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DIGITAL HIGH RESOLUTION STILL VIDEO CAMERA VERSUS FILM-BASED CAMERA IN PHOTOGRAMMETRIC INDUSTRIAL METROLOGY

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ABSTRACT

In this paper a digital high resolution still video camera DCS200 and a conventional film-based small format camera Leica R5 are compared. The image data used for the comparison were acquired during several pilot projects in a shipyard. The goal was the determination of 3-D co-ordinates of object points, which were signalised with retro-reflective targets, for dimensional checking and control in the ship building industry, as well as to test the suitability of the cameras for these applications. The image point measurements in the photos taken by the film-based camera were performed on an analytical plotter, while the digital image data were processed semi-automatically with digital photogrammetric methods. In addition, some of the analogue images were scanned and then also processed with digital photogrammetric methods. The results of simultaneous camera calibrations and 3-D point positioning are given, showing its accuracy potential, which turned out to be in the range of 1: 50,000 and 1: 75,000 for the DCS200 and up to 1: 27,000 for the Leica. Furthermore, some application-relevant handling issues are addressed.

1. INTRODUCTION

Automated or semi-automated digital close-range photogrammetric systems are very efficient and accurate tools for a number of measuring tasks in dimensional inspection, e.g. in large-scale manufacturing arenas of aircraft and aerospace vehicle assembly, in the car manufacturing and shipbuilding industries as well as in architecture. This paper focuses on practical investigations of two cameras often used in close-range photogrammetry, namely the digital high resolution still video camera Kodak DCS200 and the film-based small format SLR camera Leica R5, in applications of shipbuilding industry. The complexity of keeping an object of approximately 170 x 20 x 35 m^3 and 8,000 tons dimensionally stable over a construction period of two years demands 3-D positioning in a safe, accurate, reliable, repeatable, and cost effective manner *(Johnson, 1993)*. The flexibility, portability, and speed of close-range photogrammetric cameras allow image data acquisition without interruptions of production processes, which is an important cost saving aspect and consequently the essential key for the use of such systems in shipbuilding applications.

To be able to judge the functionality and performance of the two above mentioned camera systems in some typical applications, several pilot studies were conducted by the Institute of Geodesy and Photogrammetry, ETH Zurich, on the shipyard of Bath Iron Works Corporation (BIW), Maine, USA. The goal was the determination of 3-D co-ordinates of object points for dimensional checking and control of ship sections in order to improve and speed up the assembly of the sections in the shipbuilding production loop. Currently, dimensional checking and control through measurements is performed with theodolites and steel tapes before the final assembly procedure. This results in time and cost consuming efforts to postprocess ship sections for their adjustment.

Image data acquisition of four different objects with DCS200 and Leica R5 was performed in the shipyard under factory floor conditions, which means that an interruption of the production processes was not realistic and consequently disturbing effects like vibrations, lights of welding torches, temperature gradients, and temporal occlusions of measuring targets occurred. For the pilot studies conducted in the shipyard, a Kodak DCS200 was leased from a local photo shop. A high resolution still video camera is ideally suited for these tasks due to its independence on external power supply, frame grabbing and storage devices. While the CCD cameras typically used in digital close range photogrammetry or machine vision applications require a local host computer for image acquisition and storage, a still video camera provides a completely autonomous digital image acquisition system. The DCS200 is a camera mainly used for

Figure 1: Kodak DCS200mi still video camera

camera body:	Nikon 8008s
sensor:	1524 x 1012 full frame CCD, 14 mm x 9.3 mm, black-and-white
frame grabber:	in camera body
storage:	50 images, uncompressed, on harddisk in camera body
interface:	SCSI port
software:	Adobe Photoshop (Mac) / Aldus Photostyler (PC)
weight:	1.7 kg
power supply:	AC adaptor/charger
lens mount:	Nikon bayonet
lenses:	Nikkor 28 mm, Nikkor 18 mm

Table 1 : Technical data of the DCS200

publishing and relevant purposes and is of course not calibrated for metric applications. Investigations with this camera showed that relative object space measurement accuracy of 1: 50,000 *(van den Heuvel, 1993; Peipe et al., 1993)* 1: 80,000 *(Fraser and Shortis, 1994)*, and 1: 90,000 *(Bösemann et al., 1994)* can be achieved. As laboratory facilities or an exact calibration field were not available for the studies shown here, the camera had to be calibrated simultaneously by self-calibration methods, which yielded a relative accuracy in object space of 1: 40,000 for one of the described projects *(Maas and Kersten, 1994a)*.

In the following two sections the two cameras compared in this paper and the four pilot projects (called shell mocks, unit erection in the assembly shed and on the dock, and waveguide foundation) are described. Section 4 presents the image data acquisition, while in section 5 the results of the processing of DCS200 image data as well as analogue and scanned Leica images are given.

2. IMAGE DATA ACQUISITION DEVICE

2.1 Kodak DCS200 still video camera

The Kodak DCS200 consists of a modified Nikon 8008s camera body with a 1524 x 1012 pixel CCD sensor in the imaging plane. The camera is offered alternatively with a black-and-white or a colour CCD sensor; images can be stored on a 2 MB DRAM or optionally on a 80 MB internal harddisk, which offers storage capacity for 50 uncompressed images. The model used for these studies was the DCS200mi with a black-and-white sensor and internal 80 MB harddisk (Fig. 1). Table 1 summarises the technical specifications of this camera system. For image acquisition, Nikkor lenses 18 mm and 28 mm were used. Due to the reduced chip size the field of view of the Nikkor 18 mm lens corresponds to a 45 mm lens and the Nikkor 28 mm lens to a 70 mm lens of a normal SLR camera. The digital images were transferred from the internal camera harddisk into the computer via a SCSI interface. The software package Adobe Photoshop on a Macintosh computer allows image acquisition from the camera, standard pre-processing, and storage into different standard image formats.

2.2 SLR camera Leica R5

The used Leica R5 (Fig. 2) is an one-eye, small format (36 mm x 24 mm), full automatic SLR camera system equipped with automatic shutter and databack. For image acquisition, the Leica Elmarit 35 mm lens was used. Table 2 summarises the technical specifications of this camera. For the image data acquisition in the shipyard medium speed black and white negative films Ilford FP4 plus (ISO 125/22^0) were used.

2.3 Scanned image data

The Leica negatives from three of the projects were scanned with the desktop publishing scanner Agfa Horizon. *Baltsavias (1993)* describes the scanner and reports on some tests and experiences with the Agfa Horizon. The negatives were scanned with a resolution of 1200 dpi, which correspond to pixel size of 21 microns. The size of a scanned image was 1700 x 1134 pixels and thus comparable to the image size of the DCS200.

Figure 2: SLR camera Leica R5 with databack

camera body:	Leica R5
sensor:	36 mm x 24 mm
réseau:	7 x 5 grid
exposure time:	15 s - 1/2000 s
film:	ISO 12/12^0 - ISO 3200/36^0
weight:	0.625 kg
power supply:	battery
lens mount:	Leica R-bayonet
lens:	Leica Elmarit 1:2.8/35 mm

Table 2: Technical data of the Leica R5

3. PILOT PROJECTS

The use of close-range photogrammetry in shipbuilding applications as described in the following should shorten the time for final dimensional checking and improve data consistency. The four pilot projects dealt with the 3-D positioning of signalised targets and can be considered representative of shipbuilding applications.

- Project 1: Shell mocks (Fig. 3) are steel forms comprised of 5 to 8 plates that have a pre-designed and pre-cut shape. Each plate is secured vertically with bolts to a support structure comprised of an angle bar and I beams. Together, this forms a mold for the required shape of the steel assembly to be built. In this project, the Z-co-ordinate at the end of each form plate is of particular interest and should be determined with an accuracy of 1/8 inch. The object dimensions are approx. 3 m in width, 10 m in depth and 2 m in height.
- Project 2: Unit erection in the assembly shed is a module of approximately 25 x 12 x 6 m^3, illustrated in Fig. 4. In this figure one can witness the disturbing effects in the illumination caused by welding torches and other sources. For this ship section 3-D point positioning with an accuracy of 1/16 inch is requested.
- Project 3: Ship modules which come from the assembly shed need to be fitted on the dock into the ships existing structure. The unit erection from the assembly shed need to be fitted to the vertical part of the unit erection on the dock (Fig. 5). An accurate interfacing requires again accurate 3-D point positioning as it is requested for the unit erection in the assembly shed. This module has the dimensions of 25 m x 7 m with a small depth extension.
- Project 4: The waveguide foundation (Fig. 6) in the machine shop is a welded steel assembly (dimensions 4.0 x 1.7 x 0.1 m) with machined surfaces, and a combination of drilled and tapped holes. In this project, the smoothness of the surfaces, which were targeted with four signals in the corners, should be determined with an accuracy of 0.03 inch.

4. IMAGE DATA ACQUISITION

The functionality of the DCS200 is equivalent to the handling of a modern automatic SLR camera like the Leica R5. The user can select between a manual mode and several automatic or semi-automatic exposure programs. For these photogrammetric applications autofocus was switched off. As mentioned above, retro-reflective targets were used in all described applications; they gave sufficient light and allowed the

Figure 3: Part of a scanned Leica photo of the shell mocks (Project 1)

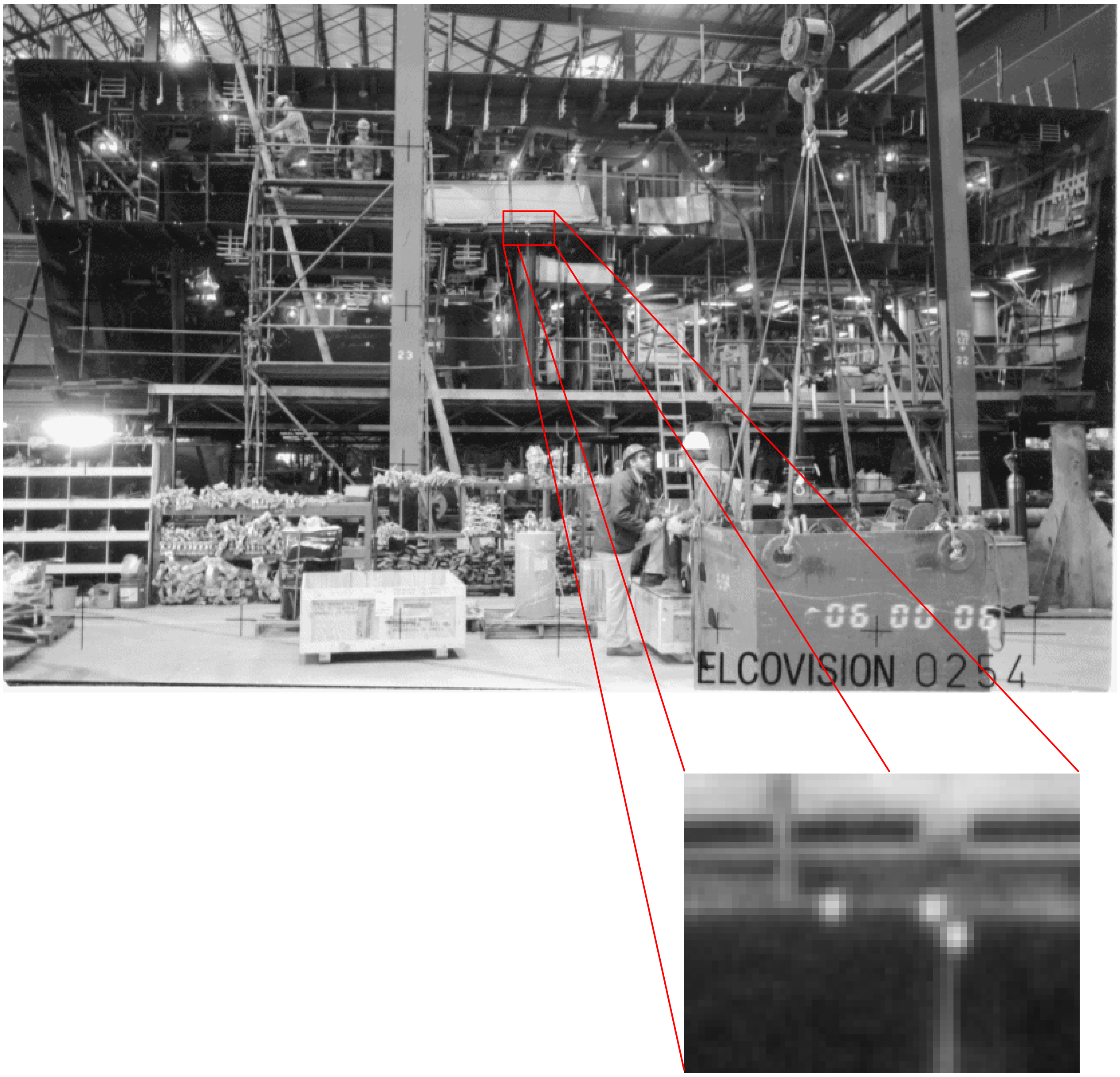

Figure 4: Unit erection in the assembly shed: scanned Leica R5 image (above), zoomed detail with three retro-targets (right)

use of small iris, so that the camera could be permanently focused on infinity. A standard Nikon flash performed well in illuminating the retro-reflective targets. The proper exposure settings for the imaging of retro-reflective targets, which should neither be overexposed nor appear too dark in the digital images, cannot be solved by the automatic exposure programs and require some experience (this applies also for the use of photographic systems).
For the Leica images, the retro-reflective targets, whose size was designed for use in combination with DCS200, were illuminated by a powerful light (500 watt) instead of a flash. Additionally, this light provided the illumination of the object. The retro-reflective targets should not appear as bright points in the dark image, because the réseau grid of the Leica should be visible to guarantee a transformation of the measured machine co-ordinates into the image co-ordinate system afterwards for data processing and reduction. Thus, illumination and exposure time must be chosen in a way that both targets and réseau grid become visible in the image. This problem can be circumvented if a pre-illumination of the réseau grid is used similarly to Rolleiflex 6008 metric *(Suilmann, 1992)*. Contrary to DCS200 the proper exposure settings were given by the automatic exposure program. To keep the calibration of the camera as stable as possible during the data acquisition period, both Leica R5 and DCS200 were permanently focused on infinity.

Figure 5: The unit erection on the dock with retro-reflective targets on the facade

To compensate for occlusions and to warrant a strong network geometry for the simultaneous calibration of both cameras, some additional images with panned or rotated camera axis were taken in Project 1 and 2. These camera configurations for both projects are described in *Maas and Kersten (1994a)*. Moreover, restricted room conditions did not allow to cover the whole object in each image.

- For shell mocks (Project 1) a total number of 8 (DCS200) resp. 11 (Leica) images (including some images with panned or rotated camera axis) were taken from five camera stations. The points were signalised with targets of size between 5 and 20 mm depending on the distance between object point and camera.
- Unit erection in the assembly shed (Project 2) was imaged from 7 stations, which yielded 32 images (including some images with panned or rotated camera axis) of DCS200 (28 mm lens) and 7 images of Leica. Because of the large number of images taken with the Nikkor 28 mm lens (due to the restricted room conditions in the assembly shed), the object was later also imaged using a Nikkor 18 mm lens from 5 stations on the ground, yielding 19 images in total including rotated images for simultaneous calibration. The target size of the signalised points was 20 mm for Project 2 as well as for Project 3.
- Unit erection on the dock (Project 3) was imaged from 11 stations with Leica, 2 camera stations on the deck and 9 in the bucket of a movable crane positioned between 10 m and 33 m above the deck. Rotated images for self-calibration were not acquired; instead, calibration parameters from former adjustments were used. For the processing of the DCS data (28 mm lens), 9 acquired images from 6 stations were used, while 14 Leica images from all 11 stations were processed.
- The waveguide foundation (Project 4) was imaged from 3 (DCS200) resp. 4 (Leica) stations. To cover the object, panned exposures were necessary for both cameras. In total, 9 resp. 10 images were acquired with each camera. The target size of signalised points was 5 mm.

5. RESULTS

The digital image data of DCS200 and the scanned images of Leica were processed semi-automatically with digital photogrammetric methods using the data processing system described in *Maas and Kersten (1994b)*. For the digital images of DCS200, image co-ordinates of signalised points were determined by least squares matching or by a centroid operator; for those images which were well suited for the centroid operator (i.e. images with uniform dark background, which is often the case in applications with retro-reflective targets) no significant differences could be found between the results of least squares matching and centroid operator.

In the scanned negatives, crosses of the réseau grid were measured by least squares matching. Due to the

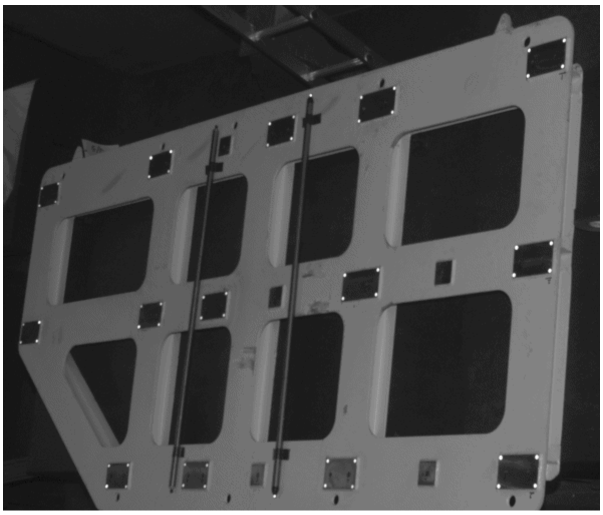

Figure 6: Waveguide foundation with retro-reflective targets (DCS200)

Project	**Object dimension [m]**	**Camera**	**Lens [mm]**	**Data type**	**Images**	**Points**	**σ_0 [µm]**	**Precision from adjustment**				
								Object space [mm]			**Image space [µm]**	
								σ_X	σ_Y	σ_Z	σ_x	σ_y
1	**3 x 10 x 2**	**DCS200**	**28**	**digital**	**8**	**20**	**0.47**	**1.03**	**3.64**	**0.27**	**0.36**	**0.37**
		Leica	**35**	**analog**	**11**	**20**	**2.97**	**0.64**	**3.21**	**0.41**	**2.45**	**2.44**
		Leica	**35**	**scan**	**9**	**19**	**5.68**	**2.07**	**9.20**	**1.17**	**4.31**	**4.81**
2	**25 x 12 x 6**	**DCS200**	**28**	**digital**	**32**	**37**	**0.50**	**0.47**	**1.47**	**0.37**	**0.42**	**0.38**
		DCS200	**18**	**digital**	**19**	**33**	**0.44**	**0.39**	**1.24**	**0.39**	**0.41**	**0.35**
		Leica	**35**	**analog**	**7**	**43**	**1.98**	**0.80**	**1.84**	**0.63**	**1.44**	**1.83**
		Leica	**35**	**scan**	**7**	**44**	**5.01**	**2.27**	**5.16**	**1.80**	**3.71**	**4.36**
3	**25 x 7**	**DCS200**	**28**	**digital**	**9**	**22**	**0.45**	**0.46**	**1.80**	**0.34**	**0.31**	**0.38**
		Leica	**35**	**analog**	**14**	**22**	**2.06**	**0.75**	**1.54**	**0.81**	**1.71**	**1.73**
4	**4.0 x 1.7**	**DCS200**	**28**	**digital**	**9**	**54**	**0.59**	**0.05**	**0.06**	**0.09**	**0.49**	**0.50**
		Leica	**35**	**analog**	**10**	**54**	**5.18**	**0.21**	**0.21**	**0.31**	**4.52**	**4.55**
		Leica	**35**	**scan**	**5**	**53**	**5.33**	**0.33**	**0.32**	**0.47**	**3.92**	**4.26**

σ_0 Standard deviation of the bundle adjustment a posteriori

σ_{XYZ} Theoretical precision in object space

σ_{xy} RMS in image space

Table 3: Results of 3-D point positioning in four typical shipbuilding applications

insufficient reflections of retro-targets in the scanned Leica images, most of the targets were measured manually. This means no automation and less accuracy in the measurement procedure. Additionally, for most projects the target size in these scanned images was too small and the contrast around the retro-targets was too weak.

Measurement in Leica negatives were performed on the analytical plotter Leica AC3. Due to the higher resolution of the negatives the targets were imaged too large (up to 2 times the size of the largest measuring mark) to perform accurate measurements on the analytical plotter. The measured machine co-ordinates of the Leica image data were transformed into image co-ordinates by an affine transformation using réseau grid points; camera orientation, object co-ordinates and, if self-calibration was requested, additional parameters were determined simultaneously by bundle adjustment.

The calibration of DCS200 (28 mm and 18 mm lens) with image data of Project 1 and 2 was described in *Maas and Kersten (1994a)*. In the self-calibrating bundle adjustment, a set of 9 additional parameters *(Brown, 1971)* was determined. This set includes the location of the principal point, the camera constant, a scale factor in x, a shear, two parameters for radial symmetric distortion (k_1, k_2) and two parameters for decentering distortion (p_1, p_2). To process data of Project 3 and 4 additional parameters derived from a joint calibration with DCS200 image data of all four projects, were used. Leica R5 was also calibrated using the image data of all four projects. Due to additional systematic errors introduced during scanning, Leica R5 was separately calibrated with the scanned images of three projects. The determined additional parameters were also used to process data from the scanned images.

The results of the 3-D point positioning in all four projects are summarised in Table 3. For the first three projects a redundant datum was fixed on three control points, while for the waveguide foundation four control points were used. In these four applications the aposteriori standard deviation of unit weight σ_0 of the bundle adjustment was between 0.44 µm and 0.59 µm for DCS200, which corresponds to approximately 1/20th of the camera pixel spacing. For the analogue Leica images was between 2 µm and 6 µm. The limitation for the accuracy of the Leica was given by the réseau grid accuracy of 2 µm and by the measurement accuracy of the AC3 of 1-2 µm. Measurements in scanned image data yielded an accuracy of approximately 1/4th of the pixel size (21 µm). For all pilot projects the accuracy which was achieved with both cameras (DCS200 and Leica analogue) was much better than the precision requirements of the shipbuilder, while the scanned Leica images did not always meet these requirements. It has to be stated that these results were obtained under factory floor conditions, where environmental conditions could not be controlled and ideal target distributions, illumination, and network configuration could not be achieved. In these investigations a relative accuracy in object space of up to 1: 75,000 was achieved with DCS200. This compares well to the aforementioned results of van den Heuvel (1993), Peipe et al. (1993), Fraser and Shortis (1994), and Bösemann et al. (1994). The relative accuracy in object space of 1: 75,000, which was achieved in Project 4 (waveguide foundation) with DCS200, might even be increased with more images from additional camera stations.

Due to the aforementioned conditions concerning target size and contrast, the precision from adjustment in object space which was obtained with Leica is worse by a factor of 1.4 to 2.0 than the precision achieved with DCS200, except for Project 1.

6. CONCLUSIONS

The results and experiences of these shipbuilding applications demonstrate that photogrammetric close-range systems with their flexibility, portability, and data acquisition speed can guarantee 3-D positioning in a safe, accurate, reliable, and cost effective manner for dimensional checking and control of ship sections. Especially the DCS200 high resolution still video CCD camera has proved to be very well suited for applications in digital close range photogrammetry. As an autonomous image acquisition system including camera, A/D conversion, data storage and power supply it offers a high flexibility and easy handling, especially for outdoor or factory floor applications. A in a bundle adjustment of 1/20th pixel in image space and a relative precision in object space of up to 1: 75,000 for the DCS200 under factory floor conditions can be regarded as good accuracy. Further examinations under laboratory conditions should be performed to show the real accuracy potential of DCS200. The advantage of this camera system compared to the film-based Leica camera is the direct control of acquired images, the degree of automation in consecutive data processing, and the superior accuracy. For an accurate and semi-automatic processing of scanned images by digital photogrammetric methods, larger targets for the signalised points than those used for DCS200 and Leica, strong contrast around the targets, and a well illuminated respectively imaged réseau must be provided.

Due to the aforementioned advantages, the use of the DCS200 for applications in industrial metrology can be highly recommended.

7. ACKNOWLEDGEMENT

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REFERENCES:

BALTSAVIAS, E. P., 1993: Evaluation of DTP Scanners - A Case Study with the AGFA Horizon. *Proceedings of ISPRS Commission I Workshop “Digital Sensors and Systems”*, Trento, Italy, June 21-25.

BÖSEMANN, W., PEIPE, J., SCHNEIDER, C.-TH., 1994: Zur Anwendung von Still Video Kameras in der Digitalen Nahbereichsphotogrammetrie. *Zeitschrift für Photogrammetrie und Fernerkundung*, No. 3/94, pp. 90-96.

BROWN, D., 1971: Close-Range Camera Calibration. *Photogrammetric Engineering*, Vol. 37, No. 8.

FRASER, C. S., SHORTIS, M. R., 1994: Vision Metrology in Industrial Inspection: A Practical Evaluation. *Int. Arch. of Photogrammetry and Remote Sensing*, Vol. XXX, Part 5, Commission V, Melbourne, Australia, March 1-4, pp. 87-91.

VAN DEN HEUVEL, F., 1993: Automated 3-D Measurement with the DCS200 Digital Camera. *Proceedings of 2nd Conference on Optical 3-D Measurement Techniques (Eds. Gruen/Kahmen)*, Zurich, October 4-7, pp. 63-71.

JOHNSON, G. W., 1993: Digital Photogrammetry - A New Shipbuilding Tool. *Unpublished BIW Report*, Bath, Maine, USA, December.

MAAS, H.-G., KERSTEN, TH., 1994a: Experiences with a High Resolution Still Video Camera in Digital Photogrammetric Applications on a Shipyard. *Int. Arch. of Photogrammetry and Remote Sensing*, Vol. XXX, Part 5, Commission V, Melbourne, Australia, March 1-4, pp. 250-255.

MAAS, H.-G., KERSTEN, TH., 1994b: Digitale Nahbereichsphotogrammetrie bei der Endmontage im Schiffsbau. *Zeitschrift für Photogrammetrie und Fernerkundung*, No. 3/94, pp. 96-102.

PEIPE, J., SCHNEIDER, C.-TH., SINNREICH, K., 1993: Digital Photogrammetric Station DPA - A Measurement System for Close Range Photogrammetry. *Proceedings of 2nd Conference on Optical 3-D Measurement Techniques (Eds. Gruen/Kahmen)*, Zurich, October 4-7, pp. 292-300.

SUILMANN, G., 1992: Rolleiflex 6008 metric - A New Camera for Industrial Photogrammetry. *Int. Arch. of Photogrammetry and Remote Sensing*, Vol. XXIX, Part B5, Commission V, Washington D.C., USA, August 2-14, pp. 60-63.