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A new, high-resolution medium-format camera for digital close-range photogrammetry

Remark: The statements in this paper refer to the special needs and tolerances of the high end photogrammetry. For those initial tests unmodified equipment was used. The results show that the precision of the ALPA exceeds the usual photographic requirements already by far. Statements regarding the back adaptation in section 5 have therefore to be seen in the light of the intensified requirements of high end photogrammetry.

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A new, high-resolution medium-format camera for digital close-range photogrammetry

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Abstract: We report our experiences with a medium-format camera by ALPA of Switzerland that can be used with digital camera backs. First results with a 22 megapixel Leaf Valeo Wi back reveal high accuracy of object reconstruction, checked with calibrated scale bars in a test field (according to VDI/VDE Richtlinie 2634).

1 Introduction

In recent years digital image acquisition in close-range photogrammetry has relied mostly on cameras that are not specifically designed for this application. This means that any newly introduced digital camera is a potential measurement tool for photogrammetrists. While many new and sophisticated features have been added to modern cameras –autofocus, zoom lenses, retrofocus constructions, image stabilizers, among many others – most of theses features are not very useful to photogrammetrists, or might even reduce the potential accuracy a given camera. Photogrammetrists make such great demands on the optical and mechanical quality of digital cameras that they can hardly be met by standard photographic gear.

In order to make standard cameras suitable for photogrammetric work, the cameras needed to be mechanically adapted, or numerical models have to be used to work with the images. Thus, the best tool to work with is a camera that requires the least adaptation to yield an acceptable level of accuracy.

In this report we investigate the ALPA 12 WA, a camera for which the manufacturer has set a high priority for mechanical and optical precision. In combination with a digital camera back and a lens optimized for digital photography this camera fulfils the basic requirements that can be asked for by a photogrammetrists in the beginning.

2 The camera system

2.1 The camera – ALPA 12 WA

The ALPA 12 WA is the core module of an image acquisition system (Fig. 1, Tab. 1). Both sides of the camera can be used interchangeably to attach, with clamps, a lens and a camera back. The quadratic mount also allows rotating lens and back by 100 grads if required. Film and digital camera backs of several camera manufacturers up to a film format of 6x9 can be fitted on the ALPA. The effective image area of this format ranges between 56 x 82 and 56 x 84 mm, depending on manufacturer specifications.

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Figure 1: ALPA 12 WA camera body frontal view (left) and with attached lens and view finder (right)

Using a lens with an image circle larger than the sensor format allows decentring the principal point of the camera by a fixed value. Such a camera is very useful for terrestrial applications, similar to the WILD Heerbrugg cameras P31 and P32.

Table 1: Specifications of the ALPA 12 WA

Material	*Aluminum*
Levelling	*2 spirit-levels, 1 circular-level*
View finder	*120° field of view*
Handholds	*Rosewood or pear*
Dimensions (camera body)	*180 x 120 x 48 mm*
Weight (camera body depending on features)	*560-580 g*
Weight with Schneider Apo-Digitar 5.6/35 mm XL, Leaf Valeo 22 Wi and view finder	*1260-1280 g*

On the top of the camera, a view-finder can be attached. In contrast to regular high-end digital cameras, the ALPA has no mirror in the optical path. This has the advantage that the distance between the rear lens element and the image plane does not require a retrofocus construction for lenses with short focal length (wide angle lenses) to place the rear lens element in front of the mirror. Lenses for the ALPA use symmetrical lens alignment to optimize image quality and reduce radial symmetric lens distortion. Such lenses are also smaller and lighter than their retrofocal counterparts.

Besides the ALPA 12 WA, the company offers two additional models. The ALPA 12 SWA allows continuous shift of a lens up to 25 mm. This model is not mechanically stable enough for photogrammetric work. The ALPA 12 TC is a compact and light weight version of the ALPA 12 WA. All ALPAs have in common that distance and exposure have to be set manually, the shutter is placed in the lens, and the exposure-release button is on the lens. An extension cord (mechanical or electric) can be used for remote shutter release. The shortest standard shutter speed is 1/500 s.

2.2 Lenses

Most lenses that can be mounted on the ALPA have originally been designed for image formats larger than 6x9. The image circle of some lenses exceeds more than 200 mm. This means that the ALPA camera only uses the center part of the lens where optimum image quality can be achieved.

The Schneider Apo-Digitar lenses of Jos. Schneider Optische Werke GmbH, Bad Kreuznach, are of most interest to digital photography. These lenses are optimized for image circles between 60 and 120 mm. The power of resolution is extremely high and the lenses are color corrected into the near infrared. Lenses with a nominal focal length between 24 and 210 mm are available. An image circle of 60 mm covers the area of most commercial sensors in digital camera backs. For this study, the Apo-Digitar 5.6/35 mm XL wide angle lens was used (Fig. 2). The image circle of this lens reaches 90 mm at an aperture opening of f/11.

Figure 2: Schneider Apo-Digitar 5.6/35 mm XL with Copal 0 shutter

2.3 Digital camera back

A Leaf Valeo Wi is the 22 megapixel digital camera back that was used on the ALPA 12 WA (Fig. 3). The sensor inside the back is manufactured by DALSA and can also be found in other digital backs. Raw image data with 16 bit color depth require approximately 40 MB of hard disk space. The back can save images on an attachable hard disk or send data through a firewire connection directly to the hard drive of a tethered computer. The latter choice was used for this test. The digital back is also powered by the firewire connection. The Leaf back featured Hasselblad V-mount and was attached to the ALPA via a dedicated adaptor plate. Additional adaptor plates are available for digital back with Hasselblad H1, Mamiya 645 AFD, and Contax 645 mounts. The size of the image sensor at the back is 48 x 36 mm and reaches almost the so-called 6x4.5 format, the effective size of which varies between 55x41 and 56x40.5 mm depending on different manufacturers' specifications. Medium-format cameras designed to take digital camera backs almost always use the 6x4.5 format. Any future sensor larger than that would exceed the image format of these cameras, while the ALPA can accept sensors up to 84 x 84 mm. The Leaf image data can be converted to typical image formats with proprietary software. The images can also be converted with Adobe Photoshop CS2.

Sensor type	*CCD*
Sensor dimensions	*48 x 36 mm* *5344 x 4008 Pixel*
Pixel size	*8.9 x 8.9 µm*
ISO rating	*25 - 200*
Color depth	*16 bit*
Frame rate	*1.2 s per frame*
RAw data per images	*40 MB*
Image storage	*10/20/30 GB hard disk, firewire*
Connections	*firewire, bluetooth*
Weight	*450 g*

Figure 3: ALPA 12 WA with Leaf Valeo 22 Wi attached. Specifications of Leaf Valeo 22 Wi digital camera.

3 Experimental setup

3.1 Testfield

The guidelines for certification and control of photogrammetric 3D measurement systems have been compiled in VDI/VDE Richtlinie 2634, Part 1 "Optical 3D measuring systems – Optical systems based on point-by-point probing" (LUHMANN & WENDT, 2000; VDI/VDE, 2002). This authoritative German standard applies to mobile 3D measurement Systems comprising one or more cameras and a PC/notebook computer with software for image measurement, orientation, and 3D object reconstruction. The procedure is based upon the photogrammetric survey of a spatial testfield with target points placed along a minimum of seven measuring lines (Fig. 4).

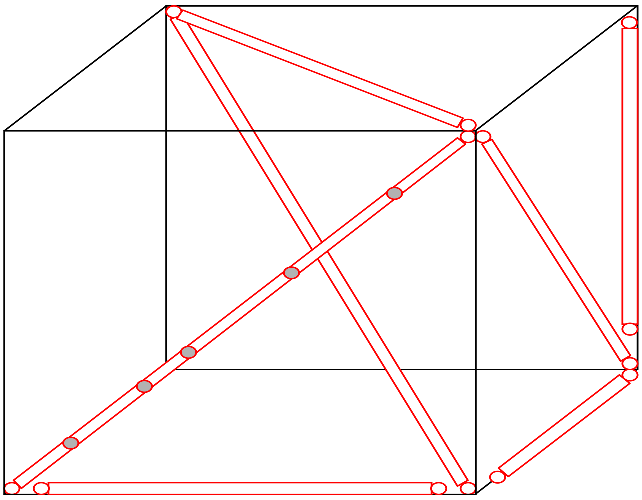

Figure 4. Recommended arrangement of measuring lines (from LUHMANN & WENDT, 2000)

At least five calibrated distances are placed on each measuring line. . The calibrated length between signalized points is compared with the distances calculated with photogrammetry. The differences between measured and calibrated length are the length measurement errors. The maximum permitted length-measurement error in the calibration volume is the criterion for the quality of the calibrated measurement system. Further details regarding the setup of the testfield and the execution of the measurements can be found in the VDI/VDE standard (VDI/VDE, 2002).

The testfield that was used for the study presented here is installed at AICON 3D Systems in Brunswick, Germany (Fig. 5). It contains 173 circular target points, 33 of which were placed on seven calibrated scale bars. The length-measurement errors are based on 58 calibrated distances.

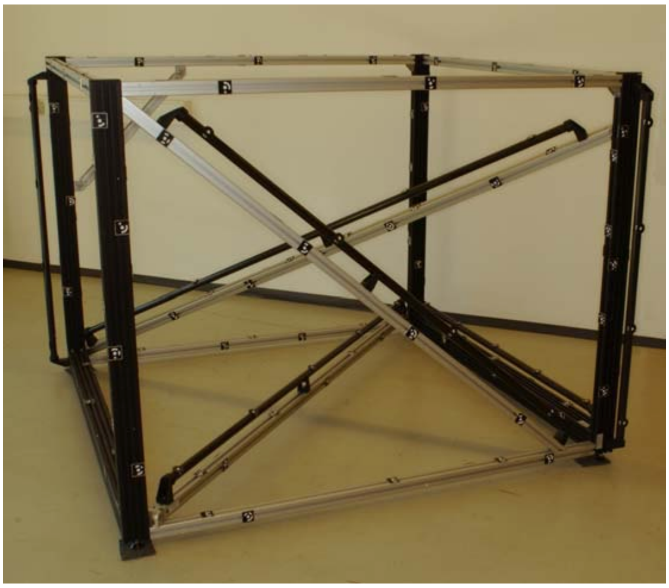

Figure 5. Testfield at AICON 3D Systems, Brunswick, Germany

3.2 Image acquisition and analysis

Moving around the test volume, 91 images were taken at room temperature. The camera was rotated about the optical axis several times to assure correct determination of the parameters of interior orientation. A Schneider Apo-Digitar 5.6/35 mm XL with Copal 0 shutter (Fig. 2) was mounted on an ALPA 12 WA (Fig. 1) for the tests. Images were recorded with a Leaf Valeo 22 Wi digital camera back tethered to a notebook computer. The diagonal angle of view of the lens was 79°, resembling the equivalent of a 24/25 mm wide angle lens on a 35 mm format camera. The focus distance was fixed to 2 m, the aperture was stopped down to a value of 11; exposure time was set to 1 s. The camera was operated from a tripod. The sensor was set to 25 ISO. The raw images were converted in Leaf software without sharpening. The calibration was calculated with DPA Pro bund block-adjustment software by AICON. The average image scale was 1: 95. The system was fixed with a single-scale distance that was placed at the center of the test volume.

4 Results

The parameters of the interior orientation (camera constant, coordinates of the principal point), radial-symmetric and tangential lens distortion, as well as affinity and shear were calculated in bundle block adjustment. Camera constant and the position of the principal changed significantly between images in this simultaneous calibration. Therefore, the adjustment was calculated with varying interior orientation of the images. The position of the principal point ranged by ±1.5 pixel on the sensor. The most significant variation can be observed when the camera was rotated around the optical axis. For the last 53 images the camera was not rotated and the position of the principal point varied by just ±0.5 pixel. The camera constant ranged by ±1.2 pixel. The maximum radial-symmetric distortion in the corner of the image was less than 0.1 mm (Fig. 6).

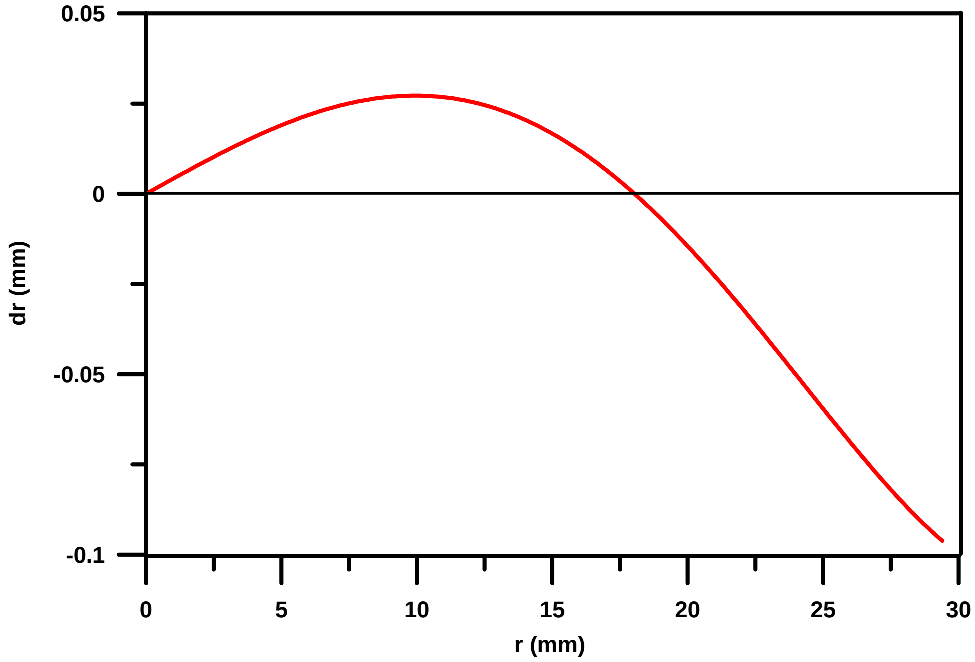

Figure 6. Radial-symmetric lens distortion (dr) of the Schneider Apo-Digitar 5.6/35 mm XL lens plotted against the radial distance from the principal point (r)

The very good impression of image quality is reflected in the precision of image measurements (σ_0) of 0.24 µm, or 0.027 pixel, respectively. This is better than for other cameras tested under very similar conditions (PEIPE & YU, 2004). The length measurement errors in object space are also remarkable. They vary between -0.053 and +0.057 mm. The span of the length measurement errors is 0.110 mm. Without the additional parameters accounting for affinity and shear, the length measurement errors increase significantly.

Raw images were converted to TIFF format in Leaf software. Results of Leaf software are visibly better than converting raw images in Adobe Photoshop CS2. The precision of image measurements in images converted with Photoshop CS varies by ±0.2 µm compared to measurements taken in images converted with Leaf software. It has to be noted that the raw image conversion in Photoshop CS2 results in cropped images. All around the edges the images are cropped by 4 pixels.

5 Discussion and conclusion

The results of the bundle block adjustment reveal that the ALPA 12 WA in the tested version exhibits a high accuracy potential in object space. The varying interior orientation can be attributed to a large degree to a lack of stability in the mount of the digital back. The connection between digital back and camera appeared "shaky". Better results may be accomplished with a sturdier connection between camera and back. A more stable mount adapter is available for Mamiya 645 AFD and for Hasselblad H1 mounts. This adaption method will be used in further tests. This effort should help more fully to utilize the potential accuracy of the camera. Additional modifications to increase the potential accuracy include removal of the focussing rail in the lens to ensure that lens elements in the lens cannot move. These considerations are based on the assumption that the sensor position is fixed inside the digital back, is not expanding due to thermic effects, and that the mounting clamps of the ALPA yield a stable connection between camera body, lens and digital back.

While converting raw images in Photoshop CS2 software is faster than using the original software, optimum results in image quality and precision of point measurements can only be achieved with Leaf software.

A tethered camera like the one that was tested here is not practicable for industrial applications. A mobile hard disk can be fitted to the digital back to make it mobile. Best mobility of the camera without tripod support is offered by the newly available Leaf Aptus camera back. This back is designed for portable use, offers data-saving on compact flash cards. It features a 60 x 70 mm TFT display for control of the back, and checking of images on location. The image sensor in the Aptus back is the same as in the Valeo back that was presented here. The ISO rating of the Aptus excels the rating of the Valeo. ISO 400 can be selected and eases handheld use.

Additional tests with the ALPA 12 WA are planned to increase the accuracy in object space. Tests will be performed with different lenses and camera backs and for different applications. The modular design of the ALPA also allows using the camera for different photogrammetric tasks like terrestrial and airborne missions. These fields of use will be explored in further studies.

6 Acknowledgements

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7 Literature

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