Photogrammetric processing of digital 360° panoramic camera image data

- Geometric modelling of a gigapixel camera -

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1. Introduction

Digital panoramic cameras have found growing interest in photogrammetry in the past few years. Originally primarily being used for purposes such as web-based animation or surveillance, panoramic cameras have meanwhile reached a performance, which makes them an interesting data acquisition tool for a number of applications in photogrammetry. New developments in sensor technology have enabled the acquisition of very high resolution 360° panoramic images with an image format of up to almost one Gigapixel. Advances in display technology and computer graphics allow to visualize images of this size dynamically. Fig. 3 shows an example of a panoramic image of Dresden in reduced size. Especially for recording indoor scenes, the use of panoramic cameras has proven to be beneficial. As a consequence, photogrammetrists have addressed the task of geometric modelling and calibration of digital panoramic imaging devices, allowing to use them for 3D measurement and object reconstruction purposes.

Various technologies have been applied to generate digital 360° panoramic images:

- Rotating linear array: A linear array image sensor is rotated on a cylinder around a vertical (or horizontal) axis, acquiring a panoramic image column-wise. Due to the sequential image acquisition manner, this type of camera is only suited for recording static objects with the camera mounted on a tripod.

- Image stitching: A number of images are taken with a conventional camera, rotation the camera on a tripod. The single images are assembled to a panorama by matching techniques.

- Fisheye lens: An image is taken by a conventional digital camera equipped with a ≥ 180° fisheye lens with the camera axis vertical up.

- Hyperbolic mirror: An image is taken by a conventional digital camera looking vertically down onto a hyperbolic mirror.

- Multisensor systems: Four or more area sensors, equipped with wide-angle lenses, are combined to an omni-directional vision system.

See e.g. (Luhmann, 2004) for an overview. Of these five basic principles, the rotating linear array technique offers clearly the highest resolution potential. In the following, the EyeScan M3 as an example of a rotating linear array panoramic camera will be described in detail. Based on a mathematical model for the camera geometry, its potential for photogrammetric applications will be discussed.

2. The *EyeScan M3 metric* digital panoramic camera

The EyeScan M3 (Fig. 1) from KST GmbH, Dresden, is currently the camera with the highest resolution of all terrestrial cameras commercially available on the market. The imaging sensor of the camera is a 10'200 pixel true RGB linear array sensor. The sensor is mounted in the imaging plane of the camera head, which is rotated about a vertical axis with the projection center on the rotation axis.

The image size of panoramic images generated by the camera depends on the chosen focal length. Images of up to 89700 x 10200 pixels in true RGB can be generated when using a narrow-angle lens (Table 1). If printed at a resolution of 300 dpi, this image format translates into a paper print of 760 cm x 85 cm. With 16 bit per channel, the corresponding file size is 5.5 GB.

As the image is exposed column-wise, the time for generating a full panorama depends on the number of columns and the illumination conditions. At 8 ms exposure time, the acquisition of a full panorama can take up to 10 minutes. For this reason it is obvious that the camera is only suited for recording static scenes from a tripod. As the horizontal distance of the three colour channels of the sensor is about 20 pixels, the three channels are not recorded strictly simultaneously, causing colour seams when recording moving objects.

3. Geometric modelling and calibration

The geometric model of image formation in a panoramic camera deviates from the common photogrammetric model of central perspective. In the case of a rotating linear array sensor like the *EyeScan M3*, the geometric model can best be described by a cylinder perspective (Fig. 2). This model is described in detail in (Schneider/Maas, 2003) and was implemented as a versatile tool for panoramic camera modelling. In order to compensate for imperfections caused by the mechanical system of the camera as well as distortion effects introduced by the optics and electronic effects, a set of additional parameters was defined, modelling the deviations between the mathematical model of cylinder projection and the physical reality of the camera.

The camera was calibrated based on images of a calibration field, which was specially designed for the purpose of panoramic camera calibration. In a spatial resection based on calibration field targets with known 3D coordinates, a standard deviation of unit weight of 25 pixel was obtained in first instance. Introducing a set of additional parameters to compensate for physical deviations from the ideal cylinder projection model, the standard deviation could be reduced to 0.24 pixel. Thus, the precision potential of the camera could be increased by two orders of magnitude by proper camera calibration. Related to the vertical field of view, the standard deviation translates into a relative precision of ca. 1 : 42'500 in object space; related to the horizontal field of view, it translates into a relative precision of 1 : 132'000 when using a 35 mm lens.

4. Photogrammetric data processing

The geometric model of the rotating linear array panoramic camera was incorporated into a number of photogrammetric data processing routines to allow for the use of the camera for photogrammetric data processing:

- Rectification: If the camera is used for recording facades, panoramic images can be used for single-image rectification. The easiest way to do that is by pre-correcting the images for distortion effects, transforming the pre-corrected cylindrical image into a tangential plane (which can be done if the interior orientation is known) and then rectifying the tangential projection (with central perspective geometry, cmp. Fig. 5) by standard rectification software tools.
- Stereo processing: If more than one panoramic images of a scene have been acquired, they can be viewed and processed stereoscopically. For stereoscopic processing of a full 360° geometry, an off-axis configuration has to be applied or at least three panoramas have to be recorded in order to avoid poor intersection geometries (see Fig. 4). If stereoscopic viewing is not required, two panoramas acquired with a vertical base are sufficient for 3D object coordinate determination.
- Bundle adjustment: The mathematical model has been extended to a panoramic image bundle adjustment, allowing for the simultaneous determination of the orientation parameters of multiple

panoramic images of a scene and the 3D coordinates of an arbitrary number of points (Fig. 4). Approximate values for the bundle adjustment can be obtained relatively easily by planimetric 'Cassini-resection' and consecutive spatial intersection. The bundle adjustment allows for on-the-job self-calibration if additional parameters are introduced as unknowns. In practical tests with 5 panoramic images and 364 object points, a standard deviation of unit weight of 0.22 pixels could be obtained. This translates into a precision of 0.4/0.3/0.2 mm for the X/Y/Z coordinates in a room of 7.5/5.0/2.5 meter.

- Epipolar lines: The mathematical can be used to define epipolar lines, which may be used to support interactive measurements or to reduce search spaces in the application of image matching techniques. In the case of cylinder image geometry, the epipolar lines are bended.

5. Conclusion

Panoramic cameras form an interesting alternative for a variety of photogrammetric object recording and modelling tasks. Their strength is clearly to be seen in their very high resolution potential and in their capability of recording 360° panoramic images, making them very suitable for capturing indoor scenes or city squares in applications requiring very high resolution. Precision and resolution have to be discussed separately when comparing panoramic cameras to conventional digital cameras: While the resolution of cameras based on linear array sensor technology is still a multiple of what can be obtained by area sensor cameras, the pure geometric precision potential of area sensor cameras has proven to be superior despite their inferior resolution as a consequence of the geometric stability of area sensors and the lack of moving parts.

The practical handling of images with a resolution of almost one gigapixel may still challenge many computers. This limitation will soon be overcome with the rapid development of computer technology and graphics board performance.

Further reading:

- Luhmann, Th., (2004): *A historical review on panorama imagery.* International Archives of Photogrammetry and Remote Sensing, Vol. 34, Part 5/W16
- Schneider, D.; Maas, H.-G. (2004): *Application and accuracy potential of a strict geometrical model for rotating line cameras.* International Archives of Photogrammetry and Remote Sensing, Vol. 34, Part 5/W16
- *WWW: http://www.tu-dresden.de/fghgipf/forschung/panocam/*

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Figures:

Fig. 1: EyeScan M3 digital panoramic camera

Lens	35 mm	45 mm	60 mm	100 mm
Sensor: linear RGB CCD array with 10,200 pixel per colour channel, Length 72 mm, Radiometric Resolution: 16 per colour channel				
Number of image columns (360°)	31400	40400	53800	89700
Vertical aperture angle	90°	80°	60°	40°
Data volume (360°, 48 Bit)	1.7 GB	2.3 GB	3.1 GB	5.1 GB
Recording time (360°, 8 ms per column)	3 min	4,5 min	6 min	10 min

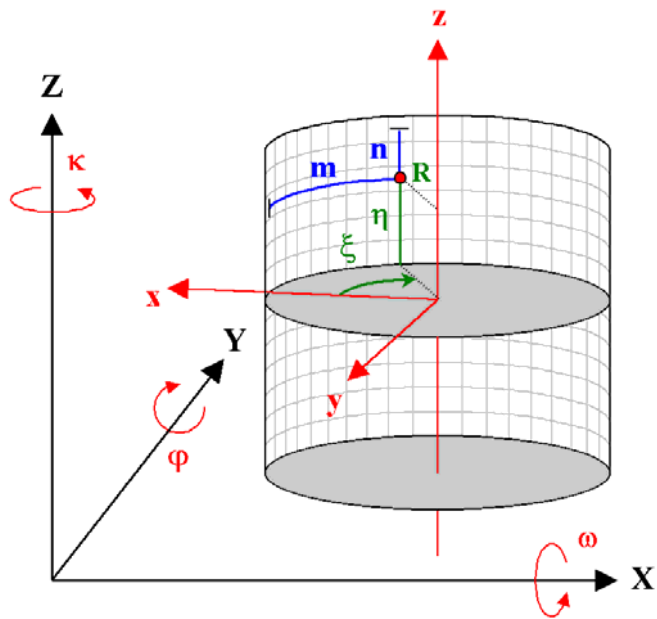Table 1: EyeScan M3 camera parameters

Fig. 2: Geometric model of cylindrical projection

Fig. 3: Panoramic image of Dresden (reduced size)

(To the publisher: This image is big enough to be printed over two neighbouring pages at the bottom of the page, documenting the extreme image format of panoramic images.)
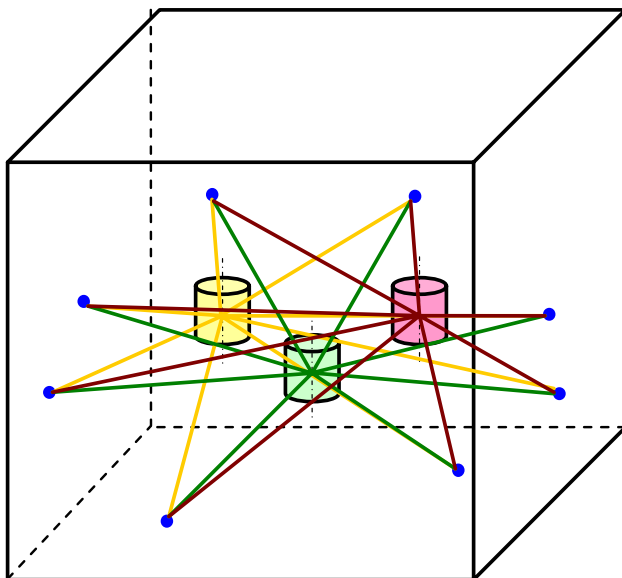

Fig. 4: Principle of multi-image panoramic bundle adjustment

Fig. 5: Tangential projection (90° panorama sector, projection on a tangential plane, rectification)