FILM DEFORMATION IN NON METRIC CAMERAS UNDER WEAK GEOMETRIC CONDITIONS - AN UNCORRECTED DISASTER?

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Abstract:

Whilst multi-station bundle adjustments are almost universally applied to high precision photogrammetric surveys for engineering purposes, the use of often as few as two camera stations for less stringent architectural and archaeological surveys is common. The effect of in-camera deformations has been well documented in the former case, but for simpler geometric situations the effects and magnitudes of unmodelled distortions on the computed object space coordinates are less well documented.

Self compensating effects of in-camera deformation within a strong network adjustment are illustrated with reference to experiments carried out using a range of film type and camera back permutations. The number of camera stations contributing to the network was then reduced and a range of film deformation correction techniques applied. By comparing results from both series of adjustments the effect of network geometry and film deformation on the computed object space coordinates was investigated.

Results show that whilst root mean square object space discrepancies can vary minimally for adjustments incorporating differing film deformation corrections and a given network geometry, significant trends due to uncorrected film deformation can be present in the computed object space coordinates .

KEY WORDS: Accuracy, Calibration, Close-range, Film, Non-metric.

1.Introduction.

Photogrammetry is used to measure dimensions and positions of objects according to some reference system or datum. This analysis sets out to investigate the influence of photographic film deformation and its correction, based on reseau measurement, on the object space coordinates derived by photogrammetric adjustment.

The influences of un-modelled image deformations on derived object coordinates have been shown to be largely self compensating in strong network multi-station bundle adjustments (Fraser 1984, Wester-Ebbinghaus 1988). However, the majority of photogrammetric surveys intended for commercial purposes, for example architectural surveys, generally try to achieve photographic coverage of the object of interest using a minimum number of stereo pairs. This means that not only are any self compensating effects reduced, but also since there are fewer redundant measurements it is often difficult to determine the effects of unmodelled errors.

This paper draws upon results produced during a comprehensive series of close range calibrations in which a variety of medium format cameras were used. Format sizes range from 130 by 180mm to 60 by 60mm. The experimental work begins with the knowledge that in-plane film deformation has been minimised (Robson 1990) and that deformations occurring in the non-metric camera used are almost an order of magnitude greater than those attributed to in-plane film deformational factors.

2. Practical Approach.

The effectiveness of film deformation correction methods can be investigated by conducting a photogrammetric survey of an array of targets with known X,Y,Z object space coordinates. Target positions as estimated by any subsequent photogrammetric adjustment based on the same datum may be directly compared with the original target positions. Any differences in position introduced either by change in network configuration or by variation of film deformation correction can be assessed. The key problem associated with this method is to obtain initial X,Y,Z target coordinates at a greater level of precision than those estimated during the photogrammetric adjustments featuring network or film deformation correction changes.

This analysis is concerned primarily with object coordinate deformation in single stereopairs. One method of deriving X,Y,Z target coordinates of suitably high precision is to carry out a free photogrammetric adjustment of the same target array based on a strong network incorporating many photographs.

2.1 Test Field Design.

A test field was designed based on several factors; the imaging abilities of a Hasselblad SWC camera, namely a resolution of at least 50 l mm^{-1} over the complete format with Technical Pan 120 film; an image measurement magnification of 200X and 0.5 µm rms provided by the modified ZKM measuring microscope at the National Physical Laboratory (Oldfield 1986, Zeiss 1985) and; on the requirement of long term durability such that the calibration procedure could be repeated as required.

The final test field design consisted of 42 targets pinned into a concrete wall by countersunk titanium bars and several additional free standing targets for densification. The starting positions of these targets could then be derived by conventional survey to provide the 'free adjustment' datum. The predominantly 2D array was then photographed from convergent camera positions to simulate a 3D array, resulting in the geometrically strong network detailed in figure 1. To strengthen further the network and enable a more precise recovery of camera inner orientation parameters, additional photographs were taken with cameras rotated by 90 degrees about their optical axis.

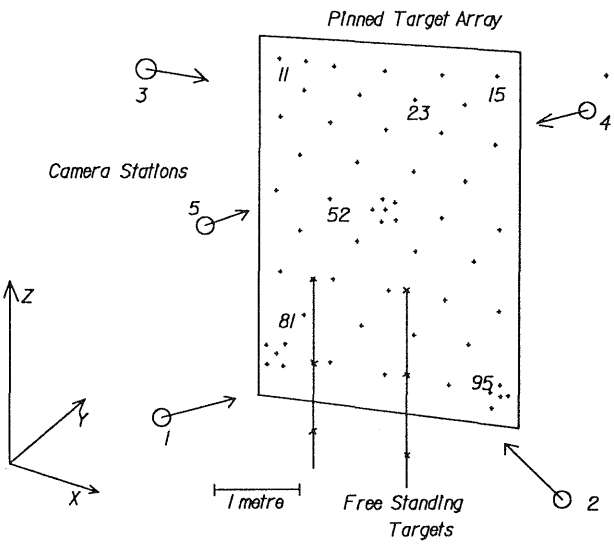

Figure 1. network geometry, detailing target array, all camera stations and survey simulation targets.

2.2 High precision estimation of reference target coordinates

One of the main requirements for the computation of target coordinates was for a datum which would not introduce shape distortions into the object space. Such a datum could be defined by the method of inner constraints, in which the seven elements of datum definition are defined by the target coordinate starting values.

The target array was photographed on two occasions, with a variety of cameras including a UMK 10/1318, a P32, a reseau equipped Hasselblad SWC with a variety of film and camera back combinations, and also an unmodified Hasselblad SMC. Photographs on glass plates as well as film were made with all cameras.

All target images were measured three times using the NPL ZKM measuring microscope. For each frame the target array and reseau images were automatically driven around with manual setting of the measuring mark on each point. The comparator coordinates produced could then be processed according to the reference mark system available in each camera.

Some of the results of these experiments have been discussed in Robson 1990 and 1991a. This paper will concentrate on data sets from two of the cameras; the UMK 10/1318 using Agfa Holotest 10E75 glass plates (Agfa 1989, Cooper and Robson 1990); and on images from a modified Hasselblad SWC used in conjunction with a 120 film back and Kodak Technical Pan film (Kodak 1987).

The main free adjustment incorporated a network with 9 physical cameras, 60 images and 3654 target image measurements. Results from the adjustment pertinent to this discussion are described in table 1. The variance factor associated with this adjustment is significantly greater than unity primarily because the image measurements were considered as independent stochastic variables. The photo-coordinates from each frame must be physically correlated, not least because film unflatness is a systematic effect. Correlation between measurements is difficult to determine in practice and generally requires that the variance components be estimated as unknowns in the adjustment (Kilpela 1980, Torlegard 1989). Such a variance component analysis is not pertinent here because the twin photo networks with which we are concerned cannot support such an estimation due to high internal correlation.

The cameras used did not conform to the assumed colinearity model, so additional parameters were included to model focal length, departures of the principal point from the optical axis and lens parameters to model radial and tangential lens distortions (Fryer 1988). These were estimated in the main free adjustment, one set of parameters for each physical camera. The resultant parameter values could then be used as starting values in subsequent adjustments each parameter being constrained by its standard error. In this way best estimates of the physical properties of each camera lens cone could be included. Since film deformation could also be partially modelled by these parameters, all reseau images in the main adjustment were corrected for film deformation. Correction was carried out using the local bilinear correction, since this too provided a best estimate of the actual deformations occurring, independent from the bundle adjustment.

Table 1. Some parameters from the "free bundle adjustment" incorporating all images

Degrees of Freedom	Variance Factor	RMS photo-coordinate residuals	RMS object space coordinate standard deviations
6702	1.290	x: 2.58 μm	X: 57 μm
		y: 3.07 μm	Y: 45 μm
			Z: 45 μm

2.3. Adjustments based on simulated survey control.

To investigate effects of image deformation on the object space a survey was simulated. Some of the target coordinates estimated from the free adjustment were constrained by standard errors of 1mm, a value considered reasonably obtainable from a three station theodolite control survey. Two target configurations were used, the first covering the whole test field area (11, 15, 52, 81 and 95) and the second with reduced control at the top right corner (11, 23, 52, 81 and 95) (Figure 1).

A set of adjustments was carried out using both the UMK and modified Hasselblad photo-coordinate data sets. In both cases each adjustment permutation was run with the appropriate complete set of photographs and then using the top left and right images as a convergent pair.

The reseau present in the modified Hasselblad camera permitted the application of several different film deformation corrections (Ziemann 1980):

(i) **Raw plate**; simply the comparator coordinates transformed to the photo coordinate system by treating the four corner reseau marks as fiducial marks. No calibration of the fiducial coordinates was assumed, the approach simply used least squares to fit a square axis through the coordinates. This approach is analogous to that applied to the UMK images.

(ii) **Affine**; in which an affine transformation (Equation 1) was applied globally to all image coordinate measurements. The parameters from the transformation were derived from a least squares fit of all 100 reseau image measurements to their calibrated positions.

$$\begin{aligned} \Delta x &= a_0 + a_1 x + a_2 y \\ \Delta y &= b_0 + b_1 x + b_2 y \end{aligned} \qquad (1)$$

(iii) **Mean Bilinear**; on the basis that film type and camera back could be identified by visual analysis of the reseau deformation patterns derived from most of the frames produced, it was decided to adopt a method of correction which reflected these similarities (Robson 90). Instead of corrections based on each individual reseau image, a mean reseau deformation pattern was computed for the complete set of images. Bilinear equations (2) could then be applied based on the computed mean deformations at the four reseau crosses surrounding the image position of interest. This method potentially offered a camera, film and camera back specific correction which included some of the localised advantages of reseau imagery but without the need to measure every grid.

$$\begin{aligned} \Delta x &= a_0 + a_1 x + a_2 y + a_3 xy \\ \Delta y &= b_0 + b_1 x + b_2 y + b_3 xy \end{aligned} \qquad (2)$$

(iv) **Local Bilinear**; the conventional bilinear correction approach applied as for the mean bilinear method, but using reseau deformations derived from measurements of each individual image.

3. Results and Discussion.

3.1. Adjustments featuring the UMK 10/1318 camera

Two adjustments based on the first survey datum were computed from the UMK photo-coordinate data. The first 6-photo adjustment exhibited larger image residuals than the 2-photo adjustment (Figure 2). Conversely the twin photo network showed larger object coordinate discrepancies, but exhibited a smaller variance factor and photo-coordinate residuals.

Table 2. Some parameters from the UMK Adjustment, Set (1)

Photos	Degrees of Freedom	Variance Factor	RMS Object Space Coordinate Discrepancies and Standard Deviations (mm)			RMS Photo-coordinate residuals (μm)	
			X	Y	Z	x	y
6	504	1.280	0.12 (0.69)	0.11 (0.74)	0.10 (0.65)	2.02	1.53
2	51	0.630	0.46 (0.55)	0.33 (0.64)	0.30 (0.54)	1.33	0.20

In the absence of gross errors, it must be concluded that significant departures from the assumed image plane were present in the glass plates at exposure. Such displacements could be due to the design of the UMK plate holders or due to humidity effects (Forno and Kearney 1987).

Interestingly no significant differences were found between the estimated values of the 8 parameter camera functional model included in each adjustment. Therefore changes in the constrained camera parameters cannot be used as a measure of functional model applicability in a weak network.

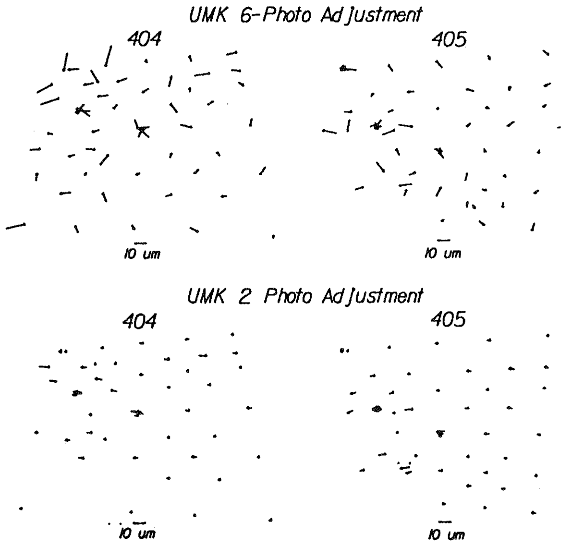

Figure 2. Image Residuals from both UMK adjustments.

Each image measurement has an associated standard deviation such that in the twin photo adjustment the image space is better defined than the object space. For this reason the majority of residuals from the least squares process have been pushed into the estimated object coordinates. Conversely the multiple photo network has provided strong constraints in the object space by virtue of its geometry, as a consequence the residuals tend to remain in the image space.

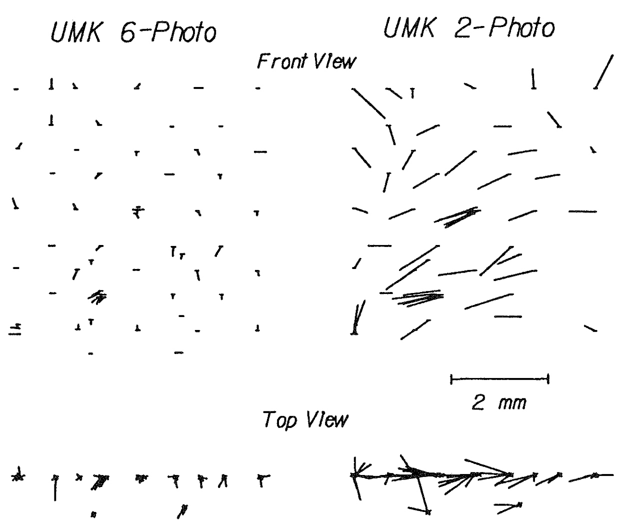

Figure 3. Object Space discrepancies from both UMK adjustments

The systematic object space discrepancies (figure 3) show that significant departures from the imaging geometry assumed by the functional model have occurred in the UMK camera. Such problems are based on holding the glass plate flat in the image plane and are probably coupled with humidity effects. In a twin camera survey without *apriori* knowledge of all locations in the object space it is difficult to see how systematic effects such as those in figure 3, could be detected and modelled reliably within the adjustment process especially given only four fiducial coordinates. A possible approach would be to stabilise the physical properties of the imaging system and to derive a physical model which could be applied either before adjustment or by the method of prior constraints. An indicator of the gross departures from the model could be based on a knowledge of fiducial mark discrepancies occurring under calibration conditions.

An interesting question can be posed at this point; are the object coordinate discrepancies significant in a real situation where we are interested in plotting three dimensional line strings? Results have been based on high contrast target images produced using high resolution emulsion, not natural features which tend to be less distinct. Also measurements were made to below 1μm rms as compared to a conventional analytical plotter with a typical rms of 3 μm. Such considerations mean that any accuracies predicted by network design must take into account the pointing ability to real features. It must then be decided if systematic effects due to departures of the emulsion surface from the assumed image plane are likely to be significant.

3.2. Adjustments featuring the modified Hasselblad SWC camera.

Three sets of adjustments were computed from the Hasselblad photo-coordinate data. The first set included all 8 images with a datum based on the first simulated survey control set, The other two adjustments used just the top left and right photographs ("3" and "4" in figure 1) in conjunction with the first and second survey control sets respectively. Each adjustment was further divided to include the four methods of film deformation correction described previously. In total there were 12 adjustment permutations.

3.2.1. Results from the 8 photograph Hasselblad camera adjustments.

Within this set of adjustments, the only variable was the method of film deformation correction applied. In such cases the variance factor can be used as a crude global descriptor of film deformation correction effectiveness.

Table 3. Some parameters from the 8 photo Hasselblad Adjustment, Set (1)

Degrees of Freedom 758	Variance Factor	RMS Object Coordinate discrepancies and Standard Deviations (mm)			RMS Photo-coordinate residuals (μm)	
Correction		X	Y	Z	x	y
Raw Plate	1.642	0.21 (0.81)	0.27 (0.88)	0.26 (0.76)	2.69	2.93
Affine	2.547	0.19 (1.27)	0.33 (1.44)	0.23 (1.16)	2.95	3.44
Mean Bilinear	1.715	0.28 (1.06)	0.26 (1.20)	0.21 (0.97)	2.49	2.96
Local Bilinear	1.206	0.25 (0.69)	0.26 (0.76)	0.19 (0.65)	2.18	2.68

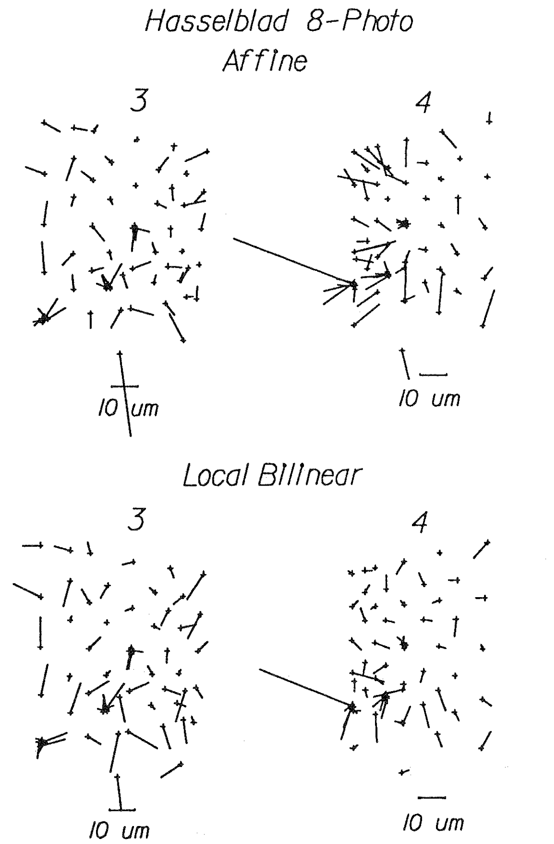

Figure 4. A selection of photo-coordinate residuals from the 8-photo Hasselblad Adjustment.

The data set which utilised the affine transformation has produced the largest variance factor, and arguably the worst solution. A probable reason for this is that larger image deformations occurring at the frame edges have made a significant contribution to all photo-coordinate corrections. The mean bilinear method has also suffered because atypicalities between frames have lead to spurious photo-coordinate corrections.

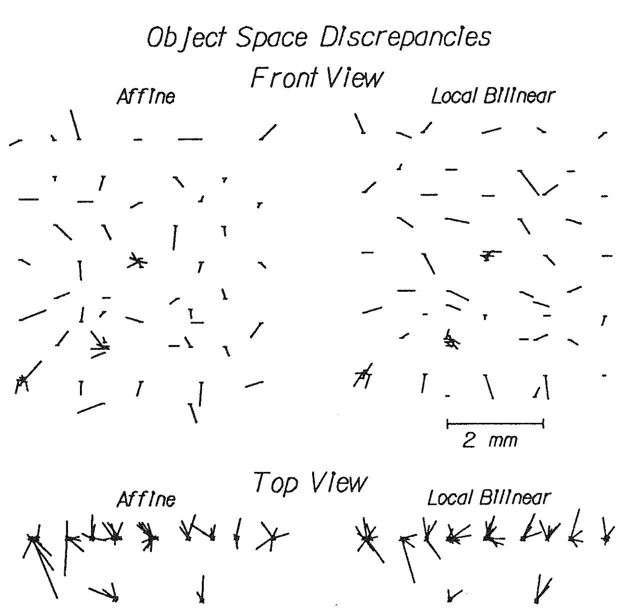

Figure 5. Object Space discrepancies from the 8-photo Hasselblad Adjustment.

Best results have been obtained from the locally applied bilinear correction. This is not surprising since the method is both local and specific to each frame, providing the best estimate of the actual image deformations occurring. Unfortunately the method is also the most measurement intensive, each complete set of reseau cross images for every frame included in the bundle having to be measured.

The radial and tangential parameters estimated by each adjustment were also significantly different within this set, implying that the parameters were also modelling some of the uncorrected film deformation. Again the image deformations have had little effect on the estimated object coordinates because the object space is highly constrained by the convergent network.

3.3.2. Results from the twin photograph adjustments with the Hasselblad camera.

All adjustments based on two photos have demonstrated that higher object coordinate precision requires localised correction provided by individual reseau measurement. Non local correction of image deformation may be ignored with this camera. This is especially true where scale corrections based on fiducials are concerned since large deformations, due to unflatness and tension at the format edges, can contribute disproportionately. The raw photo-coordinates have provided reasonable results with a minimum of both computational and measurement effort.

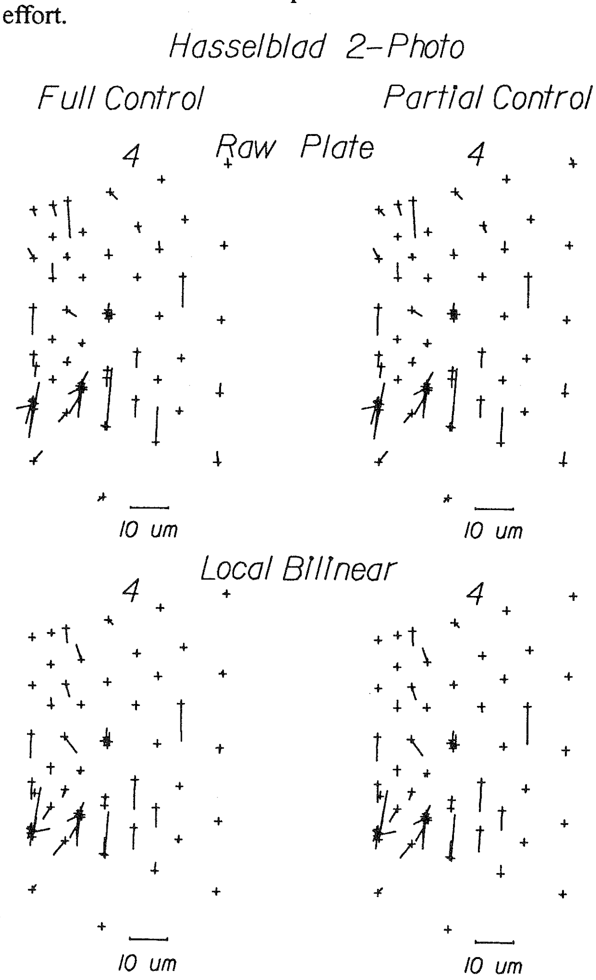

Figure 6. Some image coordinate residuals from the stereopair Hasselblad surveys.

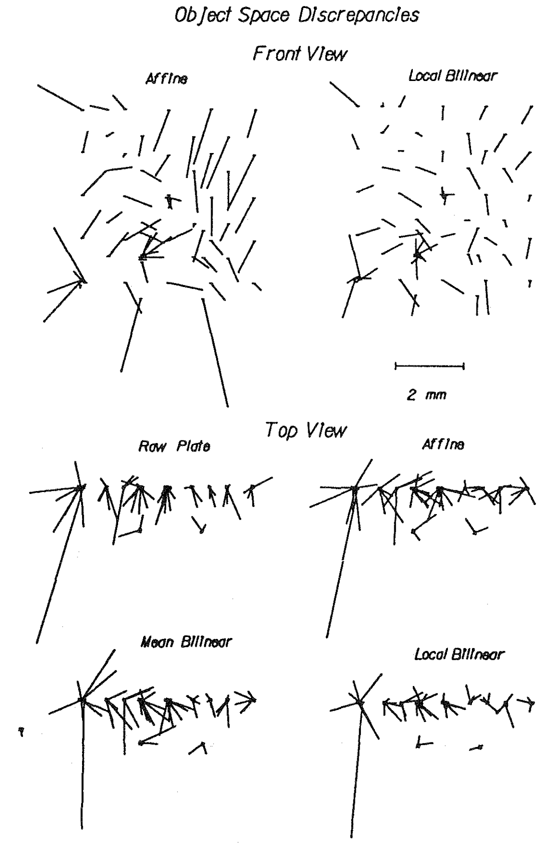

Figure 7. Object space discrepancies for the twin photo Hasselblad survey using datum 1.

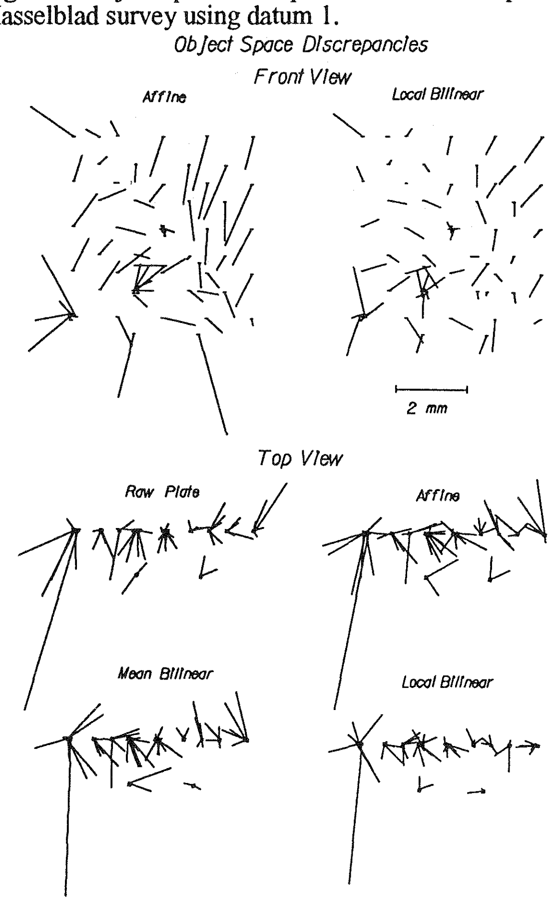

Figure 8. Object space discrepancies for the stereopair Hasselblad Survey using datum 2.

Table 4. Some parameters from the twin photograph Hasselblad adjustments

Degrees of Freedom: 64	Variance Factors		RMS Object space coordinate discrepancy, Coordinate standard eviation (mm)						RMS Photo-coordinate residuals (μm)			
Correction	(1)	(2)	X(1)	Y(1)	Z(1)	X(2)	Y(2)	Z(2)	x(1)	y(1)	x(2)	y(2)
Raw Plate	1.316	1.308	0.70 (0.89)	0.59 (1.09)	0.74 (0.80)	0.82 (0.95)	0.59 (1.18)	0.70 (0.84)	0.64	2.60	0.66	2.60
Affine	1.477	1.447	0.76 (0.94)	0.63 (1.14)	0.87 (0.84)	0.69 (1.00)	0.74 (1.24)	0.82 (0.88)	0.72	2.56	0.74	2.56
Mean Bilinear	1.088	1.081	0.55 (0.81)	0.63 (0.99)	0.52 (0.73)	0.53 (0.86)	0.71 (1.07)	0.49 (0.76)	0.62	2.16	0.63	2.16
Local Bilinear	0.857	0.857	0.45 (0.72)	0.53 (0.88)	0.45 (0.65)	0.45 (0.77)	0.53 (0.95)	0.45 (0.68)	0.51	1.90	0.51	1.90

None of the sets of camera parameters estimated during each adjustment series were significantly different from any other set. The similarity between camera models can again be explained by the relatively weak constraints on the object space. Figure 6 demonstrates that the photo-coordinate residuals are virtually independent of object space datum. This independence does not hold true for the estimated object space coordinates, as there are significant systematic errors in the estimated object coordinates when the survey control does not cover the complete object volume. A similar effect could also occur if, for example, an error was present in a surveyed object coordinate.

There are no statistically significant differences between the rms object coordinate discrepancies produced by the raw photo and local bilinear data sets. However there are significant trends in the estimated object coordinates of upto 2mm with the raw photo data set, especially where the control doesn't cover the complete object space. Again it must be decided if such systematic effects will make a significant contribution when the problems associated with the plotting of natural features with line strings in an analytical plotter are considered.

4. Conclusions.

Given a strong convergent network, image deformation corrections can be insignificant if object space coordinates are the prime requirement of the photogrammetric survey.

The pseudo photogrammetric survey was limited as intended by weak network geometry. The table of rms object coordinate discrepancies has shown that the camera system is still capable of a respectable 1 part in 6,000 to 10,000 of the object space if film deformation is taken explicitly into account. Such results agree well with Fraser 1982. If image refinement is applied, it must be applied locally at every digitised position on every plotted linestring. Results have shown that very localised changes in film surface topology can occur so the degree of image refinement possible at each plotted position will be a function of reseau density.

The rms object coordinate discrepancies demonstrate that the mean bilinear correction can provide better object coordinate precision than the raw plate or affine methods. Unfortunately the mean bilinear will not necessarily remove systematic effects, such as the rotation seen in the estimated object space coordinates (Figure 8). To remove this type of trend the complete local bilinear approach is required. If object space precision requirements are below 1 part in 5,000 it can be concluded that the extra computational effort involved in carrying out image refinement is unjustified given the physical properties of this camera.

The inclusion of constrained inner orientation and additional parameters in these weak adjustments have allowed well defined camera calibration parameters to be included. By this method it is possible to avoid some of the problems caused by high internal correlation that is often associated with self calibration and weak network geometry.

Detection of systematic effects in the data, particularly in the object space with limited networks is dependent on an *apriori* knowledge of the physical processes occurring in the imaging system. Limitations of the UMK camera show that even a system designed specifically for its geometric imaging properties can exhibit significant systematic effects which cannot be removed by use of its reference mark system. Attention to design of the complete imaging system for survey requirements is the main factor which can significantly reduce both the computational and measurement effort associated with photogrammetric survey.

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