DHAMEK STUPA – DOCUMENTATION OF A CULTURAL HERITAGE IN INDIA

R. Ladstädter *, R. Kostka

Technical University Graz, Institute for Applied Geodesy, Steyrergasse 30, 8010 Graz, Austria –
richard.ladstaedter@tugraz.at

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ABSTRACT:

The 30 m high cylindrical monument "Dhamek Stupa" is located at Sarnath in India. The Stupa was build about 2200 years ago in the district of Uttar Pradesh, where Buddha is said to have preached his First Sermon. On October 11-13th 2002 the famous Buddhist ritual "Kalachakra" will take place at Graz. On the occasion of this event the idea of building a virtual 3D-model of the Stupa using modern photogrammetric and computer vision methods was born. While on expedition in India in 1982, R. Kostka took photographs of the Stupa with a non-calibrated Hasselblad camera. Two images have been taken in approximated canonical stereo configuration, a third photo in a convergent direction (from the same position). Besides the nominal focal length (100mm), only the length of the baseline and some approximate dimensions of the Stupa are known. In order to reconstruct the Stupa's surface the stereo images have been oriented on a digital photogrammetric station (DPS). Point measurements – taken either manually or by digital point transfer – were subsequently used for self-calibration of the camera (focal length only). Once all of the Stupa's parts had been modelled geometrically using different methods (geometric primitives, point and edge measurements), the surface patches were triangulated manually or by delaunay triangulation. The non visible parts on the backside have been modelled by cylindrical and conical patches, which are continued symmetrically from the front. The different parts – which had been stored using the GNU Triangulated Surface (GTS) format - have been converted into the VRML 2.0 format and assembled into a single scene for viewing with any standard VRML viewer.

1. INTRODUCTION

Photogrammetry has always been a useful tool to document cultural heritage. The photogrammetric survey of buildings and other man-made structures makes it possible to reconstruct the object as a virtual 3D-model, even after it has been physically destroyed.

A relevant example is the Great Buddha statue of Bamyian in Afghanistan, which was photographed by R. Kostka in 1970 with a TAF photo-theodolite. Today, 30 years later, the statue is being reconstructed after it was destroyed for religious reasons in March 2001 (Gruen, 2001).

Building a virtual model from images of the real object poses several problems to photogrammetry and computer vision:

  (a) Relative orientation of the images
  (b) Self calibration of the camera
  (c) Measurement of 3D-points and edges in the stereo model
  (d) Constructing 3D-surfaces via triangulation
  (e) Extraction of texture maps
  (f) Building the VRML-scene of the whole object.

The historic "Dhamek Stupa" monument in India was chosen for applying some of these methods for exemplary reconstruction and visualisation. The result of this work is a 3D VRML scene with photorealistic texturing, which can be displayed by any VRML viewer.

2. IMAGE ACQUISITION

2.1 Configuration

Three colour transparencies of the Stupa were taken by R. Kostka on December 12th, 1982, using a Hasselblad amateur camera equipped with a 100 mm lens (see figure 1). Images #2 and #3 were taken at the end of a basis line of 20,27 m in canonical configuration. The third picture (#1) was taken from the right position in a convergent way but has not been used in the reconstruction process. The distance of the basis to the Stupa is about 130 m. The images cover about 40% (140°) of the Stupa. However, the backside is thought to be completely symmetric, so that a closed object can be modelled though.
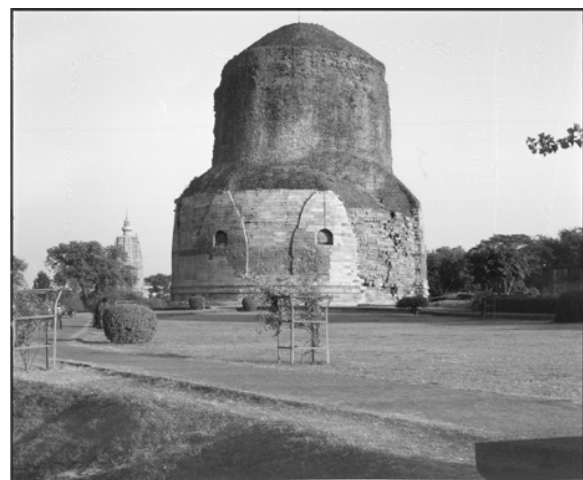

Figure 1: Image #2 (left image)

2.2 Image geometry

For further evaluation the transparencies were scanned with a resolution of 12,5 μm. Since the camera was not calibrated, some assumptions about the image geometry had to be made. First of all the principal point is assumed to be in the image center. The localisation of this point was difficult because the bottom third of the images had been cut off (because off a failure of the film winding mechanism). Two symmetrically positioned marks on the left camera frame were used to define the y_0 coordinate of the principal point. The image coordinate system is assumed to be a rectangular one ($\alpha = 0$) and to have unique scale ($\beta = 1$). Only the nominal value of the focal length has not been fixed but subjected to a self calibration process.

2.3 Object geometry

The Stupa consists of a cylindrical base with a diameter of 29m. Seven "arcs" are equally spaced spaced on the Stupa's circumfence, an eighth having being destroyed. Every arc contains a window-like niche, centered on the front side (see fig. 2, 3 and 4).

The middle part is again conical, starting at a height of 11.5 m and ending at 14.5 m with a diameter of 20.8 m. A second cylindrical part follows, reaching up to a height of 26.6 m above the ground, where the diameter is reduced to 18.6 m. The Stupa is covered by a conical roof, bringing its total height to 31 m.

3. DATA PROCESSING

3.1 Relative Orientation

Orientation of the images #2 and #3 was performed on a digital photogrammetric station (DPS). The resulting stereo model provided a good understanding of the Stupa`s surface properties. In order to level the model, several points on the cylindrical parts of the Stupa were measured. This was done on different height levels, resulting in circular cross-sections. Points lying on the same cross-section were then constrained to a unique height value.

The scale of the model was deduced from the known length of the base line. An absolute scale is not needed for visualisation tasks, put allows for deriving dimensions from the reconstructed model.

3.2 Self-Calibration

Self-calibration of cameras as well as reconstructing in the case of weakly calibrated cameras are central issues in computer vision. As only two images of the Stupa are available, at most two parameters of the interior orientation can be determined. This is due to the fact that five parameters are necessary to define the relative orientation of the images and that epipolar geometry contains only seven degrees of freedom. Considering this the focal length was introduced as a single parameter into the calibration process.

The algorithm follows the concept of the projective block adjustment (Niini, 1998). Point correspondences and intrinsic parameters are corrected in the iterative adjustment process.

The iteration stops, when the epipolar constraints are fulfilled and the error is minimised in a least squares sense.

3.3 Determining the Stupa's geometry

The geometry of the Stupa is determined by measuring points and edges, which serve as input data for a triangulation process. The resulting surface patches are finally combined to obtain the complete model. The modelling process made use of the cylindrical shape of the Stupa. The intact walls of the lower part are approximated by a combination of the geometric primitives "cylinder" and "truncated cone".

More complex parts, e.g. the arcs and niches, on the other hand, must be modelled by measuring their edges. Even more points needed to describe the irregular surface of the damaged parts of the Stupa with sufficient precision. Since some parts of the Stupa have a more complex surface than the others different methods were used in the modelling process.
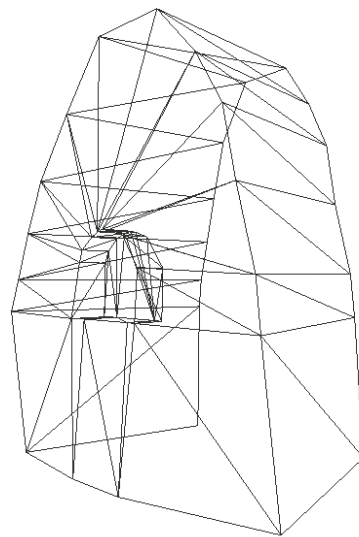
Figure 2: A wireframe model of the arc

3.3.1 Approximation using geometric primitives: This strategy is very effective for surface modelling because only a few geometric parameters must be determined: radius, height, center point, starting- and endpoint of the cylinder segment. These parameters can easily be deduced from measurements on the DPS. This method was applied to the lower (intact) parts of the Stupa and to the non-visible parts.

3.3.2 Extracting edges: Some parts of the Stupa, e.g. the arcs and niches, consist of flat surface segments, connected by sharp edges. This parts are best modelled by measuring the edges and triangulating the surface spanned by them (see figure 2). The edges were manually digitised on the DPS. An automatic edge extraction and correlation procedure as described in (Zach et al., 2002) could also be used, which is especially efficient when applied to (regular) urban facades.

3.3.3 Irregular surface parts: Very complex parts containing holes and self occluded sections are very difficult to model (e.g. the upper damaged part of the Stupa). A sufficient number of points and edges must be measured to model the surface accurately. Non visible edges must be added to obtain a closed surface. Triangulation of this kind of surfaces tends to be very time consuming and prone to errors.

3.3.4 Automatic surface measurement: Digital points transfer is capable of measuring points on the surface with a high sampling rate. The algorithm used in this work is an area based matcher (LSM) which is restricted to areas with moderate perspective distortions and good image texture. Therefore this method was applied to the upper cylindrical part only where this requirements are fulfilled.

3.4 Building the virtual model

The 3D points, edges and faces measured were stored in ASCII files using the GNU Triangulated Surface Library (GTS) file format (http://gts.sourceforge.net/). These files contain a list of the 3D coordinates (vertices) followed by a list of the edges and finally the faces. The edges and faces are defined by their two respectively three indices in the point list. The GTS file format is very similar to the "IndexedFaceSet" object node which allows for easy conversion into the VRML format. The GTS library also supports 2D Delaunay triangulation, surface analysis and optimisation.

3.4.1 3D Surface triangulation: Regular surfaces like cylinders and cones (see section 3.3.1) can easily be generated using the GTS format. A program utility was written for this purpose, which approximates cylindrical or conic surface patches by flat segments that are subdivided again into triangles. If the surface must be constructed from point or edge measurements, however, a 3D triangulation process is needed.

For each of the manually measured surface parts, a GTS file containing only the vertices was build. The edges and faces were defined manually and another program utility was used to update the GTS file with the new defined faces. Figure 3 shows a triangulated arc created by this method.
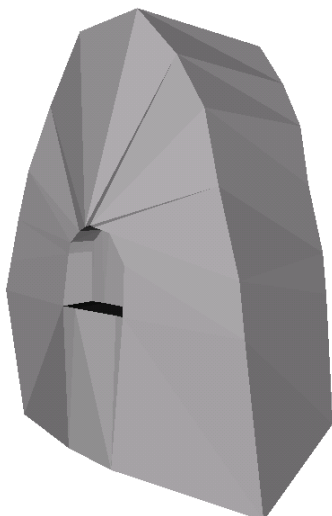

Figure 3: Flat shaded model of the arc

Of course, this method can only be used for simple objects, modelled by a small number of vertices. For larger datasets automated triangulation algorithms would have to be used.

After triangulation, the surface must always be checked for modelling errors. This can easily be done after conversion into the VRML format using a 3D viewer. The flat shaded model can be rotated in 3D space and checked for false or missing triangles.

Digitally measured points were also stored using the GTS file format. The 2D Delaunay triangulation provided by the GTS library was used for this purpose. Again the GTS file was updated with the faces created.

3.4.2 Creating textures: To achieve a realistic appearance of the object, phototexture must be added to the virtual model. The "TextureCoordinate" nodes within the IndexedFaceSet can be used for this purpose. These coordinates are calculated by back projecting the face vertices into the images, so that the applied texture is perspectively corrected. Figure 4 shows the textured version of the already known arc.

Figure 4: Textured model of the arc

The quality of the generated texture strongly depends on the angle between the surface normal and the direction to the camera. If this angle is too large, texture pixels are stretched (e.g. at the conical top of the Stupa), resulting in a poor visual impression. This problem can be avoided, if enough images taken from various directions are available, by choosing the best image for texture extraction (Mayer et al., 2001). It's also possible to eliminate occlusions caused by non modelled objects in the foreground. However, these advanced texturing techniques were not applied in this sample project.

3.4.3 The resulting model: The completed model of the Stupa was put together from all surface patches (see figure 5). The non-visible parts were added symmetrically but have not been textured. The two arcs visible on the front side have been copied fife times to the backside with equal spacing. One could extract texture of the intact parts and apply it repeatedly around the Stupa, thus creating a "restored" version. However, this has not been performed for the present model, which can be viewed at http://www.cis.tugraz.at/photo/richard.ladstaedter/ (visit the *Project* page).

Figure 5. Complete VRML model of the Stupa

4. CONCLUSIONS

The creation of photo-realistic 3D models from images involves several methods from photogrammetry, computer vision and computer graphics. Adequate geometric modelling and careful texture extraction are prerequisites for obtaining a high quality model.

Although the methods used in this work are fairly simple, the model of the Stupa created provides a fairly good impression if viewed using a VRML viewer. The restriction of having only two images of the Stupa did not allow for a complete reconstruction. This would have been possible only with more images taken around the monument.

5. REFERENCES

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