Photogrammetric Documentation of Alois Payer's Art Studio

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Photogrammetry as a quick and versatile documentation method

Photogrammetry is the science and art of making precise and reliable measurements from images. While in the perception of some people this term evokes the notion of photographic images, the technique as such is by no means restricted to those but incorporates all sorts of non-photographic images as well. The term ‹digital› emphasizes the use of digital images, in whatever form, be it from the X-ray, visible range, near and far infrared, or microwave portion of the electromagnetic spectrum. Even ultrasound and electron-microscopic images and the like could be concerned. Over the years photogrammetry focused on some particular aspects of the overall data acquisition, reduction, analysis and representation process. Special expertise has been accumulated in the areas of geometric modeling of sensor imaging processes, observation network design and analysis, execution of precise and reliable measurements, refinement of estimation models and statistical analysis of results including comprehensive error propagation through the whole data reduction process. This has been amended in recent years by appropriate image analysis, feature extraction and object reconstruction techniques, thus giving digital photogrammetry a relevant status as a discipline in its own right within the broad «vision community» [1] (computer, machine, and robot vision). From the early 1980s on much attention has been paid on digital close-range photogrammetry, which is synonymous to ‹machine vision›, applying the sensors from terrestrial platforms. After almost a decade of intense research and development this technique has reached a degree of maturity such that it can be used in a great number of diverse applications. Both photogrammetry and remote sensing are image-based techniques for the extraction of metric and semantic information from images. Originally close-range photogrammetry, aerial photogrammetry and satellite remote sensing developed along separate lines, both in terms of types of sensors used and processing methodology and tools. Today, within an almost totally digital environment, we see a strong trend towards convergence. This opens the path for a much more cost-efficient use of a variety of different sensor data and processing tools. [2]

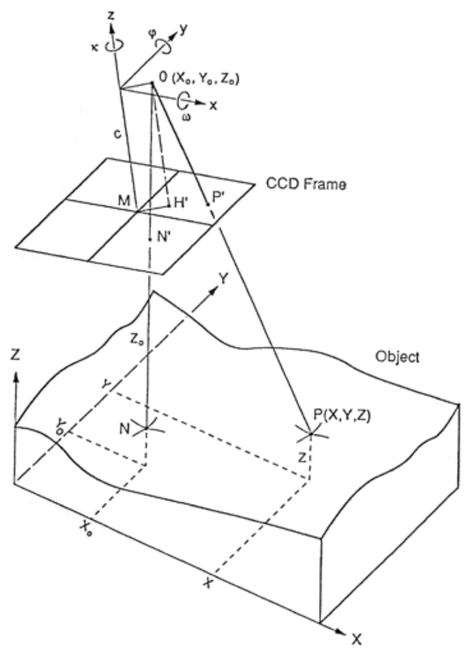
We will concentrate here on digital close-range photogrammetry to be used for quick documentation of natural and cultural heritage objects, given the specific example of Alois Payer's art atelier in Einsiedeln. The following paragraphs give a brief introduction into the analytical basis of photogrammetry and explain the image data acquisition, photogrammetric processing, stereoscopic visualization, panoramic image generation and realization of the spatial database steps.

Basics of analytical photogrammetry

In photogrammetry predominantly the principle of optical triangulation is applied, both in passive and active mode. ‹Passive› means that ambient natural or artificial illumination is used such that it provides for the marking or visualization of the object. In the ‹active› mode artificial illumination of a specific pattern, also called ‹structured light›, is introduced into the measurement process as a geometrical constraint or just for visualization. In photogrammetry, characteristically the object to be measured is recorded (imaged) by a certain number of digital images, taken from different locations. A single frame is not sufficient information to reconstruct a 3D object in general. Two frames (a stereo model) are mathematically required. Although the stereo model measurement concept is widely used in applications, it has some serious drawbacks: a) it does not provide sufficient redundancy in observations for the detection and location of blunders in measurements, b) in case of a more complex object not all parts might be visible from only two camera positions, c) some parts of the object, while visible, may generate a bad measured geometry, thus leading to in-

1 Gruen, Armin: Fundamentals of videogrammetry – a review, in: Human Movement Science 16 (1997), pp. 155–187.

2 Gruen, Armin: New technologies for efficient large site modeling. Proceedings of the International Workshop 3D-ARCH'2005 (3D Virtual Reconstruction and Visualization of Complex Architectures). Venice, 2005 (only on CD-ROM).



1 **Sensor model of bundle adjustment**

2 **View in room 2 during the documentation**

3 **Work in progress**

accurate results, and d) large objects cannot be covered with only two images at a given high accuracy level. Therefore we recommend to use more than two images, thus generating a geometrically strong and statistically reliable network.

The bundle method The bundle method is the underlying mathematical model, also called sensor model, of photographic or CCD single frame cameras. This bundle method is considered the most flexible, general and accurate sensor model. Long before it became a standard procedure in aerial photogrammetry it was used in a variety of close-range applications. It is based on the laws of perspective projection. **Fig. 1** The object point *P* is imaged by a straight line through the perspective center *O* into the image point *P'*. This straight line condition is called ‹co-linearity condition›. It can be formulated as

$$\begin{bmatrix}X\\Y\\Z\end{bmatrix}_i = \lambda_{ij} R_j \begin{bmatrix}x_i-x_o\\y_i-y_o\\-c\end{bmatrix}_j + \begin{bmatrix}X_o\\Y_o\\Z_o\end{bmatrix}_j, \qquad (1)$$

with

X_i, Y_i, Z_i Object space coordinates of object point (P_i),

X_{oj}, Y_{oj}, Z_{oj} Object space coordinates of perspective center (O_j),

x_{ij}, y_{ij} Measured image coordinates of point (P'_{ij}),

x_{oj}, y_{oj} Image space coordinates of principle point (H'_j),

c_j Camera constant of CCD-frame (j),

R_j Rotation matrix (orthogonal) between image and object space coordinate systems,

λ_{ij} Scale factor for imaging ray (ij),

$i = 1,\ldots,n$ n = number of object points,

$j = 1,\ldots,m$ m = number of CCD frames.

In equation (1) the interior orientation of an image (j) is defined by the parameters x_{oj}, y_{oj}, c_j while the parameters $X_{oj}, Y_{oj}, Z_{oj}, \omega_j, \varphi_j, \kappa_j$ define the exterior orientation. Here $\omega_j, \varphi_j, \kappa_j$ are the three rotation angles which build up the rotation matrix R_j. The three components of equations (1) are reduced to two by canceling out the scale factor λ_{ij}, and then rearranged according to

$$x_{ij} = -c_j \frac{r_{11j}(X_i-X_{oj})+r_{21j}(Y_i-Y_{oj})+r_{31j}(Z_i-Z_{oj})}{r_{13j}(X_i-X_{oj})+r_{23j}(Y_i-Y_{oj})+r_{33j}(Z_i-Z_{oj})} + x_{oj},$$
$$y_{ij} = -c_j \frac{r_{12j}(X_i-X_{oj})+r_{22j}(Y_i-Y_{oj})+r_{32j}(Z_i-Z_{oj})}{r_{13j}(X_i-X_{oj})+r_{23j}(Y_i-Y_{oj})+r_{33j}(Z_i-Z_{oj})} + y_{oj}. \qquad (2)$$

$r_{11j} \ldots r_{33j}$ are the elements of R_j.

Since equation (2) provides for a general sensor model, it accommodates easily some specific cases. Depending on the parameters which are considered either known a priori or treated as unknowns, these equations may result in the following cases (the image coordinates x_{ij}, y_{ij} are always regarded as observed quantities): a) General bundle method: All parameters on the right side of (2) are unknown (interior orientation, exterior orientation, object point coordinates); b) Bundle method for metric camera systems: x_{oj}, y_{oj}, c_j (interior orientation) are given, all the others unknown, c) Spatial resection: (ca) Interior orientation and object point coordinates (X_i, Y_i, Z_i) are given, the exterior orientation has to be determined, and (cb) Only object point coordinates are given, the interior and exterior orientation have to be determined; d) Spatial intersection: The interior and exterior orientation are given, the object point coordinates have to be determined. This includes the stereo as well as the multiframe approaches.

Any combination of these procedures is possible within the general bundle concept. Also, incomplete parameter sets of exterior/interior orientation and object point can be handled. For the estimation of unknown parameters the Gauss-Markov model of least squares estimation is used. A standard CCD-camera is a non-metric camera in the sense that its interior orientation is not given a priori. The camera constant *c* and the parameters of the principal point x_o, y_o have to be determined by the user. This procedure is called ‹camera calibration›. At this point it is worthwhile to note that in photogrammetry the following technical terms are distinguished:

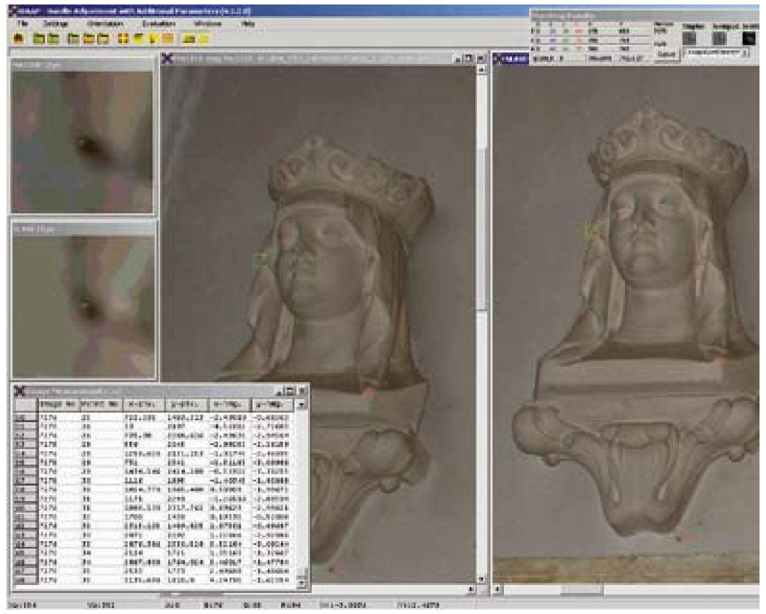
- Point positioning: The aim is to determine the 3D coordinates of object points within given accuracy specifications. For that the techniques (a), (b), (d) may be used, depending on the prerequisites.
- Orientation: The aim is to determine the parameters of exterior orientation. The techniques of choice are (a), (b), (ca).
- Calibration: The aim is the determination of the parameters of interior orientation plus additional parameters for the systematic image errors. The methods (a), (b), (c) plus other special techniques may be used to solve this problem.
- Simultaneous solution: Essentially, this integrates all previous tasks of calibration, orientation and point positioning into one joint system. The most general formulation here is provided by method (a).

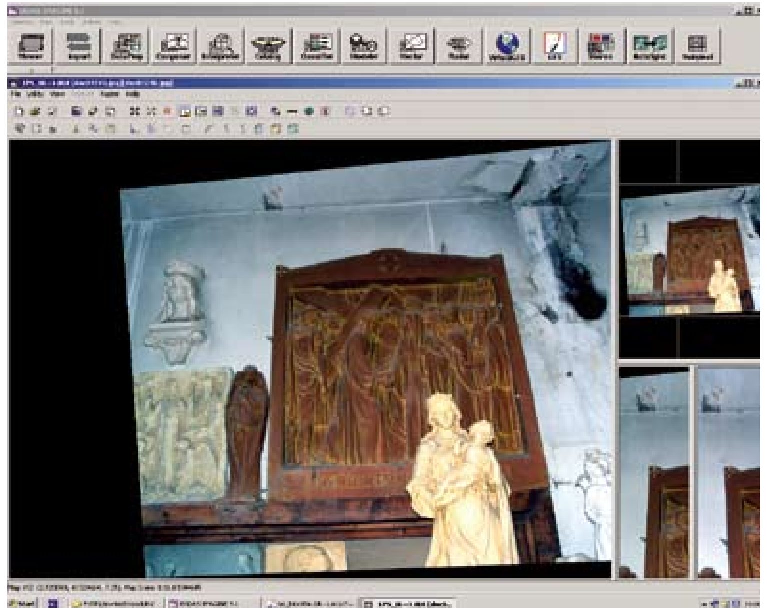
Image data acquisition in Einsiedeln

Totally 789 digital images were acquired in two days (February 8 and March 3, 2008) on site. Four rooms (number 1, 2, 4, 5, see Fig. 5 in the contribution of Glaser/Marti/Schink in this publication) of Payer's atelier were imaged. Two classes of images were taken with different acquisition geometries: a) Single photogrammetric images for stereo-vision and point positioning (measurement), and b) Single images in sequence to form panoramic images.[3] In the rooms 1 and 2 one central view point was chosen, in rooms 4 and 5 two view points were used. The rooms (especially rooms 1 and 2) are untidy and the statues are located all around. **Fig. 2, 3** This leads to limitations for accessing the objects. Thus, the photogrammetric images were taken freely, positioning the camera by hand rather than using a tripod. The photogrammetric images were taken in very short baseline mode with two considerations: a) Images should give multi-image overlap to be used in photogrammetric measurements, and b) Images should satisfy the stereoscopic vision conditions. The stereoscopic vision imitates the human vision system. There are critical conditions for the stereoscopic vision:

- All images must be sharp from front to back. This is accomplished with a large depth of field, and thus a smaller lens aperture. In general, the working aperture is recommended to be at least F/5.6, or better F/11. In our case, a smaller aperture had to be utilized, and

3 We used a SONY DCS F828 digital camera. Some technical details for this camera: Sensor: 2/3" CCD, sensor size: 8.8 x 6.6 mm, pixel size: 2.7 microns, image format: 3264 x 2248 pixels, image size: 8 Megapixel, lens: Carl Zeiss T* Vario-Sonnar, focal length: 7.1–51.0 mm, optical zoom: 7x, auto focus, aperture: F/2.0 – F/8.0, output formats: JPEG and TIFF.





4 Image measurement in the BAAP software

5 A screenshot of the LPS software

6 BARCO Baron high performance projection system

– For ease of viewing there should be no y-parallax on the stereo images. Epipolar lines should be parallel. There are two solutions for satisfying this condition: a) the mechanical solution: The stereo images are taken on a single camera slide bar or a twin camera slide bar so that no rotational difference occurs between the images and the camera axes are parallel to each other; and b) the numerical solution: The rotational differences and the non-parallelity between the left and right images are calculated mathematically (image orientation) and both images are re-sampled to the normal case (image normalization).
– Image pointing axes should not be too convergent (see before) except that stereo images may be taken slightly convergent in order to come a 100% overlap.
– The spatial depth causes a lateral displacement (x-parallax) of the two corresponding points in the left and right stereo images. For close objects the displacement is larger, and for distant objects it is smaller. In order to keep the x-parallax in a reasonable range the following rule should be applied for the base length:

$$\frac{1}{5}\, d_{close} > b > \frac{1}{20}\, d_{far} \qquad (3)$$

with
d_{close}: closest distance from the base
d_{far}: furthest distance from the base
b: base length

In contrast to the stereo images the individual frames of the panoramic images are acquired on a tripod. At six image stations panoramic images were acquired in four rooms of the atelier. Each station covers 360^0 along the horizontal direction.

Photogrammetric processing of the imagery

The Sony DSC F828 camera was calibrated using the self-calibrating bundle adjustment method. The image measurement and the computation procedures were performed by the in-house developed software package BAAP (Bundle Adjustment with Additional Parameters). **Fig. 4** A few representative stereo pairs were oriented using the relative orientation with the Linear Transform (RLT) [4]. The RLT is a closed form solution which does not need any approximate values for the unknown orientation parameters. The RLT was implemented in the BAAP software.

Stereoscopic visualization with the BARCO system

We used the LPS (Leica Photogrammetry Suite, version 9.1) photogrammetry software for the stereoscopic visualization. **Fig. 5** It uses the active-shutter glass technology for stereo vision. We straightforwardly imported the images and the associated interior/exterior orientation values which were computed with the BAAP software. As display hardware we used the BARCO Baron high performance projection table [5]. Our BARCO Baron system **Fig. 6** is equipped with four stereographics infrared emitter [6], continuously sending signals to liquid-crystal active shutter glasses. This configuration gives a large signal coverage (almost 120^0 in the horizontal plane) to the viewers. Viewers can freely move in the environment while they can continuously watch the 3D scene.

Panoramic image generation

The word ‹panorama› is a combination of Greek terms, namely the suffix ‹pan›, meaning all, and ‹horama›, meaning sight. In more technical terms, a panorama is defined as a picture or a series of pictures of a landscape, a historical event etc., representing a continuous scene, enclosing the spectator and providing an unlimited view in all directions (synonymously the term omnidirectional is used). In both cases the meaning of a very wide field of view is conveyed.

The techniques of panorama production can be divided in two different groups: catadioptric and dioptric systems. [7] Dioptrics is the science of refracting elements (lenses) whereas catoptrics is the science of the reflecting surfaces (mirrors). The combination of refracting and reflecting elements is called catadioptrics. Catadioptric systems use one or more mirrors with one or more cameras to capture a wide view angle of the scene. The images then need mosaicking and special cases, seamless panoramas can be created. Planar and curved mirrors are used in these systems.

A dioptric system relates to its refractive elements (lens). Mirrors may be included in these systems, but then the aim is to fold the optical system assembly and not increase the field of view. Dioptric systems are divided into four groups: camera cluster, fisheye lens, stitching and direct scanning. The first group uses several cameras, mounted on a surface and looking outwards onto the scene, which enables the capturing of the wide view. The second group consists of a camera with a fisheye lens which usually has more than 180^0 field of view. They have been used in measurement applications. The third group produces a panoramic image by mosaicking or stitching the images. This technique has also been used in measurement applications. The fourth group is related to a camera system with a rotating camera or rotating lens, which produces a seamless image without any need of stitching.

We opted for the stitching method for generating the panoramic images. **Fig. 7** At six stations in four rooms, totally 18 single image sets were taken to form the panoramas. In each station, three sets of panorama images, pointing to floor, horizontal and ceiling directions, were acquired. Prior to the procedure, images were corrected to the systematic error-free case. The systematic errors of the images (radial and decentric distortions due to the lens system, calculated by the camera calibration procedure) were corrected by resampling them to the ideal case.

Panoramic imagery provides a 360^0 view of the entire scene with continuous roaming possibility. Depending on the technical features of the camera very high resolution can be achieved. These aspects are espe-

4 Khlebnikova, T.A.: Determining relative orientation angles of oblique aerial photographs, in: Mapping Science and Remote Sensing 21/1 (1983), pp. 95–100; Chang, B.: The formulae of the relative orientation for non-metric camera, in: Internal Archives of Photogrammetry and Remote Sensing 26/5 (1986), pp. 14–22; Shih, T.-Y.: On the duality of relative orientation, in: Photogrammetric Engineering and Remote Sensing 56/9 (1990), pp. 1281–1283.

5 Its specifications are given as: screen size: 67" (1.7m) diagonal (3200 x 2560 pixels), horizontal scan frequency: 30–180 KHz, vertical scan frequency: 37–240 Hz. Further information in: http://www.barco.com (April 2008).

6 See for more information: http://www.reald-corporate.com/scientific (April 2008)

7 Amiri, Parian J.; Gruen, Armin: Sensor modeling, self-calibration and accuracy testing of panoramic cameras and laser scanners. Submitted 2008 to: ISPRS Journal of Photogrammetry and Remote Sensing.

7 Panoramic image of room 1b (i) and its single images (a–h). Zoom into the left part of the panoramic image (j)

8 The hotspot concept which relates the artifacts graphically on the panoramic images contextually to their attributes

cially important for the documentation of complex environments as in the case of Payer's art studio. We use the panoramic images mainly for the following two tasks: a) photographic overview of each room and b) spatial layout for the art object database (see the next chapter).

A database system by hotspot definition on the panoramic images

We designed and realized a database concept for Payer's artifacts (see Fig. 6 in the contribution of Glaser/Marty/Schink). Each artifact is related to an attribute table of which the geometric and semantic information is stored. The geometric attributes (object size, height etc.) were measured by the use of photogrammetry. Artifacts were signalized as hotspots on the panoramic images and the attribute tables were related to the hotspots. **Fig. 8** The ArcGIS 9 GIS software was used for this procedure.

Conclusions

Fast and cost-effective methods are preferable for many kinds of documentation tasks of natural and cultural heritage objects. Photogrammetry is a quick-and-clean method for the documentation of art objects. Our method has the following advantages:

Photogrammetry is a cost-effective method. One person takes the pictures of the object using an (free hand) amateur type of digital still image camera. This gives great flexibility and speed to the data collection procedure. In addition, the instrument and labor costs are minimized.

Basically, the material cost is shifted from hardware components to the software components. The historical mechanical and electromechanical solutions are nowadays implemented as diverse photogrammetric software packages. Sophisticated mathematical and vision algorithms are performed.

Photogrammetric data collection is scalable in terms of the project demands. While working on site all necessary image data is collected at minimal cost. The office work can be carried out only using a small subset of the whole data. After enough funding becomes available, all the image data can be processed for any task, e.g. 3D mensuration of individual art objects, 3D modeling of individual art objects, 3D modeling of the whole environment, etc.

Photogrammetry is one of the main data sources of the geographical information systems (GIS). Any documentation project can be turned into a spatial information system of the art objects, provided that attribute information of the individual objects is collected as well.

The image data contains rich semantic content. Any object can be located and identified in the image database without ambiguity. In contrast to photogrammetry, this is not possible for the terrestrial laser scanning point cloud data sets.

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