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GEOMETRIC ASSESSMENT OF THE KODAK DCS PRO BACK

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Abstract

This paper reports on an investigation into the suitability of the Kodak DCS Pro Back for use in close range photogrammetric measurement. The camera back, being used in conjunction with a medium-format non-metric camera, has been assessed with a view to using it for low- to medium-order photogrammetric work in architectural recording. Examinations centred upon the stability of the camera back with respect to the camera body and the effects of the removable infrared filter that is present immediately above the camera's focal plane. Ultimately the camera combination was deemed suitable for application in recording of this kind and is now in active use by the Metric Survey Team at English Heritage.

KEYWORDS: architectural recording, camera calibration, digital photogrammetry, Kodak DCS Pro Back

INTRODUCTION

DESIGNED for "advertising and catalogue photography, high-end portraiture and commercial applications, in the studio or on location" (Kodak, 2002a), the Kodak DCS Pro Back series is the latest in a line of digital camera system (DCS) technology that has caught the attention of the photogrammetric community. Starting with the release of the DCS 100 in 1991 (Henshall, 1993), the subsequent DCS 200 (Henshall, 1993), DCS 4xx (Henshall, 1994, 1995), 5xx (Henshall, 1998a,b), and more recent 6xx (Kodak, 2002b) and 7xx (Kodak, 2002c) cameras have been the subject of much photogrammetric research. Investigations have centred on the metric stability of the cameras (for example, Shortis et al., 1998; Ahmad and Chandler, 1999) together with their suitability for photogrammetric application through a variety of scales, ranging from close range industrial measurement with multi-station convergent imagery (for example, Peipe et al., 1993; Fraser and Shortis, 1995; Bürger and Busch, 2000) to aerial survey using a normal case stereoconfiguration (for example, Fraser and Shortis, 1995; Mason et al., 1997; Graham and Mills, 2000). With many modern digital cameras now having the potential to rival small-format film cameras in terms of frame size, applications that use the normal case stereoconfiguration are now much more feasible with such cameras (Mills et al., 2001). This is true not only for aerial survey, but also for many normal case close range applications (for example, Chandler et al., 2001) that have traditionally been the mainstay of film cameras.

Whilst contemporary digital camera backs, such as those reviewed by Peipe and Schneider (2002), have not captured the imagination of photogrammetrists in the same manner as the mainstream Kodak DCS cameras (see Godding and Woytowicz (1995) and Peipe (1995, 1997) for several examples of photogrammetric application), the potential for such instrumentation in photogrammetry is high now that the technology has matured. With such large-format digital camera technology now readily available at a reasonable cost, one area of photogrammetry where digital image acquisition has great potential for application is in architectural recording. With this in mind the English Heritage Metric Survey Team invested in a Kodak DCS Pro Back for use with their Mamiya RZ67 Pro II camera body in the summer of 2001. The DCS Pro Back consists of a 4080 × 4080 element CCD array that can be fitted to a variety of medium-format cameras (Kodak, 2002a). Bryan et al. (1999) and Clowes (2002) describe the types of low- to medium-order accuracy photogrammetric application (essentially rectified photography and orthophotography of historic sites) for which English Heritage would like the camera combination to be used. Before the camera could be used however, it was deemed necessary to conduct an investigation into its suitability for survey work of this nature.

CAMERA SPECIFICATION

The Kodak DCS Pro Back contains a 16 megapixel CCD sensor which, with square pixels of 9 μm, has a format size of 36·7 × 36·7 mm. The sensor generates 96 Mb, 12 bits per colour images that are recorded on an IBM microdrive. The camera can record one image every 2 s in burst mode, with up to four images being recorded before the camera records the data to the card. Whilst this is fast enough for close range photogrammetry, it does limit the camera in terms of airborne photogrammetric data capture (Graham and Mills, 2000).

The Mamiya RZ67 Pro II is a single-lens reflex, medium-format (60 × 70 mm) camera fitted with a Mamiya 90/3·5 W lens, leaf shutter and bellows focusing. The suitability of the Mamiya camera's non-metric lens and bellows focusing system was of obvious interest to this photogrammetric assessment. An additional concern related to the fact that the DCS back is connected to the Mamiya camera body via an interface plate produced by Kodak. This non-rigid relationship between the camera body and back is reminiscent of the older Kodak DCS cameras (Shortis and Beyer, 1997), and creates uncertainty in the stability of the camera. Indeed there is noticeable visible

FIG. 1. Kodak DCS Pro Back mounted onto the Mamiya RZ67 Pro II camera body.

movement between the body and the back when the camera is routinely handled. However, it was a desire of English Heritage that the DCS back should not be modified such that it became rigidly fixed to the Mamiya body, in order that it could be "hot-swapped" onto other camera bodies during fieldwork. The camera combination, weighing nearly 4 kg, can be seen in Fig. 1. Further details on the camera can be found in Kodak (2002a).

GEOMETRIC ASSESSMENT

Aims and Objectives

The overall aim of this project, jointly carried out between English Heritage, TU Dresden and the University of Newcastle upon Tyne, was to determine whether the Mamiya–DCS Pro Back camera combination described above was suitable for photogrammetric architectural recording, and could satisfy the type of survey work carried out on a day-to-day basis by English Heritage. Within this overall aim, the research reported in this paper has concentrated on the stability of the various camera calibration parameters with respect to the non-rigid camera body–back combination and the effects that the presence of a removable infrared filter, located directly above the CCD's focal plane, have on these parameters. In order to assess this, the camera has been subjected to a series of geometric tests based upon repeated self-calibrations.

Unfortunately time restraints on the project prohibited any investigation into the radiometric properties of the camera; however, findings of a separate study into the radiometric properties, together with a preliminary study into geometric behaviour, of a Kodak DCS Pro Back 645M (a variant of the DCS Pro Back series) are reported by Jantos et al. (2002).

Network Design

Fryer (1996) describes the factors that are critical in achieving a satisfactory result in a self-calibration. Amongst these factors he lists the geometrical arrangement of the camera stations, the intersection angles of rays from object points to cameras, the number of targeted points and the spread of these points across the image format. This research made use of an existing planar calibration field of 54 circular retro-reflective targets located on the end of the Cassie Building at the University of Newcastle upon Tyne (Mills, 1996). Whilst a planar test field is not ideal in terms of recovering the camera calibration parameters, the test field's close proximity (within 10 m) to an adjacent building that provided access to a second-floor balcony afforded a good convergent network geometry that satisfied all of Fryer's criteria.

Whilst Fraser (1996) describes the design stages in achieving optimum network geometry, this research adopted a heuristic approach to network design. This developed from the need to standardise on a minimal number of images that were to be used in each calibration. Minimising the number of images was deemed necessary due to the large number of calibrations being carried out—the capture, download, formatting and processing of the imagery was considerably time consuming and undertaking this with more images than was absolutely necessary was too demanding.

For the tests described here, six different camera positions were adopted, three from ground level and three from the second-floor balcony, 7 m above ground level (Fig. 2). Three images were taken at every position, at 0°, −90° and 90° roll angles (180° roll was not easily achievable due to the weight of the camera), providing 18 possible images per calibration set. Imagery was imported into the processing computer via the camera's PCMCIA adaptor and converted to grey scale before being processed in the vision measurement system (VMS) software developed by Shortis (University of Melbourne) and Robson (UCL). A block invariant (Fryer, 1996) self-calibration was performed for each set of images, with parameters determined for the principal distance (f), principal point offset (p_1 and p_2), radial distortion (k_1 and k_2), tangential distortion (t_1 and t_2) and affinity (a). The calibration process was repeated 16 times, with one image systematically removed each time until only three images remained (see Table I). The focal length was kept constant throughout the tests by fixing the bellows focusing system to its rearmost position.

Fig. 3 shows the precision of the principal distance and principal point offset values for each calibration. The calibration failed at three images due to an insufficient number of images to solve for the calibration parameters (although a solution may have been possible had one of the exposures been made with the camera in a rolled position). Examination of Fig. 3 reveals, as expected, that there is a falloff in the precision of the derived values as the number of images is reduced. However, up until eight images in the network the rate of falloff is small, after which the precision of the solution tails off considerably. Fig. 4 shows the same data for 18–8 images with an

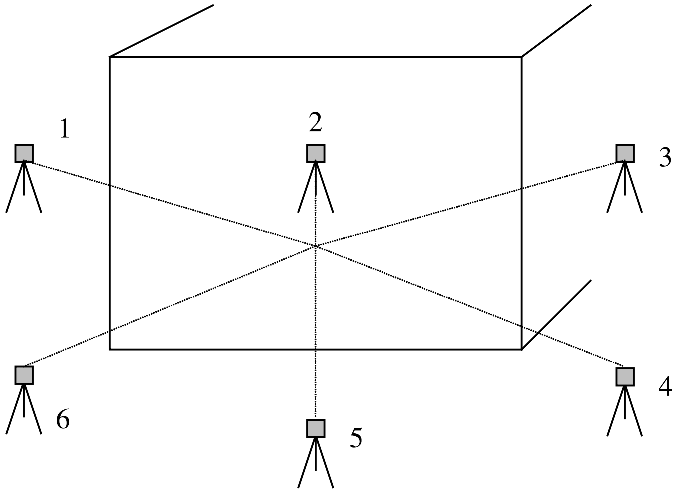

FIG. 2. Relative positions of the camera stations used in the calibration network.

TABLE I. Scheme for decreasing the number of images in the calibration network. A black spot indicates that the image was used in the network.

	Camera station (roll angle 0°, 90° and −90°)																	
Number of images	*1*			*2*			*3*			*4*			*5*			*6*		
18	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
17	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
16	●	○	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●
15	●	○	●	●	●	●	●	●	○	●	●	○	●	●	●	●	●	●
14	●	○	●	●	●	●	●	●	○	●	●	○	●	●	●	●	○	●
13	●	○	●	●	○	●	●	●	○	●	●	○	●	●	●	●	○	●
12	●	○	●	●	○	●	●	●	○	●	●	○	●	●	○	●	○	●
11	●	○	○	●	○	●	●	●	○	●	●	○	●	●	○	●	○	●
10	●	○	○	●	○	●	●	●	○	●	○	○	●	●	○	●	○	●
9	●	○	○	●	○	●	●	○	○	●	○	○	●	●	○	●	○	●
8	●	○	○	●	○	●	●	○	○	●	○	○	●	●	○	●	○	○
7	●	○	○	●	○	○	●	○	○	●	○	○	●	●	○	●	○	○
6	●	○	○	●	○	○	●	○	○	●	○	○	●	○	○	●	○	○
5	●	○	○	○	○	○	●	○	○	●	○	○	●	○	○	●	○	○
4	●	○	○	○	○	○	●	○	○	●	○	○	○	○	○	●	○	○
3	○	○	○	○	○	○	●	○	○	●	○	○	○	○	○	●	○	○

enlarged y axis scale. A network configuration of 8 images exhibits standard errors of approximately twice that for 18 images (see Fig. 4), yet can be processed in a considerably quicker timeframe.

It could therefore be deemed necessary to use only eight images in each calibration and achieve a satisfactory result. However, the precision of the solution is not simply a function of the number of images used but also the number of exposures taken with the camera rolled and the position of the camera stations. Therefore, prior to

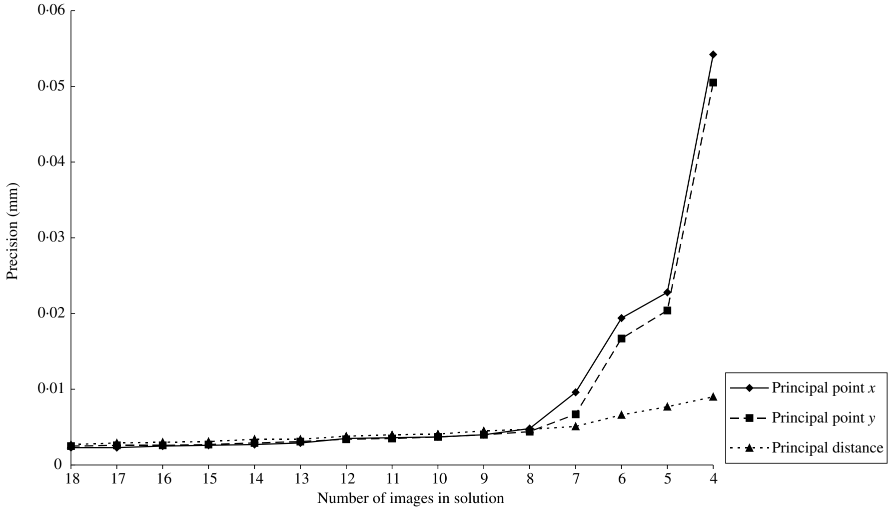

FIG. 3. Precision of calibrated values p_1, p_2 and f plotted against the number of images used in the solution.

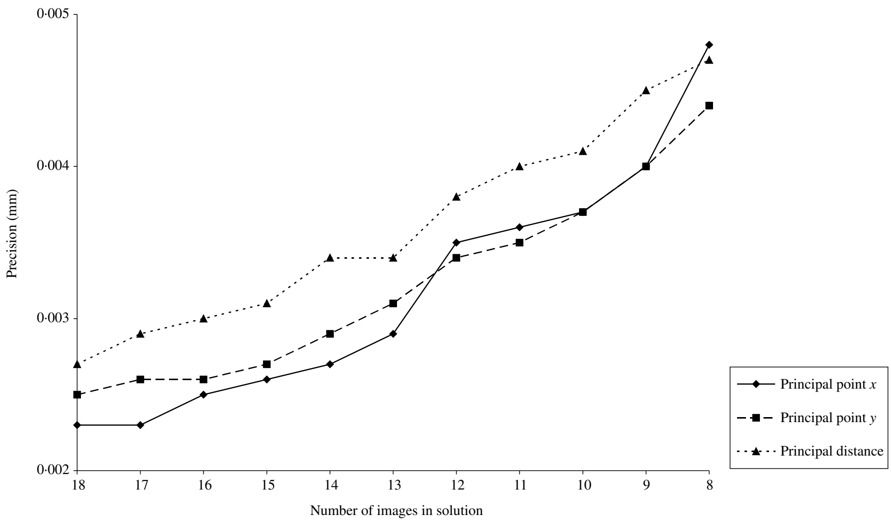

FIG. 4. Precision of calibrated values p_1, p_2 and f plotted against the number of images used in the solution (adjusted y axis scale).

embarking on tests to determine the stability of the camera, a second preliminary investigation was carried out in order to determine the optimum network of eight images according to the number of rolled exposures and number of different camera station positions. A further 20 calibrations were performed, each consisting of eight

TABLE II. Scheme for different image networks of eight images. A black spot indicates that the image was used in the network.

	Camera station (roll angle 0°, 90° and −90°)																	
Number of positions		*1*			*2*			*3*			*4*			*5*			*6*	
3	●	●	●	●	●	○	●	●	●	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○	●	●	●	●	●	○	●	●	●
	●	●	●	○	○	○	●	●	●	○	○	○	●	●	○	○	○	○
	○	○	○	●	●	○	○	○	○	●	●	●	○	○	○	●	●	●
4	●	○	○	●	●	●	●	○	○	○	○	○	●	●	●	○	○	○
	○	○	○	●	●	●	○	○	○	●	○	○	●	●	●	●	○	○
	●	●	●	●	○	○	●	●	●	○	○	○	●	○	○	○	○	○
	○	○	○	●	○	○	○	○	○	●	●	●	●	○	○	●	●	●
4	●	○	●	○	○	○	●	●	○	●	●	○	○	○	○	●	○	●
	●	○	●	●	●	○	○	○	○	●	●	○	●	○	●	○	○	○
	●	○	●	●	●	○	●	●	○	○	○	○	●	○	●	○	○	○
	○	○	○	●	○	●	○	○	○	●	●	○	●	●	○	●	○	●
5	●	○	●	●	○	●	●	●	○	●	○	○	○	○	○	●	○	○
	●	○	○	○	○	○	●	○	○	●	●	○	●	●	○	●	○	●
	●	○	●	○	○	○	●	●	○	●	○	○	●	●	○	●	○	○
	●	○	○	●	○	●	●	○	○	●	●	○	○	○	○	●	○	●
6	●	○	●	●	○	○	●	○	●	●	○	○	●	○	○	●	○	○
	●	○	○	●	○	○	●	○	○	●	●	○	●	○	○	●	○	●
	●	○	○	●	○	●	●	○	○	●	○	○	●	●	○	●	○	○
	○	○	●	●	○	●	○	●	○	○	●	○	●	●	○	○	○	●

images but with various network configurations, as shown in Table II. The precisions of f, p_1 and p_2 resulting from each of the solutions are shown in Fig. 5. With little to separate the different configurations visually, a trend line has been inserted in order to try to better understand the data. The principal point position appears to be better determined with fewer camera stations but more exposures at various roll angles, whilst the principal distance appears to behave inversely to this. These findings are consistent with Fryer (1996) who states that to successfully recover the principal point position "it is useful to roll the camera through 90°" and that "convergent photography is crucial in successful recovery of the principal distance if the object under consideration is planar". Therefore, in order to ensure a satisfactory solution, all further calibrations were performed with the 10-image network described in Table I. This provided a sensible compromise of convergent multi-station exposures taken with several roll angles yet could still be processed in a reasonable timeframe.

Principal Point Behaviour

The apparent movement of the DCS Pro Back relative to the Mamiya body was cause for some concern, and was therefore the first phenomenon to be investigated. In order to achieve this, repeated geometric calibrations were performed, with the camera system being reassembled between calibrations, and the resulting principal point positions (p_1 and p_2) compared against each other. Six sets of calibration images were captured, each consisting of 10 images. The data was then downloaded and the digital back was demounted from the Mamiya camera before being replaced and a further six sets of 10 images captured. This process took place six times, resulting in 36 sets of calibration images. Each data-set was processed, as before, using VMS and the

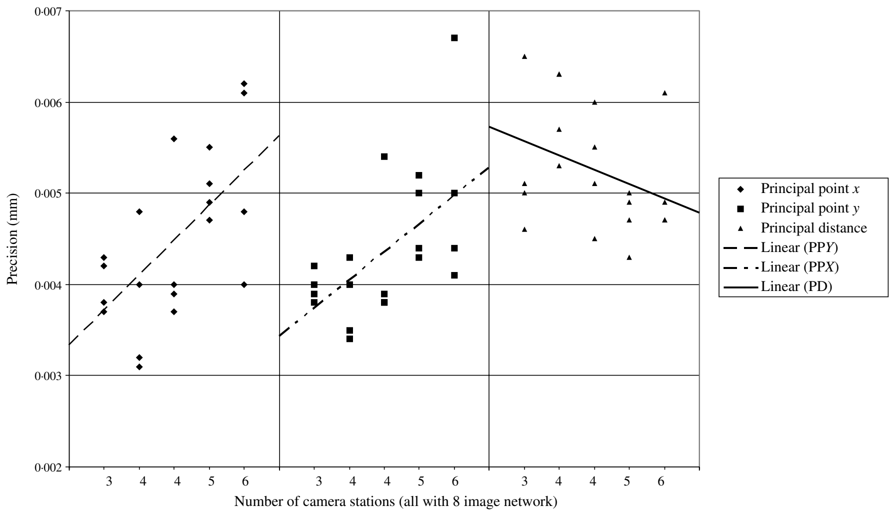

FIG. 5. Precision of calibrated values p_1, p_2 and f according to network scheme.

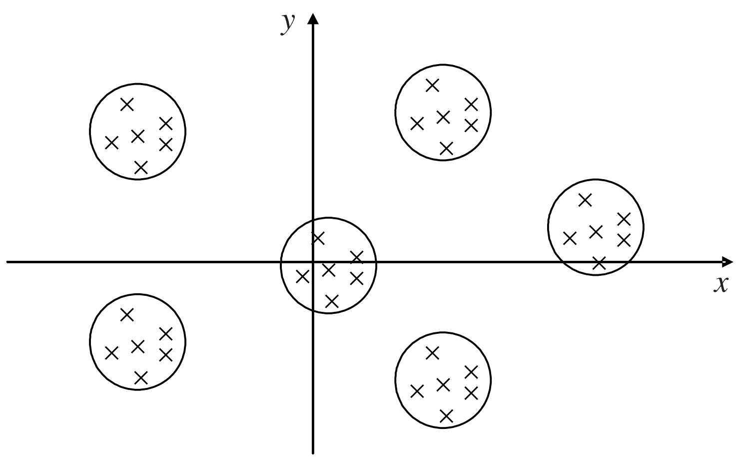

FIG. 6. Schematic graph of anticipated principal point positions for the 36 calibrations.

principal point positions examined. If, as was suspected, the camera back was moving on demounting of the back from the body, a pattern of principal point positions was anticipated along the lines of that illustrated in Fig. 6, that is, clustered groups of points for each individual set of calibrations.

Fig. 7 shows the determined positions of the principal points for each of the 36 calibrations. The results are biased in the positive direction, particularly in the x axis; however, this can be attributed to the way in which the DCS Pro Back is attached to the

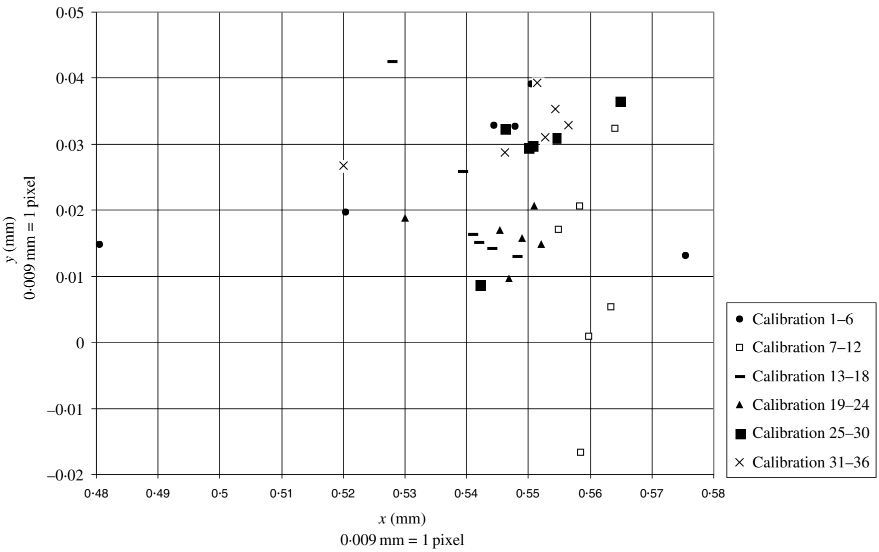

FIG. 7. Actual determined principal point positions for the 36 calibrations.

Mamiya body. Although not as distinct as the suggested scenario in Fig. 6, there is some visual evidence to suggest clustering of common calibrations (for example, calibrations 7–12 appear in a different area of the graph to 31–36 and so forth). Fig. 8 shows the mean position of the principal point for each of the six assumed clusters and their standard errors. In order to determine whether the differences between the mean principal points of the point clusters were significant, a hypothesis test was carried out. A two-tailed test, based on a *t*-distribution at the 5% significance level, was used with the test divided into *x* and *y* offset values. This would determine whether, for example, the mean *y* value of calibrations 1–6 was significantly different to the mean *y* value from calibrations 7–12, etc. This was performed for all possible combinations of the six mean positions, with the significantly different values being highlighted in Table III. Of the 30 possible combinations for the *x* and *y* coordinates, only six *x* values and five *y* values are significantly different from one another (a total of 18%). Moreover, with all but a few of the 36 determined point positions lying within a 4×4 pixel area, the movement of the principal point as a result of dismantling and rebuilding the camera would appear to be negligible.

Principal Distance Behaviour

The effect of removing the DCS Pro Back might, of course, affect other parameters as well as the principal point position, perhaps the most critical being the principal distance. Fig. 9 shows the calculated values of the 36 determined principal distances. The mean value of the 36 determined distances is 50·889 mm with a standard error of 0·019 mm, which would appear a reasonable value for such a parameter. As for the principal point offset, the mean value for each group of calibrations was determined

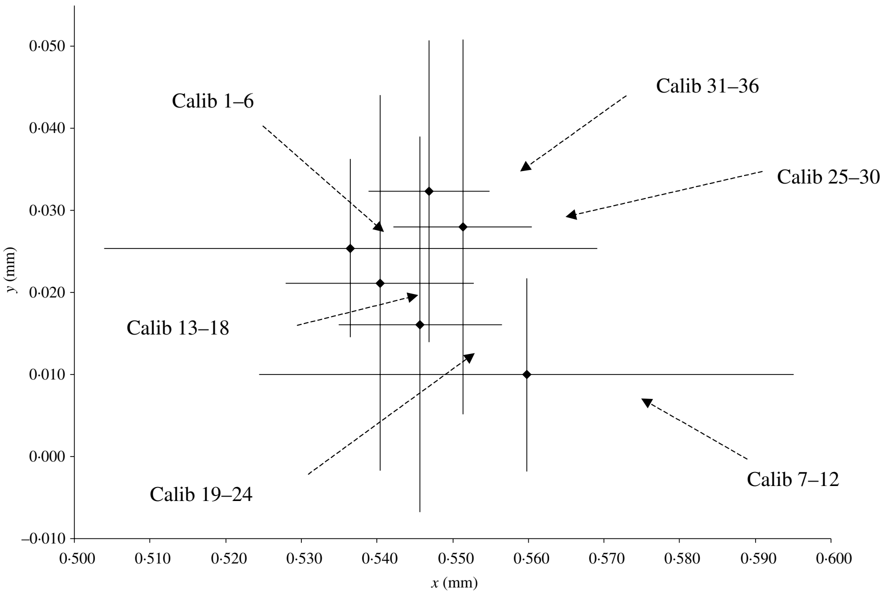

FIG. 8. Mean principal point positions and associated standard errors.

TABLE III. Significantly different combinations (indicated by *x*, by *y* or *x, y*) of the mean principal point coordinates.

	Calibration set					
Calibration set	*1–6*	*7–12*	*13–18*	*19–24*	*25–30*	*31–36*
1–6	–	*y*	○	○	○	○
7–12	*y*	–	○	○	*y*	*y*
13–18	○	*x*	–	○	○	○
19–24	○	*x*	○	–	○	○
25–30	*x*	○	*x*	○	–	○
31–36	*x*	*x, y*	○	○	○	–

(Fig. 10), and a *t*-test computed to check for significantly different mean values. Table IV illustrates the significantly different combinations (9 out of a possible 30, or 30%). With overriding issues relating to the stability of the bellows focusing system this value was also assumed to fall within the error budget of the camera.

Lens Distortion

Lens distortion coefficients for both radial (k_1 and k_2) and tangential distortion (t_1 and t_2), plus an affinity value (a), were determined in all 36 calibrations. The mean values for these parameters are given in Table V, with the radial distortion curve for the camera presented in Fig. 11. Again the parameters were checked for any significant differences and the results, with similar percentages of significant

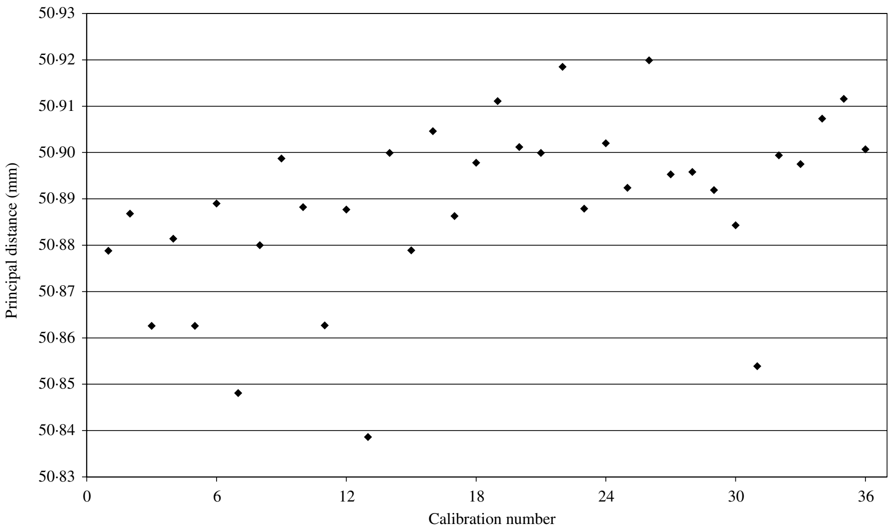

FIG. 9. Actual determined principal distance values for the 36 calibrations.

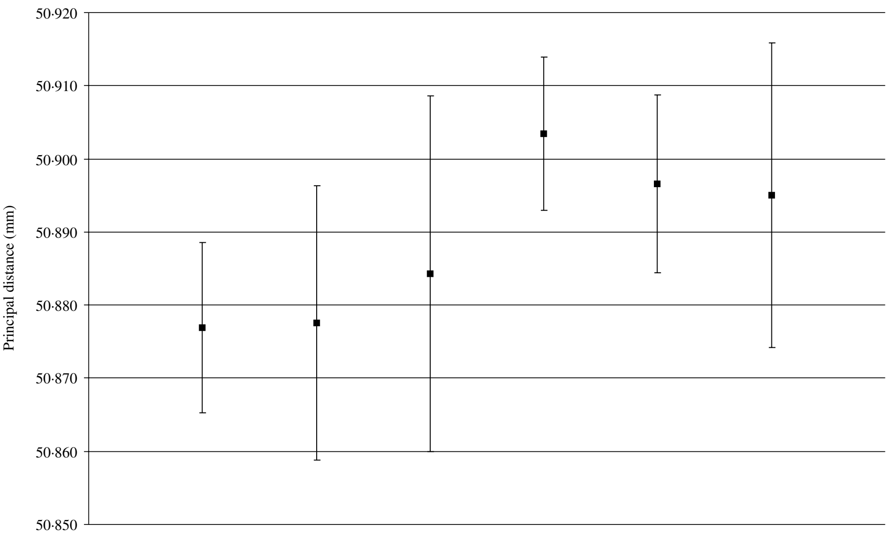

FIG. 10. Mean principal distance values and associated standard errors.

differences to those found for the principal point and principal distance, are presented in Table V.

Although containing significant distortion (41 pixels of displacement in the sensor corner), the radial distortion curve is to be expected since the lens used on the Mamiya is non-metric (Luhmann, 2000). Moreover, the standard error is small enough

TABLE IV. Significantly different combinations (indicated by a black spot) of the mean principal distance values.

Calibration set	1–6	7–12	13–18	19–24	25–30	31–36
1–6	–	○	○	•	•	•
7–12	○	–	○	•	○	○
13–18	○	○	–	○	○	○
19–24	•	•	•	–	○	○
25–30	•	•	○	○	–	○
31–36	○	○	○	○	○	–

TABLE V. Lens distortion coefficients and number of significant combinations for the Kodak DCS Pro Back and Mamiya camera.

	Radial distortion		*Tangential distortion*		*Affinity*
	k_1 *(m)*	k_2 *(m)*	t_1 *(m)*	t_2 *(m)*	*a (m)*
Mean value	$-3{\cdot}97 \times 10^{-5}$	$1{\cdot}50 \times 10^{-8}$	$-5{\cdot}67 \times 10^{-6}$	$7{\cdot}98 \times 10^{-6}$	$-0{\cdot}16 \times 10^{-4}$
Standard error	$0{\cdot}06 \times 10^{-5}$	$0{\cdot}09 \times 10^{-8}$	$0{\cdot}81 \times 10^{-6}$	$1{\cdot}32 \times 10^{-6}$	$1{\cdot}45 \times 10^{-4}$
No. of significant differences	2	12	9	7	8
Percentage of significant differences	7	40	30	23	27

to provide a sub-pixel precision when refining the coordinates of a point in the very corner of the frame (±0·6 pixel). Hence, provided a valid calibration is available and applied during measurement, the camera would appear suitable for the intended type of architectural recording work.

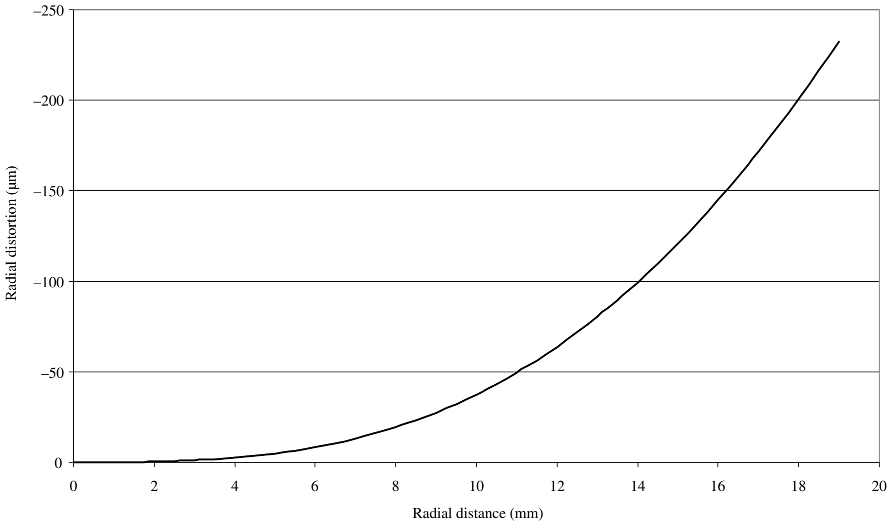

FIG. 11. Radial distortion curve for the Kodak DCS Pro Back and Mamiya camera under test.

Effect of the Infrared Filter

An interesting aspect of recent digital technology produced by Kodak has been the incorporation of infrared filters above the focal planes of the cameras. Investigations with a DCS 660 camera have highlighted significant image quality issues that are related to this when manually focusing the camera. One further investigation therefore centred on the effects of the presence of the filter on the determined camera calibration values. Twelve sets of 10 calibration images were taken with the filter present, and 12 without. Fig. 12 shows the positions of the principal point determined with and without the infrared filter present, and Fig. 13 the mean positions. A *t*-test performed on the mean values indicated a significant difference in both the x and y axes.

The infrared filter had an even more significant effect on the principal distance, with the mean value changing by 0·2 mm (Fig. 14). *t*-tests carried out on the other determined parameters revealed significant differences in the values determined for k_1 and t_2, although the other values (k_2, p_1 and a) showed no significant differences. Obviously these effects are only of relevance if the filter is removed after a calibration has been performed (in which case a hot mirror filter should really be used in order to eliminate any spurious infrared light from entering the camera), however, it should be kept in mind that calibration values vary depending on the presence or otherwise of different filters.

CONCLUSIONS

This paper has described the initial geometric testing of a Kodak DCS Pro Back used in conjunction with a Mamiya RZ67 Pro II medium-format camera prior

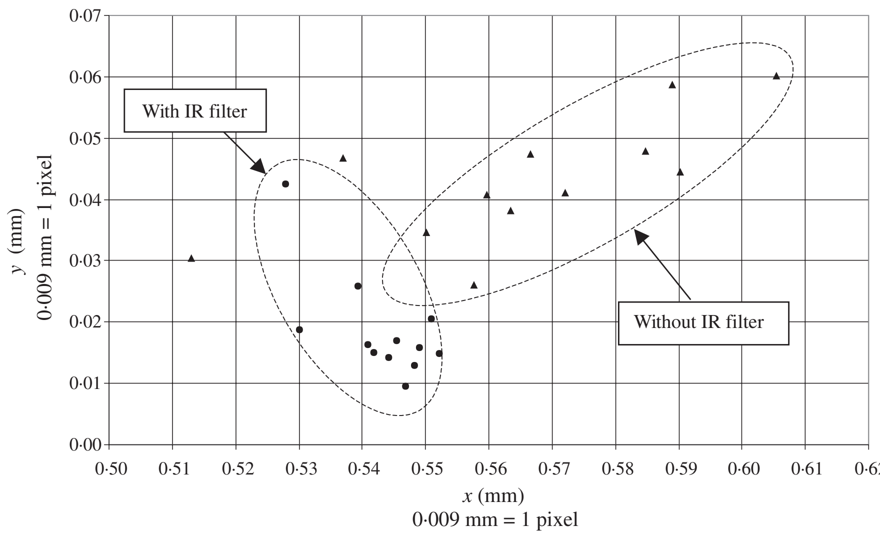

FIG. 12. Principal point positions with and without the infrared filter present.

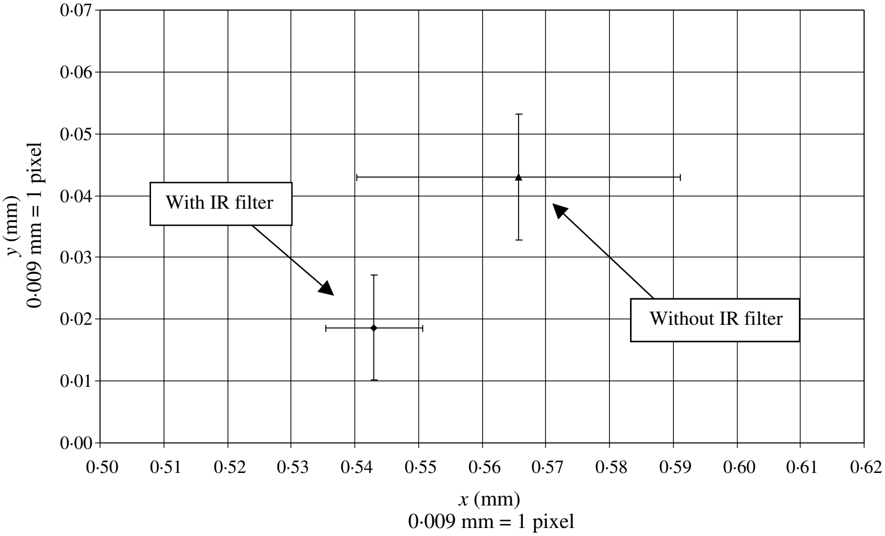

FIG. 13. Mean principal point positions, and associated standard errors, with and without the infrared filter present.

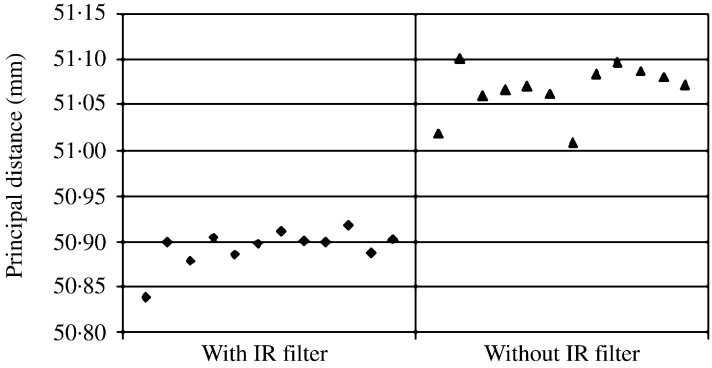

FIG. 14. Principal distance values with and without the infrared filter.

to its application in close range photogrammetry of low- to medium-order accuracy (namely architectural recording). Despite the high lens distortion values present in the non-metric lens, the presence of a removable infrared filter and an issue surrounding the unstable nature of the camera body and back combination, the camera was found to be suitable for use in photogrammetric measurement of this kind. However, modifications to the camera to minimise the apparent body–back movement would undoubtedly be necessary were it to be employed in high-precision vision metrology. The Kodak DCS Pro Back (now superseded by the Kodak DCS Pro Back Plus), with its 16 megapixel CCD sensor provides high-resolution imagery and is currently being used by English Heritage for photogrammetric architectural recording, with geometric recalibrations being carried out on a regular basis.

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Résumé

Cet article est un compte-rendu d'une recherche faite sur la Pro Back Kodak DCS pour savoir si on pouvait l'utiliser dans des déterminations photogrammétriques à courte distance. On a évalué le fond de cette caméra, elle-même reliée à une caméra non-métrique à moyen format, pour connaître ses possibilités dans des travaux de photogrammétrie architecturale qui ne soient pas de premier ordre. On a examiné la stabilité du fond de chambre par rapport au corps de la chambre et l'influence du filtre infrarouge amovible qui se trouve placé juste sur le plan focal de la caméra. On a finalement trouvé que cette caméra ainsi combinée convenait pour des travaux de ce genre et celle-ci est d'ailleurs maintenant d'un emploi courant par l'équipe des relevés métriques du Patrimoine anglais.

Zusammenfassung

Dieser Beitrag präsentiert eine Untersuchung über die Eignung eines Kodak DCS Pro Back in der Nahbereichsphotogrammetrie. Das Digitalrückteil wurde in Verbindung mit einer mittelformatigen, nichtmetrischen Kamera eingesetzt, und in Hinblick auf Projekte für die Architekturphotogrammetrie mit niedriger bis mittlerer Genauigkeit untersucht. Die Untersuchungen waren hauptsächlich auf die Stabilität des Digitalrückteils in Bezug auf den Kamerakörper ausgerichtet und auf die Effekte des abnehmbaren Infrarotfilters, das direkt über der Kamerafokalebene platziert ist. Letztendlich konnte die Kamerakombination als tauglich für Aufnahmen dieser Art erachtet werden und sie ist bei der Arbeitsgruppe für metrische Vermessung beim staatlichen Denkmalschutz im aktiven Einsatz.