. No expensive equipment or cumbersome calibration steps are necessary. The first phase consists of a set of consecutive, automatic steps that lead to the calibration and the pose of the camera for every image. A sparse set of feature points that describe the scene is reconstructed in 3D as well.

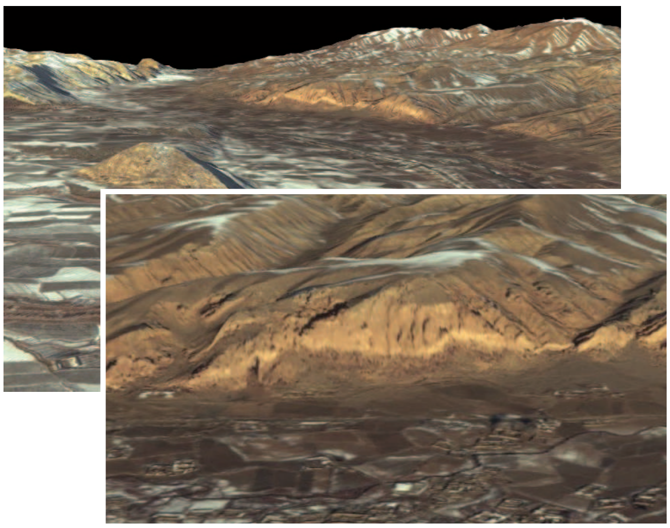
In a second phase a dense stereo matching algorithm is applied to the images. As a result dense depth maps are obtained for every image. From these data textured 3D models can be built.





The digital models of the Bamiyan Buddha (left) and of its niche (right)

An important advantage of this approach is its ease-of-use. No heavy, complicated or fragile apparatus is involved. Taking images is part of regular, archaeological practice for



Digital terrain models of the Bamiyan site instance. The ability to turn normal photographs into 3D models literally adds a new dimension. Compared to non-image based techniques there is the important advantage

Another application: the statue of Mercator, original (left) and textured model (right)

that surface texture is directly extracted from the images. This adds to the realism and authenticity of the reconstructions. Both videos and photos can be used.

For the showcase, different types of images (terrestrial and satellite) have been used and a detailed terrain model (area of ca. 49x38 km) as well as the 3D models of the rock cliff (ca 1 km wide), the Great Buddha statue (53 m high) and its actual empty niche have been produced.

Technical details The image based modeling is based on (1) the calibration and orientation of the images, (2) the manual or automatic image matching for 3D point cloud and surface generation and (3) the texture mapping of the 3D model for photo-realistic visualization.

The 3D model of the Great Buddha and its empty niche have been reconstructed with a relative accuracy of ca 1-2 cm while the digital terrain model has an overall accuracy of ca 1.5 pixel (ca 3.5 m). The generated digital models are now used for the documentation and visualization of the destroyed monument, for virtual flights over the cultural heritage site, for animations as well as for the setup of a tourist information system.

The partners The showcase *Image-Based Modeling* is being developed by the following EPOCH partners:

- ETH Zürich, Switzerland
- KU Leuven, Belgium

Interested?

Are you interested in this showcase? Do you think that this approach can help you in creating effective Cultural Heritage presentation projects or can be integrated in new research projects? Please contact Prof. Luc Van Gool (Luc.VanGool@esat.kuleuven.ac.be) of KU Leuven at +32 16 321705.

EPOCH is a Network of Excellence on Intelligent Cultural Heritage within the IST (Information Society Technologies) section of the Sixth Framework Programme of the European Commission. EPOCH showcases demonstrate innovative solutions and technological integration for target application areas in the Cultural Heritage domain. As they are created with real world content, they stimulate creative thinking about the use of the technologies in Cultural Heritage, and are used to validate new technological approaches with key stakeholders in the Cultural Heritage domain. For more details, visit the project web site:

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