Panorama Photogrammetry for Architectural Applications

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Abstract:

The paper discusses the potential of photogrammetric multi-station panorama processing for the 3D reconstruction and documentation of architectural objects. It is a summary of various paper by the author dealing with panorama imaging, mathematical models and photogrammetric processing..

Panorama images can be generated by any kind of digital cameras. If, as usual, cylindrical panoramic images are desired, they can be acquired if a suitable camera mount is used. In this case single image frames can easily be stitched together to a complete or partial panorama under consideration of the strict camera model (calibration parameters). Alternatively, a rotating line-scanner camera can be used that may produce very high resolution images.

The mathematical model of cylindrical panoramas is presented. If at least three different panoramas have been generated from different local stations, they can be oriented by bundle adjustment. Due to the stable geometry of the cylindrical panorama model the bundle adjustment can be performed with very few object points. Once each panorama is oriented with respect to global coordinate system, photogrammetric object reconstruction procedures such as space intersection or a moving floating mark can be applied.

Three practical examples demonstrate the process of panorama object recording and modeling. The entrance hall of the university has been reconstructed in 3D yielding a wireframe model of the interior. For the Great Hall of the Oldenburg castle again four panoramas have been processed whereby special effort has been spent to produce a high-quality colour panorama. Finally, a historical wall mosaic has been recorded and orthorectified.

1. Introduction

The use of panoramic photographs dates back until the early years of photography. First panorama images have been recorded with rotating frame cameras or by swing-lens techniques. During the 19th century, panoramic cameras have been combined with angular reading in order to measure the rotation angle of the camera. Consequently, panoramic photography and the use of photo-theodolites were closely connected. A more detailed view on the history of panorama photogrammetry can be extracted from Luhmann (2004).

Panorama imagery is becoming more and more popular for 360° presentations of natural environments, e.g. for touristic purposes (e.g. www.oldenburg.de), metric site documentation for facility management applications (Chapman & Kotowski, 2000), or for the combination with 3D laser-scanners. Panoramic images are mostly created by off-the-shelf stitching programs (e.g. Photovista Panorama) that can match uncalibrated frame images into a cylindric projection with limited user interactions. A closer view to the resulting image quality of such programs shows that image deformations occur if lens distortion is not considered properly (Luhmann & Tecklenburg, 2002, 2003).

The recent generation of digital rotating line scanners offers very high geometric and radiometric resolution. A special problem is rising since the geometric quality of such a camera is mainly depending on the mechanical precision of the scanning device, and the concentricity between perspective centre and rotating axis. Amiri Parian & Gruen (2005) and Schneider & Maas (2005) have developed camera calibration approaches that, in addition to photogrammetric interior orientation parameters, model the specific rotating line-scanning characteristics such as tumbling of the vertical rotation axis.

Panoramic images from multiple stations can be used for the 3D reconstruction of objects. Due to the cylindrical constraints of panoramas the orientation of multiple panoramic images can be calculated with much less tie points than for usual image bundles. It has been shown that only 5-7 tie points in 3-D space are necessary to compute a bundle adjustment for a number of >3 single panoramic images (Luhmann & Tecklenburg, 2002). Similar approaches have been used to model archaeological environments (Petsa et al, 2001). The concept of two frame cameras mounted on a rotating bar has been discussed by (Heikkinen, 2002) where the advantage of cylindrical constraints is combined with stereo capability for 3D reconstruction.

2. Panorama imaging

2.1 Frame cameras

In order to create panorama images for photogrammetric object reconstruction, modern digital cameras can be used. If high precision and resolution shall be achieved, professional digital cameras can be applied that offer up to 5000 x 4000 pixels or even more.

As described in Luhmann & Tecklenburg (2003) digital frame cameras yield high quality panoramic images if the whole imaging and resampling process is performed under strict consideration of geometric properties of all involved components. The two most critical features refer to the calibration of the camera, and the adjustment of the rotating panorama adapter with respect to the (calibrated) principal point.

The panorama generation can be summarized as follows:

1. Camera calibration (for non-metric cameras)
2. Adjustment of panorama adapter (principal point lies on rotation axis)
3. Image acquisition (number of images depend on focal length, appropriate image overlap required)
4. Measurement of tie points (automation possible by interest operators or feature matching)
5. Bundle orientation of image set (result are orientation parameters of each single image)
6. Panorama resampling (a cylindrical panorama image is resampled from the original images with adjustable resolution)

Fig. 1: Digital camera Kodak DCS 645M mounted on panorama adapter

Fig. 2: Digital panorama line-scanning camera KST EyeScan M3

Although the above mentioned process seems to require a high amount of work, most of the steps can be handled easily or they can be automated. Since there is no stitching process where overlapping image areas are analyzed and "pasted" together, the presented approach leads to accurate panoramas where the border between two source images is almost not visible. However, if invalid camera calibration parameters exist, or if the panorama adapter adjustment is insufficient, displacement errors remain in the final panoramic image.

2.2 Rotating line scanner

The process of panoramic image acquisition becomes more convenient if a rotating line scanner is used as shown in Fig. 2. The digital panoramic line-scanning camera KST EysScan M3 (Fig. 2) has been developed in colaboration between KST and DLR (Scheele et al., 2001). It offers superb images of highest geometric and radiometric resolution (see Fig. 3 and Fig. 4). It consists of a 10200 pixel RGB CCD line sensor with infrared filter. Lenses of 35mm and other focal lengths are available. Depending on the lens full panoramic images consist of up to 54000 columns leading to a maximum image size of 1.8 GB.

Fig. 3: Panoramic image generated by EyeScan M3, 35mm lens (IAPG building)

Fig. 4: Original image window from Fig. 3 (see arrow and square)

The geometric accuracy of the camera has been investigated by Schneider & Maas (2003, 2005). A sophisticated set of parameters has been found that handles most of the geometric and mechanical errors of the camera.

3. Photogrammetric model

3.1 Fundamental equations

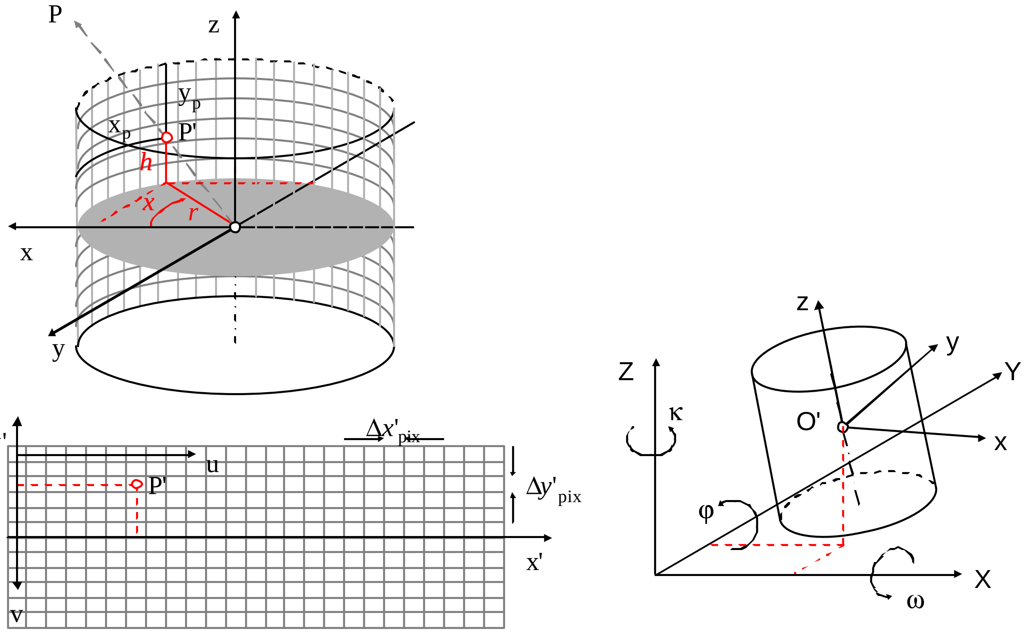

Fig. 5: Pixel and cylindrical coordinate system

The mathematical model is based on the relationship between the pixel system x'y' of a digital panorama image and the spatial coordinate system xyz. Each pixel position can be transformed into a spatial direction vector that points to the corresponding object point in the XYZ system. In the reverse way, the collinearity equation for cylindrical panorama images can be derived:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} r_{11} \cdot (X - X_O) + r_{21} \cdot (Y - Y_O) + r_{31} \cdot (Z - Z_O) \\ r_{12} \cdot (X - X_O) + r_{22} \cdot (Y - Y_O) + r_{32} \cdot (Z - Z_O) \\ r_{13} \cdot (X - X_O) + r_{23} \cdot (Y - Y_O) + r_{33} \cdot (Z - Z_O) \end{bmatrix} \quad (1)$$

The pixel coordinates can be calculated by introducing the scale factor λ and the vertical shift of the horizon y_h:

$$l = \frac{r}{\sqrt{x^2 + y^2}} \quad (2)$$

$$x'_{Pix} = r \cdot \arctan\left(\frac{x}{y}\right) + \Delta x'$$
$$y'_{Pix} = y_h - z \cdot l + \Delta y' \quad (3)$$

This set of equation is the fundamental mathematical model that serves for the basic photogrammetric algorithms such as spatial intersection, space resection, rectification and bundle adjustment. A complete description is given in Luhmann et al. (2006).

The correction values $\Delta x'$, $\Delta y'$ are resulting from camera specific calibration functions. Usually, the optical sensor is modelled by the standard parameters for radial and decentring distortion, and optionally affinity and shear. For panorama cameras, parameters for mechanical deviations such as decentring or tumbling of the rotation axis or shift/tilt of the CCD sensor line can be added.

3.2 Epipolar geometry

The epipolar plane is defined as the plane built by an object point P and the two image points P', P'', or the two principal points O', O'', respectively. The epipolar plane intersects the panorama cylinder in an arbitrary position and orientation, hence an ellipse is resulting as intersecting curve (Fig. 6). In contrast to perspective images panoramic epipolar lines appear as sine curves in the panorama image matrix (Fig. 7).

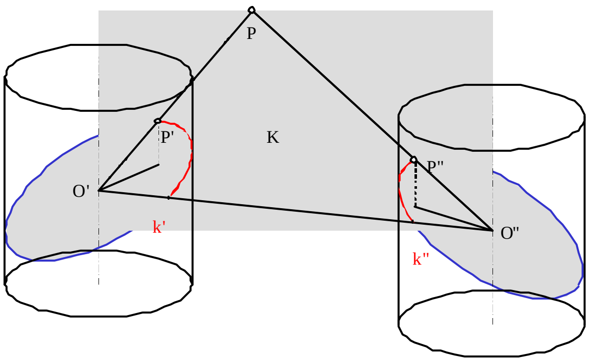

Fig. 6: Epipolar plane K and epipolar lines k' and k''

For large panorama images the determination of homologous points can be difficult since the visual impression is, in the first instance, unusual, and large bitmaps are not easy to handle. If epipolar lines are available, the search space for homologous object features can be restricted significantly. Fig. 8 shows an example of four panorama image areas showing a horizontal object edge. The epipolar lines intersect the edges differently, so that the homologous point can be detected.

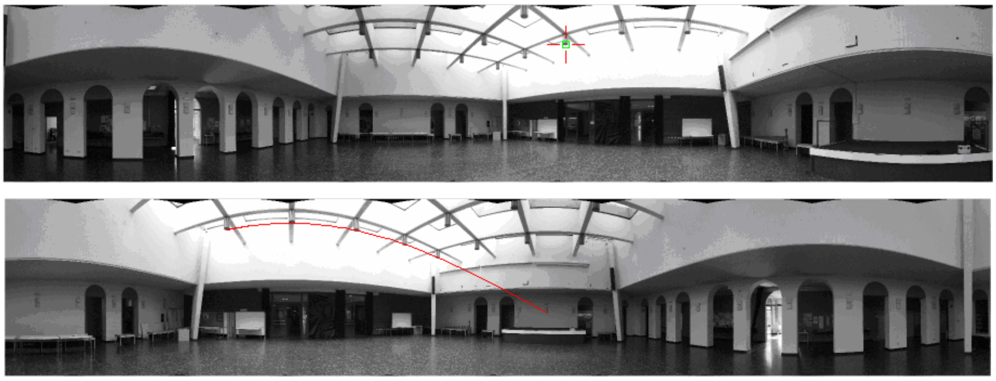

Fig. 7: Measured point in left panorama (top) and corresponding epipolar line in right image (bottom)

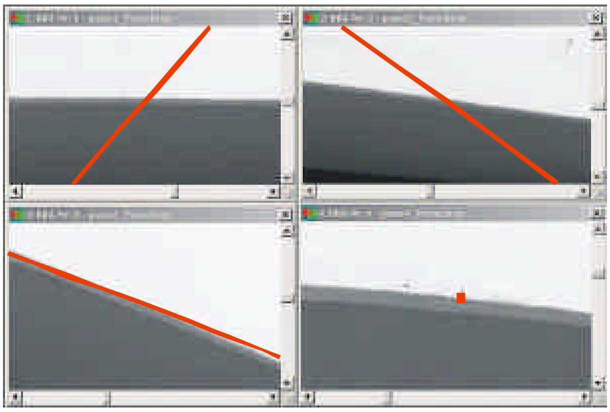

Fig. 8: Location of epipolar lines at almost horizontal object edges

4. Example applications

4.1 3D model of entrance hall

The university main entrance hall has served as a test object for 3D modelling from panorama images. The dimensions of the hall are about 25m x 25m x 8m. It consists of a number of arcs that form the arcades on three sides of the hall. Four panorama images have been generated based on high-resolution frame imagery (Kodak DCS 645M). The mean pixel size in object space results to about 2mm.

For this example, 170 object points have been measured in order to provide basic geometry data for the 3D reconstruction. The average accuracy of object points measured by space intersection is estimated to about 5mm depending on geometrical intersection conditions. This result corresponds to an image accuracy of about 2 pixels. A higher accuracy of about 1 pixel can be expected if better calibration parameters of the Kodak camera were available. In this case, the camera has been calibrated a couple of days before the actual measurement.

Fig. 9 shows the 3D wire frame model of the reconstructed hall. The data is processed by StereoMess, a software package developed in our institute.

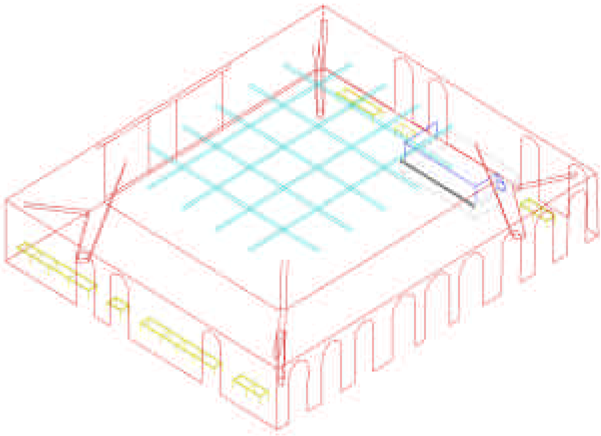

Fig. 9: 3D model of the entrance hall

Using the parameters of interior and exterior orientation, orthophotos can be calculated from the panorama image. Fig. 10 shows two examples where the image is projected onto a wall of the building (top) and the floor (bottom).

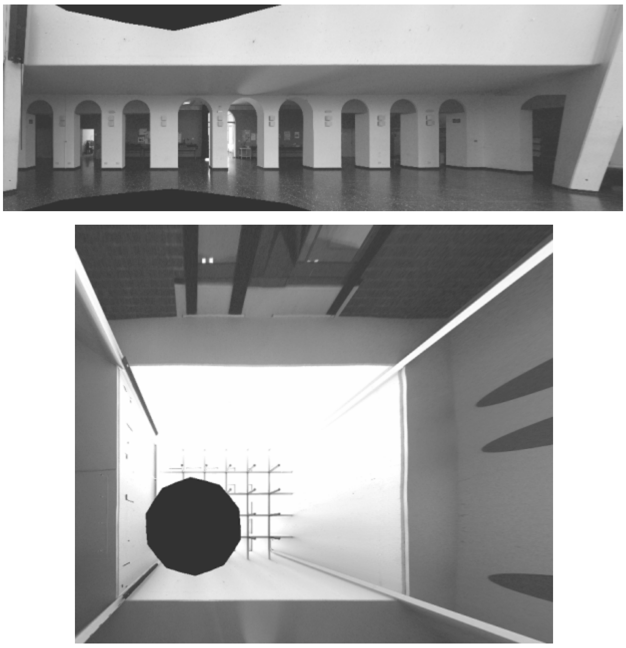

Fig. 10: Orthophotos generated from panorama imagery

4.2 Multiple image panorama mosaic

The Great Hall of the Oldenburg castle has been surveyed within a student's project. Again, the Kodak DCS 645M camera was used to acquire four panoramas located close to the four corners of the hall (Fig. 12). One additional panorama has been taken from the centre of the hall in order to provide image data for a high-quality panorama presentation of the interior. A number of control points have been measured by non-contact tachymetry.

Each panorama originally consists of 10 frame images (Fig. 11). Based on calibrated camera data and a number of tie points measured in the overlapping zones of each image, four panoramas are generated that are located in the corners of the hall (Fig. 12). Finally, the complete panorama, with a virtual station in the centre of the hall, could be resampled (Fig. 13). The final panorama image has a resolution of about 25900 x 5300 pixels.

Fig. 11: Original images of one panorama station

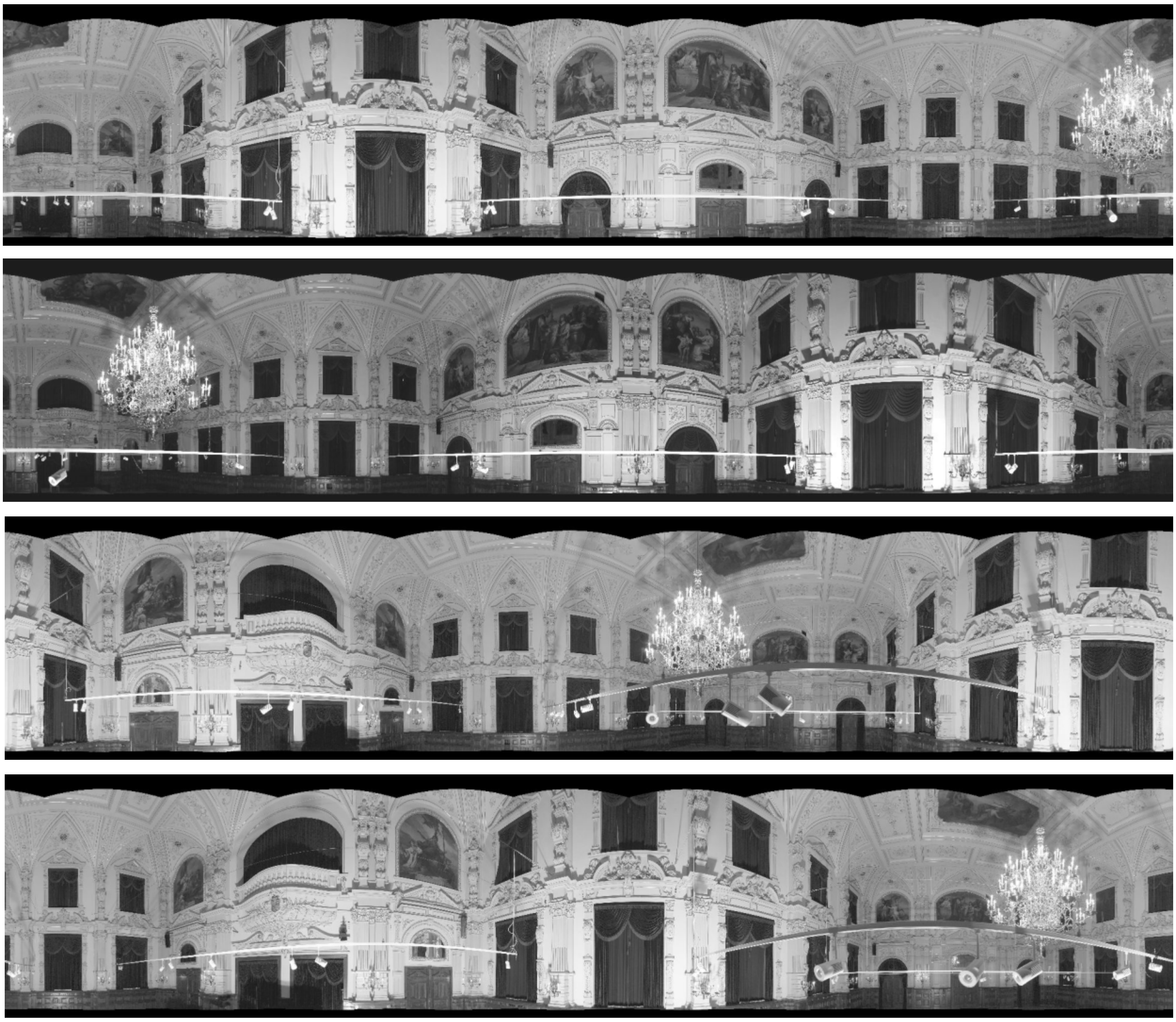

Fig. 12: Four measurement panoramas (cameras stations in hall corners)

Fig. 13: Resulting panorama of Great Hall (camera station in hall center)

4.3 Plane rectification

This project is a comparison of two approaches for high-definition rectification of planar objects, such as historic mosaics or paintings. The objective is to achieve not only a high-resolution document of the object, but also high quality in terms of colour correctness and geometric accuracy.

For this investigation again the two high-resolution digital cameras (Fig. 1 and Fig. 2) have been used. An artwork showing Oldenburg's Graf Anton Günther (1583-1667) has been created in 1959 and is located on the outside wall of a school. The desired resolution of the image rectification is specified to 1mm in object space.

Fig. 14: Wall mosaic

A set of nine images has been recorded that covers the complete object with an overlap of about 20-30% (Fig. 15). A number of control points have been measured by a theodolite. Each image of the set was rectified by plane projective transformation. The final orthoimage results from a mosaicing process where each rectified image has been stitched without colour adjustment (Fig. 17 left).

Fig. 15: Set of nine high-resolution images (each 4000 x 4000 pixels)

Fig. 16: Sector panorama image and example details

Parallel to the image acquisition by a normal digital camera, the KST panorama camera has been applied. In this case, only a sector panorama of about 30° has been recorded. The image was oriented by space resection and rectified by ortho-projection to the plane of the object (Fig. 17 right).

a) Image mosaic   b) Rectified panorama image

Fig. 17: Rectified results

5. Summary

The paper presents some examples and techniques for the use of panoramic images for architectural photogrammetry. Panorama images can be acquired quite easily by any type of modern digital camera. However, special notice must be given to geometric camera calibration if precise panoramas and/or photogrammetric products shall be achieved. In addition to standard calibration parameters, panorama adapters have to be adjusted in order to ensure alignment of the rotation axis and the perspective centre of the camera.

The mathematical model of panorama images is usually based on cylindrical coordinates. Since collinearity equations can be derived easily, all standard photogrammetric algorithms from space intersection to bundle adjustment can be applied.

Three practical examples are given in the paper. For documentation purposes, panoramas are most useful inside rooms where an all-around image is desired. Panorama images can be acquired with very high image resolution and colour quality, so that the image is a valuable document of the object. For 3D modeling purposes panoramas have the advantage that only a very limited number of tie points have to be measured. As a drawback, only very few software packages are available that can handle panorama images for photogrammetric purposes.

6. References

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