IMAGE ACQUISITION FOR DIGITAL PHOTOGRAMMETRY USING „OF THE SHELF“ AND METRIC CAMERAS

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ABSTRACT: Photogrammetric recordings in fields like architecture or archaeology have to be taken in a rapid and easy manner. Therefore and under consideration of processing the images for getting data formats for interactive Web publishing, VRML or O2C for example, an overview about utilizing „of the shelf“ cameras for dimensional analysis from photos is given.

Most of the photo evaluation processes need the definition of an image co-ordinate system due to the mathematical model that is assumed as central projection. Model deviations should be parameterised and corrected. A major influence is provided by the interior orientation, the camera parameters. The position of the principle point and the amount of lens distortion should be known. Insufficient film flatness or in general image deformation is important while using lager format and film scanning.

Typical device attributes like format, film or digital, SLR or viewfinder classify the cameras. It is not possible to cover the whole range of good camera equipment available. The cameras introduced here are representatives for their category.

Camera calibration strategies and procedures are described from a practical point of view. Results from desktop image evaluation software will be discussed.

1 DIGITAL IMAGE ACQUISITION

More or less any camera is suitable for photogrammetric applications. A camera can be used as a metric one if the position of the projection centre relatively to the image co-ordinate reference system is known and if the amount of lens distortion can be corrected. Film flatness in case of larger formats could be a problem of accuracy. Following a short overview about analogous film cameras, digital cameras and metric cameras is given. It is not possible to cover all the products complete. Only equipment with special features is mentioned here. CIPA Working Group VII provides on its Web site a collection of cameras with more technical details, (CIPA WG VII 2001).

1.1 ANALOGOUS FILM CAMERAS

35mm cameras are available as SLR types or equipped with a viewfinder. The wide range of lenses from 8 mm fisheye, 16mm or 22mm wide angle up to long focal length lenses of 500 mm provide solutions in extreme situations. A sample is given with the 8mm fisheye configuration and the spherical panorama calculated from two of those images, see figure 1. The newer APS film format is not recommended for metric applications since there are no benefits to detect. Image formats in the range of 60mm x 60mm are known as medium format cameras. Hasselblad, Pentax or Rollei for example are vendors of professional equipment. The here mentioned brands all provide modified solutions as metric versions using a réseau or vacuum for film flattening. Larger formats for landscape photography are for example the Mamiya 7II, a 6x7 cm format viewfinder camera or the Fuji GX617 panorama camera with an image format of 60x170mm. For the Mamiya a 4,5/50mm wide-angle lens is available in comparison to a 35 mm format this equals a 24 mm focal length. The image angle covers 84 degree. It is important to compare the focal length of a lens in respect to the image format or to focus on the image angle.

1.2 DIGITAL CAMERAS

Digital cameras are still in a rapid changing development process. Their suitability for metric applications is not a question. Image format and resolution should be reviewed critical particular for architectural applications. One can group the types of digital cameras today into mega pixel cameras, 35 mm SLR cameras and digital data backs for medium formats.

The Kodak DCS 290 is one of the low cost mega pixel cameras. A Matshushita MN3957OPT sensor comes in its physical size of 7,56*4,8 mm with a resolution of 1800 x1200 pixel. The aspect ratio of 3:2 is the same as for a 35mm film. Pixel size is 4.2 microns. Adopting RGB Bayer arrangement in colour filter array provides colour reproduction; see (G. Pomaska, 1999). Setting the zoom lens to one of the predefined positions and fixing the focus enables camera calibration. A calibration sample for the 35 mm focal length at infinity shows radial symmetric lens distortion of about maximum 0.030mm.

A solution with modifications to metric requirements, provided by Rollei with the d7 or d30 metric digital cameras, closes the gap between mega pixel cameras and SLR cameras with changeable lenses or full format frames. The metric version was introduced 1999 (G. Pomaska, 1999). A further development including a 5 million pixel resolution sensor is introduced 2001 at the occasion of the CIPA Symposium.

Figure 1: Standard SLR consumer camera with an 8 mm fish eye lens mounted on a panoramic head. Two of those shots with 180-degree different exposure directions can be converted to a full spherical panorama.

A representative for the 35mm SLR digital professional cameras is the Nikon E2. This camera does not reduce the field of view due to a smaller sensor area compared to 35 mm film, a special feature not found on most other digital cameras. This means the full field of view of any lens will be preserved. The lenses can be calibrated on different fixed focusing stops. The 2/3“ CCD sensor provides a resolution of 1280 x 1000 pixel. The sensitivity corresponds to ISO 800 or ISO 1600. The camera is compatible with almost all Nikon objectives (even older Nikkor objectives). Another examples for professional 35 mm digital cameras are the Kodak DCS professional series, which are widely used in photogrammetry today.

Kodak with the Kodak Pro Back introduced one of the latest developments. The sensor size is approx 4 x 4 cm with a resolution of 16 million pixels. This data back can be mounted on different medium format camera bodies.

1.3 METRIC CAMERAS

Known 35 mm camera modifications to fulfil metric requirements are the Rollei 35, the Ricoh KR-10M, Contax and at the high-end quality range the Leica R5. Ricoh and Leica are distributed by PMS AG, Switzerland.

The Ricoh KR-10M, a low-cost camera distributed by PMS AG, offers an economic entry into photogrammetry. This camera does not provide quite the accuracy of the Leica R5 but it offers a new feature for photogrammetry; a zoom lens calibrated at the focal lengths 35mm, 50mm and 70mm. The Ricoh KR-10M is a suitable 35mm camera for smaller architectural projects, for the recording of minor accidents, for landscape planning wherever a medium accuracy suffices. A réseau with 3*3 crosses references the image co-ordinate system.

Efficiency, optical and mechanical precision together with the outstanding Leica lenses are the features of the 35mm camera Leica R5. For use in the photogrammetric measuring systems the camera is modified. The built-in réseau grid plate in front of the film plane, and the lenses calibrated at fixed focusing stops, guarantee exact results. All Leica lenses are calibrated at two fixed focusing stops (close range and infinity focus).

Probably the widest known metric camera for close-range applications is the Rolleiflex 6008 metric. A réseau camera with 121 x 121 crosses; mesh distance 5 mm. Insufficient film flatness can be corrected numerically due to the high density and the precision of the réseau. The lenses are equipped with click-stops for precise reproduction of the focal length. With the wide range of accessories available this camera is the ideal solution for photogrammetry in cultural heritage recording.

Tomtecs A.G. Corporation presents the HIEI G4 a camera for aerial and ground photogrammetric systems. The Image format is 115 x 115 mm. This kind of camera is in a certain extend comparable with the former UMK from Jenoptik.

	35 mm	Medium format	View finder	Larger format
				
Camera	Canon EOS	Pentax 645	Mamiya 7II	Fuji GX 617
Image Format [mm]	36 x 24	56 x 41,5	69,5 x 56	168 x 56
Res. 1200 ppi	1700 x 1133	2645 x 1960	3283 x 2645	7937 x 2645
Res. 2700 ppi	3826 x 2551	5924 x 4411	7388 x 5924	17858 x 5924

Table 1: Analogue film cameras – comparison of image Formats and resolution after film scanning.

	Megapixel	SLR fixed lens	SLR	Medium format
				
Camera	Kodak DC 290	Rollei d-metric	Kodak DCS	DCS ProBack
Image Format [mm]	7,6 x 4,8	8,8 x 6,7	27,5 x 18,1	36,7 x 36,7
Resolution	1800 x 1200	2588 x 1960	3032 x 2008	4028 x 4028
Pixel size [microns]	4,2	3,4	9,1	9,1

Table 2: Digital cameras – comparison of sensor formats and resolution

	35 mm	Medium format	Larger formats
			
Camera	Leica R5	Rolleiflex 6008	Tomtec
Image Format [mm]	36 x 24	60 x 60	115*115
Res. 1200 ppi	1700 x 1133	2834 x 2834	5433 x 5433
Res. 2700 ppi	3826 x 2551	6378 x 6378	12224 x 12224

Table 3: Metric cameras from Leica, Rollei and Tomtec

1.4 DIGITIZING WITH DESKTOP SCANNERS

A wide range of high quality image scanners with high optical resolution, good geometric quality and colour depth with 14 bit for each colour is available today. Applying 35 mm slide scanners can be difficult if the film frame must define the reference system for the image co-ordinates. The frame shown in the digital image can be identical with the scanners frame. Therefore as well as in case of scanning prints the reference system must be defined by a réseau or fiducials, see figure 2.

Two samples of desktop scanners with transparency units are mentioned here. The Canon FB 1210 U flatbed scanner provides optical solution up to 1200 ppi. A Resolution of 2500 ppi can be reached with the AGFA DuoScan T2500. The scanning area covers larger formats, which is not the case with slide scanners. For 35 mm slides are scanners with resolutions up to 4000 ppi available. Metric cameras with a réseau are best suited for film scanning because of the control possibilities of image deformation caused by the scanning process.

As shown in the camera comparison tables, the resolution of the professional Kodak DCS 760 can be easily reached with a standard analogous 35 mm camera and a film scanner. On the other hand larger film formats in combination with desktop scanners provide resolutions never reached by CCD cameras.

Comparing the mentioned resolutions in tables 1 – 3 need to be focused to the object resolution. Image format, focal length and object size are the parameters, which impact those most important value for calculating accuracy and degree of detail for an application in advance. One example is given for a 25 m object size fitting the longer side of the image frame. With the Kodak DC 290 the average image scale is 1: 3300, one 0.0042 mm pixel should show 0.14 m of the object. In case of the Rolleiflex 6006 the image scale is 1: 420, object resolution of one pixel resulted from 2700 ppi scanning is 0.04 m of the object dimension.

A first step to image co-ordinates is the transformation of the scanner coordinates to the cameras reference system. The highest accuracy provides a réseau grid in front of the film plane. Fiducial marks with known positions require mechanical film flattening. Two of those marks are at minimum necessary for defining a reference system. If a camera is not modified, the image frame itself can be used. Figure 2 displays different solutions. The Rollei réseau shape of the 6006 is shown left. A recommendation of EOS Systems with two fiducials enables scanning without use of the full format. The pixel position in a digital camera is already defined as the reference.

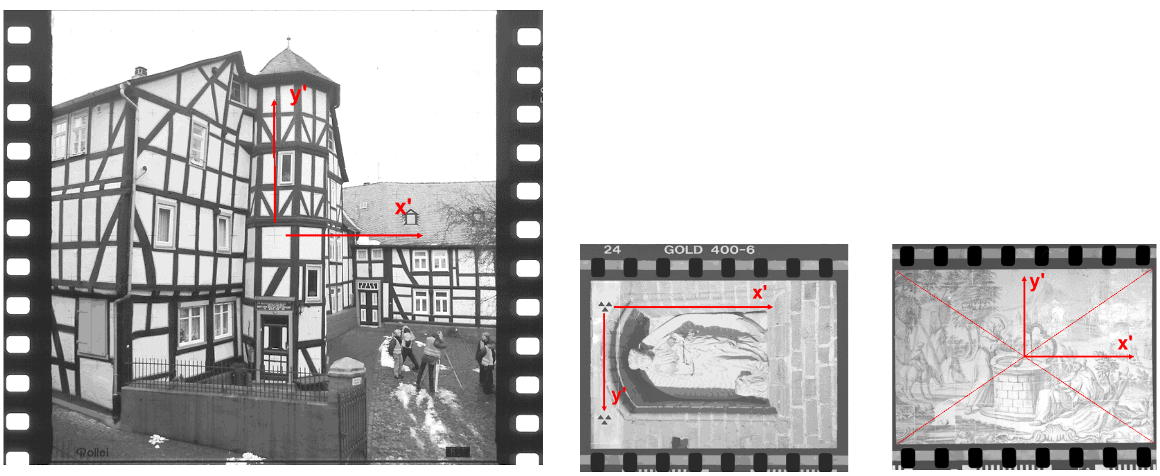

Figure 2: Definition of reference systems for the photo (image) co-ordinate system. Left: Rèseau camera. Centre: Fiducial marks. Right: Image frame.

2 IMAGE REFINEMENT

Correction of photo-coordinates is known as image refinement. The effects of image deformation result from different sources. Atkinson (K.B. Atkinson1996) separates the impact of lens distortion from geometric effects like lack of flatness or non-orthogonality. Since camera calibration is the determination of the parameters of the complete imaging data acquisition system, including camera and scanner, I prefer to handle lens distortion correction in the same context. The process is transform the device coordinates into the reference system, shift the co-ordinates into the images system take into consideration the principle point position and other image deformations, correct lens distortion and do interpolation with neighboured points.

2.1 IMAGE COORDINATE SYSTEM

The image, or photo, co-ordinate system is defined as a right-handed orthogonal system in the projection centre of the camera as shown in figure 3. In case of terrestrial applications rotation about the y-axis is the exposure direction, rotation about the z-axis is named swing and rotation about the x-axis is named as tilt. The distance from the origin to the film plane is the focal length. The entire pixels given in the digital image have to be shifted to the image coordinate system first. The difference between the cameras reference system and the origin of the image coordinate system are the coordinates of the principle point, which are given from the camera calibration. In other words, the position of the principle point relative to the reference system is part of the interior orientation of the camera.

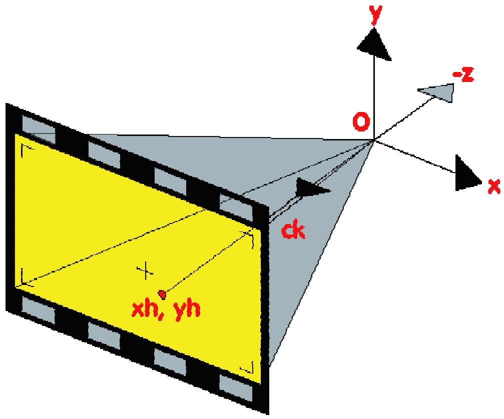

Figure 3: A camera's reference system to the image coordinate system in terrestrial applications.

2.2 THE LENS DISTORTION MODEL

Variations in angular magnification with angle of incidence are usually interpreted as radial lens distortion. Tangential lens distortion results from misalignment of the components of a lens. Further parameters can be defined for higher accuracy, see K.B.Atkinson, 1996. The above-mentioned components are described in a balanced or unbalanced form in terms of polynomial series where the two lower order terms are significant here. Lens distortion graphs typically show the distortion in micrometers against the radial distance in millimetres, see figure 6. The balanced form is transformed by shifting the principle distance such that the mean value of the transformed curve out to a certain radial distance is zero. This distance, usually named r0, is chosen at approx. 2/3 of the half of the diagonal distance in an image

2.3 EXAMPLES OF IMAGE REFINEMENT

The impact of image refinement can be made visible by a difference image. One of the photos taken for the purpose of calibration, see figure 5, is taken as the original and after image refinement as described above. The software used is the Rolleimetric DistortionFree Package that is distributed with the Rollei digital metric cameras. The difference image can be calculated with any image processing software like Adobe´s Photoshop. Without any image distortion all grey values shown would have a zero value. Easily detectable in figure 4 are the both zero passings, one in the centre and the other at position r0. Viewing stereoscopic image pairs taken with non-metric wide-angle cameras displays curved surfaces where flat surfaces are estimated. Two samples can be viewed on CIPA's WG VII web site.

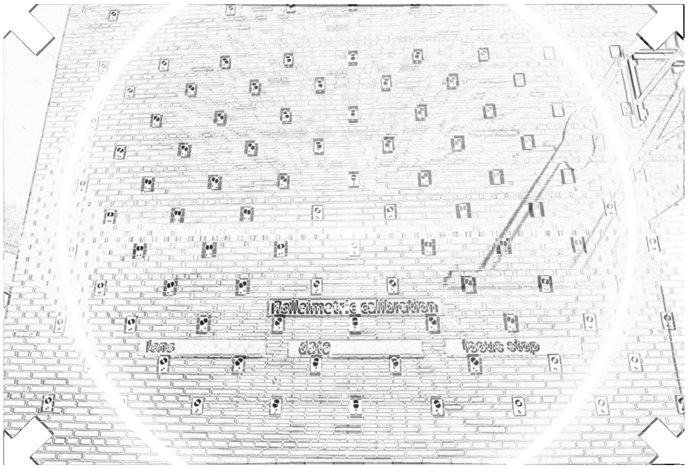

Figure 4: Digital difference image of two photos. One image including all deformations without refinement, the second image after correction.

3 CALIBRATION STRATEGY

There are several calibration strategies existing, which fit very well to their applications. In case of applications in cultural heritage recording, architecture or archaeology on-the-job calibration is not possible due to the environment, object shape and exposure arrangement. A field calibration in advance provides the parameters for the imaging data acquisition system.

Camera calibration does not need a high accurate 3D control point field today. A plane field of automatic detectable points is sufficient. Images from different positions with variations in the camera swing on the same position have to be taken. Image point measurements are performed by automatic point detection methods. Additional observations in object space are the definition of a local co-ordinate system and a scale. A bundle adjustment procedure calculates the camera's interior orientation, the photo positions and the co-ordinates of the calibration points. Standard deviation of the image co-ordinate measurement and the accuracy of the point co-ordinates indicate the accuracy.

Figure 5 is a photo used for calibration of a non-metric camera with a 22 mm lens. Since the photo frame is sometimes difficult to detect, some pre-processing is recommended. Numbering the control points in the image is only done here for demonstration purposes. The negatives are scanned with 1200 ppi on a Canon FB 1210 U flatbed scanner. Point measurement was done manually with a standard deviation of 0.023 mm, point accuracy is in the range of 4 mm. Distortion model including affine distortion increases the accuracy about 50 %. Total 12 photos were used from three positions. Figure 6 displays the result of the lens distortion calculation graphically for this example.

According to the above-described calibration strategy, which is used at Rollei Fototechnic, is a procedure recommended by EOS Systems. The company provides a file with a calibration shape. A large format plot should be photographed from eight positions. An additional scale must be measured. Image point detection is automatically done. An adjustment procedure calculates the interior orientation of the camera.

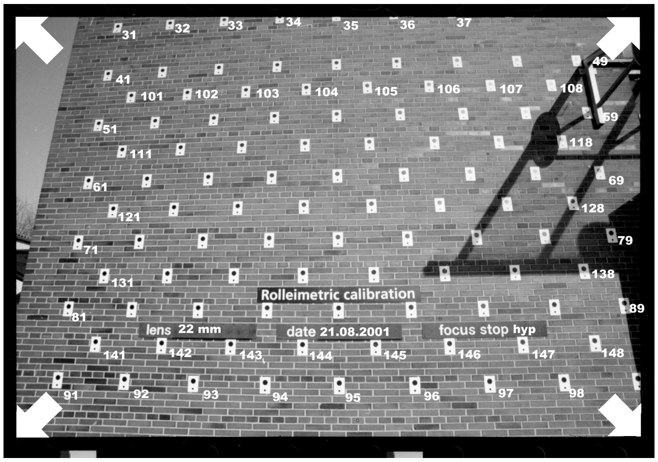

Figure 5: Calibration field at Rollei Fototechnic, image prepared for further processing.

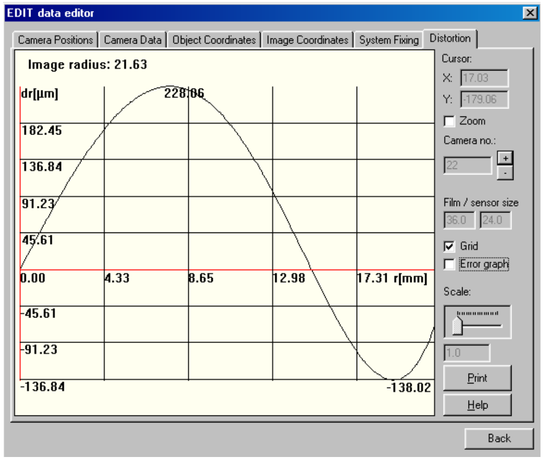

Figure 6: Balanced form of radial-symmetric lens distortion of a 22 mm zoom lens.

CONCLUSION: An overview about different types of cameras and its features particular regarding format is given. Definitions of references for the image co-ordinate systems and their usage are described. Image deformations and their corrections are discussed. A camera calibration strategy is presented. The impact of image deformations of a non-metric camera is shown by the calibration result and application samples, view stereoscopic images at www.imagefact.de. Non-metric cameras "of the shelf" can be applied to photogrammetry if the model deviations are corrected and the requirement to accuracy is not the highest.

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