HIGH-RESOLUTION IMAGE RECTIFICATION AND MOSAICING – A COMPARISON BETWEEN PANORAMA CAMERA AND DIGITAL CAMERA

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ABSTRACT:

The paper describes the acquisition and rectification of high-resolution images of a valuable stone mosaic in the city of Oldenburg. The piece of art is located on an outer wall of a school building, hence image recording had to be done under daylight conditions. We have used a 16 mega-pixel camera Kodak DCS 645M for the acquisition of nine overlapping images of the whole object. In addition, the panorama camera KST EyeScan M3 was used to acquire the complete mosaic in one scan. For the Kodak camera the image resolution in object space was about 0.6mm per pixel while the panoramic image yields 1.4mm per pixel. The geometric accuracy of the mosaic reconstruction is specified to about 2mm.

Previous investigations have shown that the digital camera provides a geometric accuracy potential of better than 1:100000 if an appropriate camera model and calibration is available and well-defined point targets are used. The color quality of the camera is excellent. The geometric accuracy of the panorama camera is lower since the mechanical drives are less accurate and harder to calibrate. However, since the accuracy specifications of the project are not very high both cameras should provide a sufficient precision.

The object is assumed to be flat within a few millimeters. A number of control points have been measured by theodolite observations. They are used to calculate image orientations and/or parameters for projective transformations. The images of the digital camera were processed individually, each resulting in a separate rectification with respect to a global object coordinate system. The panorama image could be oriented by space resection. The final image mosaic was then generated by stitching the separate images together. The upper regions of the result shows some remaining errors of about 2-3mm. Since no radiometric adjustment was performed color edges are still visible in the complete image mosaic. In contrast, the panoramic image can be oriented by space resection and rectified by orthophoto calculation. The resulting image does not show any radiometric discontinouities and a sufficient geometric accuracy. Future improvements are necessary with respect to color calibration and radiometric mosaicing. The required methods are available but not implemented yet.

1 APPLICATION

A wall of a building of the Graf-Anton-Günther school in Oldenburg is covered with a 5.0m x 5.3m stone mosaic that was created 1959 by the artist Wilhelm Tegtmeier (Fig. 1). It displays Earl Anton Günther (1583-1667), Oldenburg's famous diplomat during the Thirty Years' War, riding his favourite horse "Kranich" (Crane). It consists of approximately 70.000 single tessera.

In spring 2004 the mosaic has to be removed temporarily due to an extension of the building. The IAPG has initiated a high-resolution acquisition of images in order to provide a metric image documentation prior to the construction work. These images should be used as a precise data base in case of any damages of the art work. On the one hand, a 4K x 4K digital camera Kodak DCS645M (Fig. 1) was used, on the other hand a digital panoramic camera KST EyeScan M3 was applied. Both cameras have been investigated previously, and they have shown excellent image qualities (Luhmann & Tecklenburg 2004). The images should be acquired such that a subsequent rectification with an object resolution of 1mm would be possible. In this case gaps between the tessera can be registered for reconstruction of the mosaic. Since a reproduction of the mosaic in original true colors was not required, no special effort was spent on site for color calibration.

Fig. 1: The wall mosaic of Earl Anton Günther in Oldenburg

Fig. 2: Digital camera Kodak DCS 645M

Fig. 3: Digital panorama line-scanning camera KST EyeScan M3

In terms of geometry an object accuracy of about 2mm should be achieved. The object surface was assumed to be flat enough in order to apply a plane projective transformation for the generation of the complete image mosaic map.

In principle, the processing of the frame imagery can follow one of the two procedures displayed in Table 1. The first case describes the individual processing of each image whereby the final result is obtained by mosacing of the single rectifications. Alternatively, the complete set of images can be oriented by bundle adjustment followed by the calculation of an orthophoto. Since self-calibration becomes weak on plane objects the camera should be calibrated in advance.

Table 1: Procedures for mosaic production from multiple frame images

Single images	**Multiple images**
1. Measurement of control points	1. Measurement of control and tie points
2. Projective rectification of single images	2. Bundle adjustment
3. Mosaicing with optional color adjustment	3. Orthophoto with optional color adjustment

For the panoramic image (Table 2) a single space resection based on the mathematical model of panorama photogrammetry is sufficient (Lisowski & Wiedemann 1998). Subsequently, a complete orthophoto can be calculated the oriented panoramic image.

Table 2: Procedures for mosaic production from one panoramic image

Panoramic camera
1. Measurement of control points
2. Space resection
3. Orthophoto

The required control points were measured by theodolites and processed by 3-D net adjustment using the bundle adjustment program BINGO (GIP, Aalen, Germany). A total number of 16 control points were determined (examples in Fig. 4). The accuracy (RMS) of adjusted object points was calculated to 0.5mm in the mosaic plane.

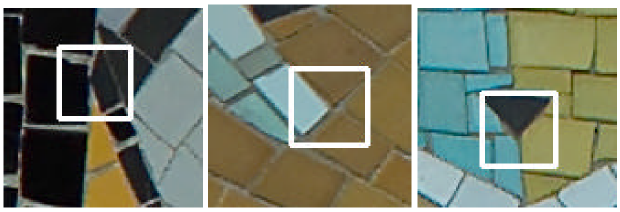

Fig. 4: Examples of natural control points

2 HIGH-RESOLUTION MULTIPLE IMAGES

2.1 Image acquisition

The digital camera Kodak DCS 645M was used with a 35mm wide angle lens. The camera is based on a standard Mamiya body where the Kodak digital sensor back with 4072 x 4072 pixel can be attached. The pixel element size of 9µm leads to a total sensor format of 36mm x 36mm. One color image (RGB) requires up to 48 MB data storage in uncompressed raw format. The camera has successfully used for a variety of photogrammetric projects. Given suitable imaging configurations and calibration methods a relative accuracy of up to 1:100.000 (length measurement error) can be obtained (Hastedt et al. 2004).

Fig. 5: Image set recorded by Kodak DCS 645M, 35mm lens (IAPG)

The images were taken at clear sky but without direct sun light. However, slight over-exposures are registered at the upper edge of the mosaic that could not be avoided. The image resolution meets the specified values as shown in the example image subsets of Fig. 4. With an average image scale of 1:70 the resulting pixel size is equivalent to 0.6mm in object space.

The camera was calibrated in advance by test field calibration. As shown for the single images of Fig. 5 the used lens has a relatively high radial-symmetric distortion that has to be taken into account for the subsequent rectification and mosaicing (Fig. 6).

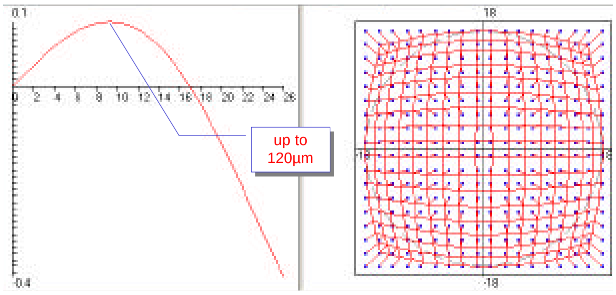

Fig. 6: Radial-symmetric distortion of the 35mm lens

2.2 Rectification and Mosaicing

Due to the fact that the distribution of control points was not optimal for each image, an overview image (similar to Fig. 1) was used to create a basic rectification using all control points. This "geo-referenced" image served as the basic reference system for the measurement of additional reference points. Using this approach the geometric residuals of the rectified overview image may affect the quality of the final result. Since the geometric accuracy of the basic rectification was better than 0.5mm, this effect can be neglected. In addition, control point errors or local deviations from the assumed plane surface may be compensated by the averaging behavior of the procedure.

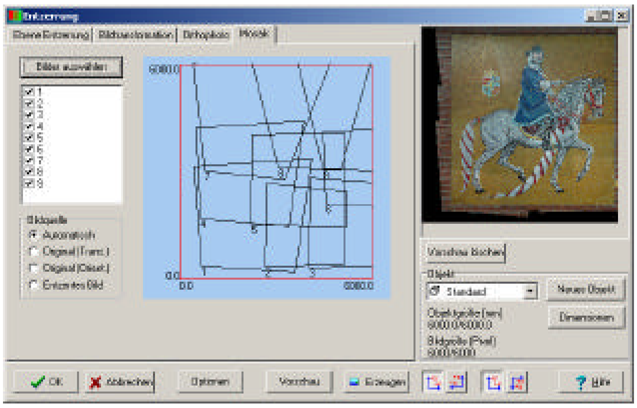

Fig. 7: User-interface for rectification and mosaicing (program StereoMess, IAPG)

Subsequently, the single rectified images are stitched together for the complete image mosaic for a specified object window and object resolution (Fig. 7). Within the overlapping zones the color value is optionally taken as the mean of all images, or by the one with the most suitable viewing direction. A radiometric adjustment is not applied here. The methods are well known from orthophoto maps in remote sensing or in architectural photogrammetry (Wiedemann & Tauch 2005).

The final result is displayed in Fig. 10. The still visible color edges will be removed in a later project period.

3 HIGH-RESOLUTION PANORAMIC IMAGE

3.1 Image acquisition

The digital panoramic camera KST EyeScan M3 is available at the IAPG. It provides cylindrical color panoramas with up to 54000 x 10300 pixel. Either 360°-images or partial horizontal sections can be recorded. The system was investigated previously (Luhmann & Tecklenburg 2004, Schneider & Maas 2004, Amiri Parian & Gruen, 2003). Using sufficient calibration methods image accuracies of better than 0.5 pixels can be achieved.

The camera was calibrated in advance by means of the multiple station measurements of the AICON 3D Systems calibration room and self-calibration using the bundle adjustment program PanoOrient. The mathematical calibration model is based on Schneider & Maas (2004) using additional parameters for the radial distortion that can be observed in column direction.

Fig. 8: Original panorama section

The original image (Fig. 8) was taken from 5m distance using a 35mm lens. A pixel resolution of 1.4mm was achieved. The scanned image section covers a horizontal angle of 30° equivalent to 4400 x 10300 pixel.

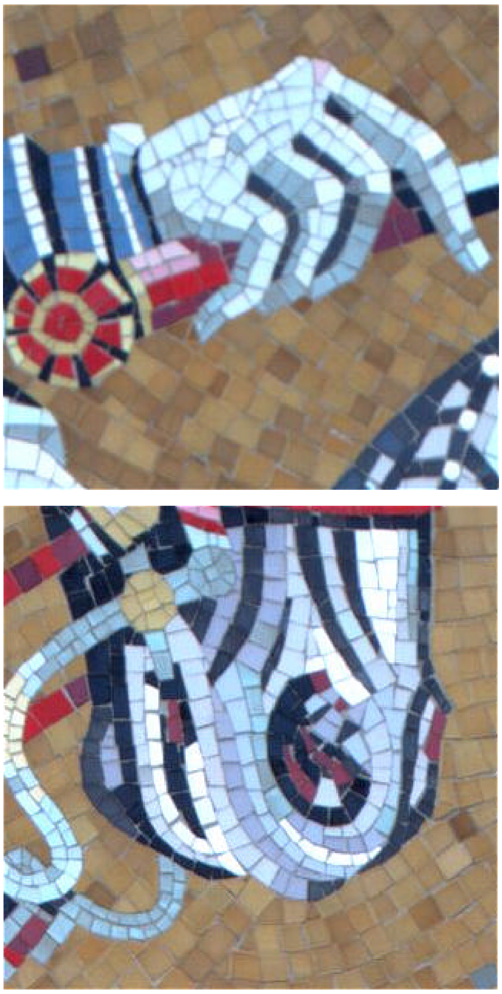

Fig. 9: Original 1:1 image subsets

Fig. 10: Resulting mosaic from multiple image set

Fig. 11: Resulting orthophoto from panorama image

3.2 Orientation

For photogrammetric processing of panoramic images the programs PanoOrient (bundle adjustment) and StereoMess (image measurement, 3-D processing, ortho-rectification) are available at the IAPG. Control points are measured in analogy to the measurement of frame imagery. Orientation is performed by space resection.

3.3 Orthophoto

Orthophoto rectification was applied by the program StereoMess under consideration of the mathematical imaging model of the panorama camera. Since a plane surface is assumed a digital surface model is not required. After specification of desired object area and object resolution the final orthophoto is resampled (Fig. 11).

4 SUMMARY

Both high-resolution imaging approaches have provided a sufficient geometric accuracy of the rectified image plan. It is necessary to apply correct mathematical models and calibration methods that represent both cameras for the time of image acquisition. In both cases the achieved geometric accuracy is about 2-3mm in object space which is slightly less than specified previously. The reasons for the obtained result may be assumed as follows:

- manual image measurement due to the use of natural object points
- unflatness of the object surface
- insufficient focus in the upper image parts
- independent single image processing for the multiple image set

Processing of the multiple image set has required much more time as for the panorama image. This is mainly caused by the higher number of measured image points, the handling of large data amounts and the final optimization of the mosaicing in terms of minimizing geometric errors. As an advantage, photogrammetric standard software can be used that must provide image rectification and mosaicing under strict consideration of camera parameters.

In contrast, the photogrammetric processing of panoramic imagery is only possible with specific software tools that are rarely available on the market. In addition, investment costs for a high-resolution panoramic camera are approximately three times higher as for a highest resolution digital camera. The price gap will become even larger in future.

Image acquisition and measurement of the art work will be repeated in near future. Then a digital surface model of the mosaic will be measured, either by laser-scanning or by stereophotogrammetry, in order to increase the geometric accuracy of the orthophoto. If a multiple set of frame images is acquired, these images should overlap with at least 60% in both directions. In addition, an on-site color calibration of the camera(s) and a color adjustment for the multiple image mosaic will provide a radiometric correct documentation. In this context a powerful imaging and processing procedure is available for the high-resolution recording of large mosaics or other art works.

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