GEOMETRIC AND RADIOMETRIC PROPERTY OF LARGE SIZE DIGITAL AERIAL FRAME CAMERAS

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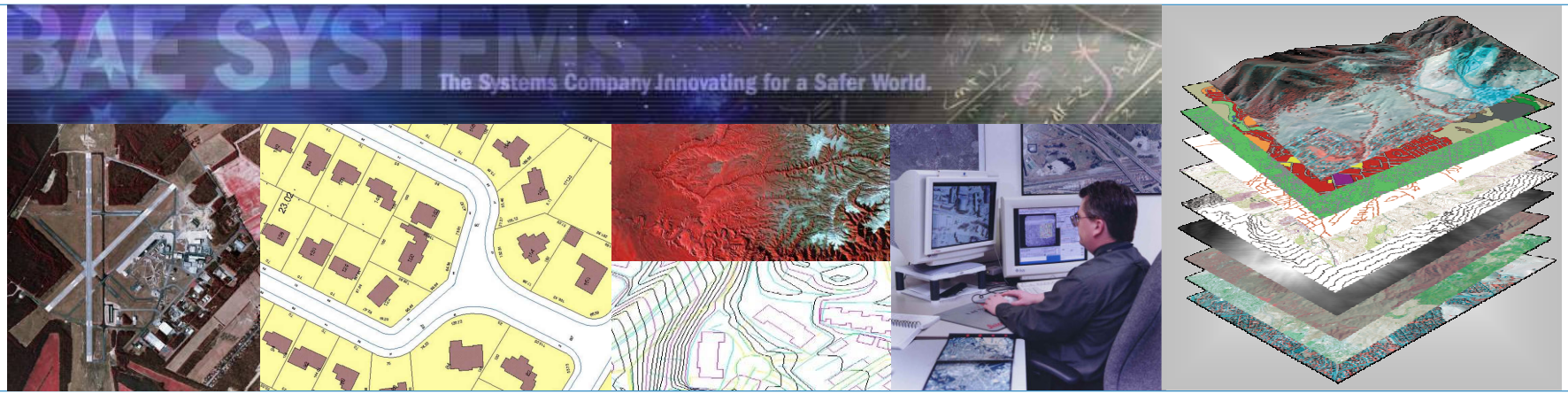


BAE SYSTEMS

MOTIVATION OF THE STUDY

FOR THE MOMENT:

1. **RADIOMETRIC CHARACTERISTICS: Information Contents through the "Effective Pixel Size"**
2. **GEOMETRIC CHARACTERISTICS: Accuracy performance through bundle block adjustment with and without self-calibration and model deformation**

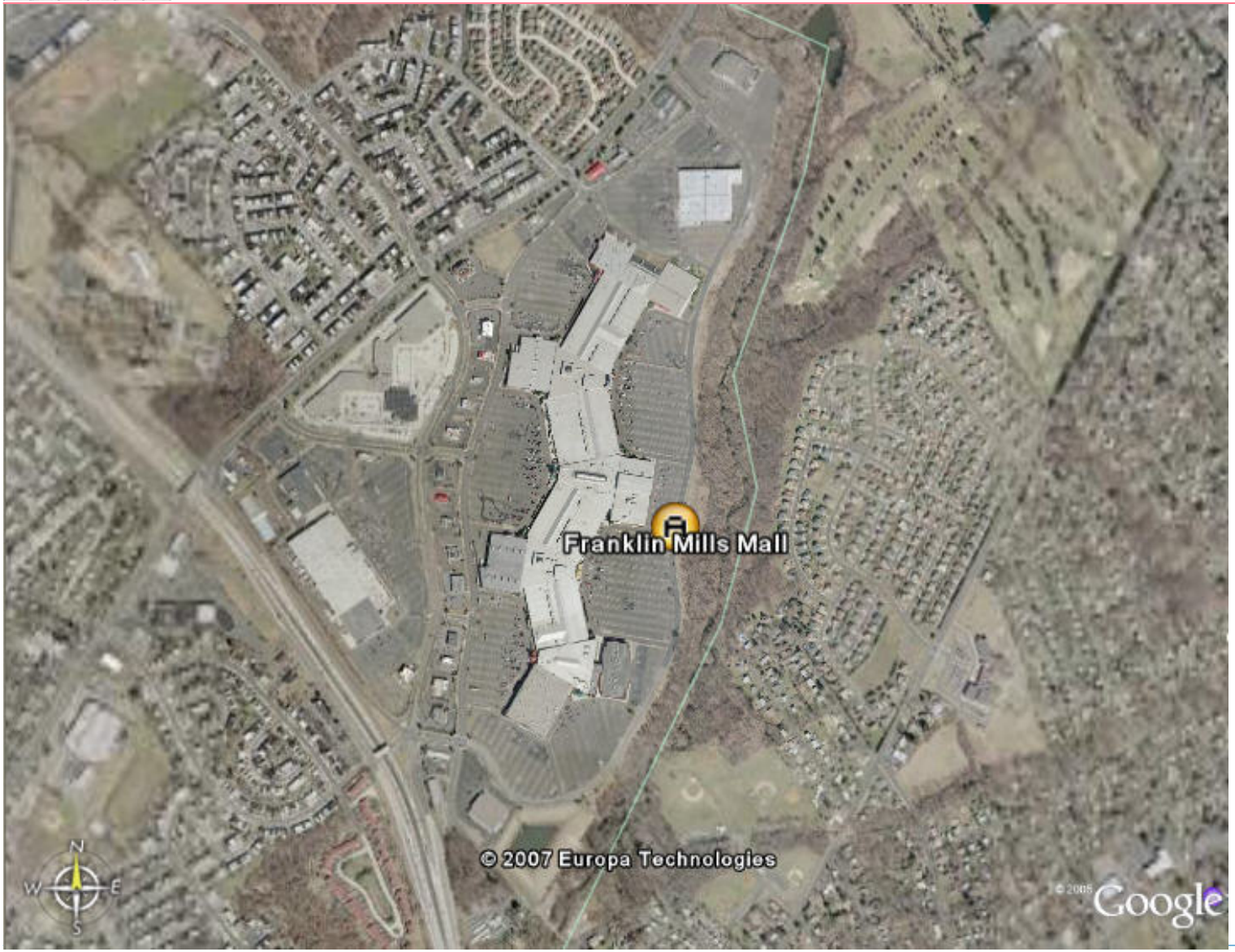
EXPERIMENTAL TESTS

1. **AREA CHOSEN FOR THE EXPERIMENT**
2. **USED DIGITAL CAMERAS, CHARACTERISTICS OF THE GCPs & ChkPts, NUMBER AND DISTRIBUTION, FIELD SURVEY MEASUREMENT, ACCURACY, PHOTOGRAMMETRIC FLIGHT PARAMETERS, etc**
3. **DATA ACQUISITION, DATA REDUCTION, COMPUTATIONS AND RESULTS**

-CONCLUSSIONS AND RECOMMENDATIONS

EXPERIMENTAL TEST AREA

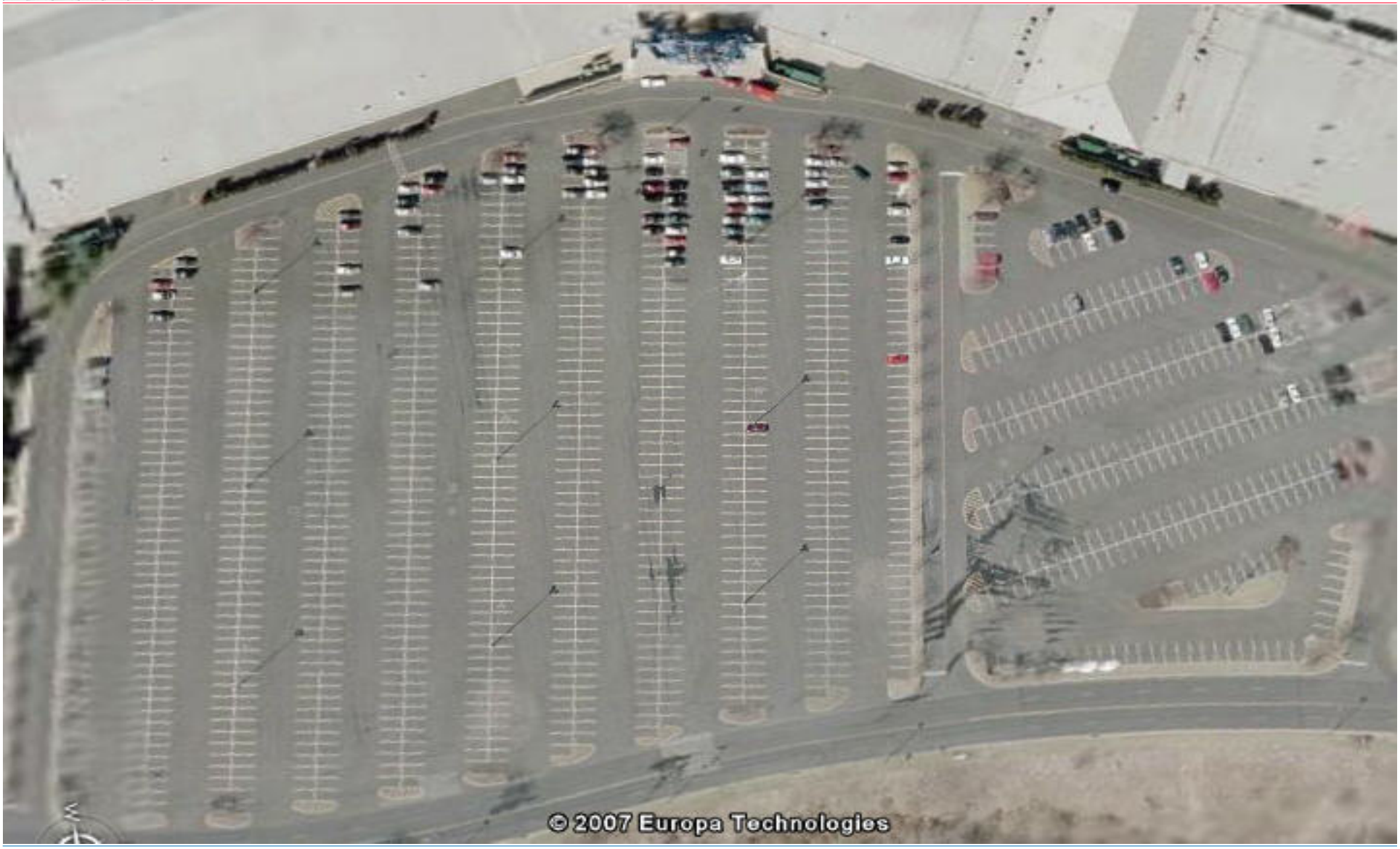
BAE SYSTEMS



NORTH EAST PHILADELPHIA. RELATIVELY OPEN AREA. FLAT. LARGE SHOPPING MALL: FRANKLIN MILL MALL INCLUDING LARGE PARKING LOTS WITH PARKING STRIPES. WIDE ROADS AND STREETS WITH PAINTED TRAFFIC SIGNALIZATION

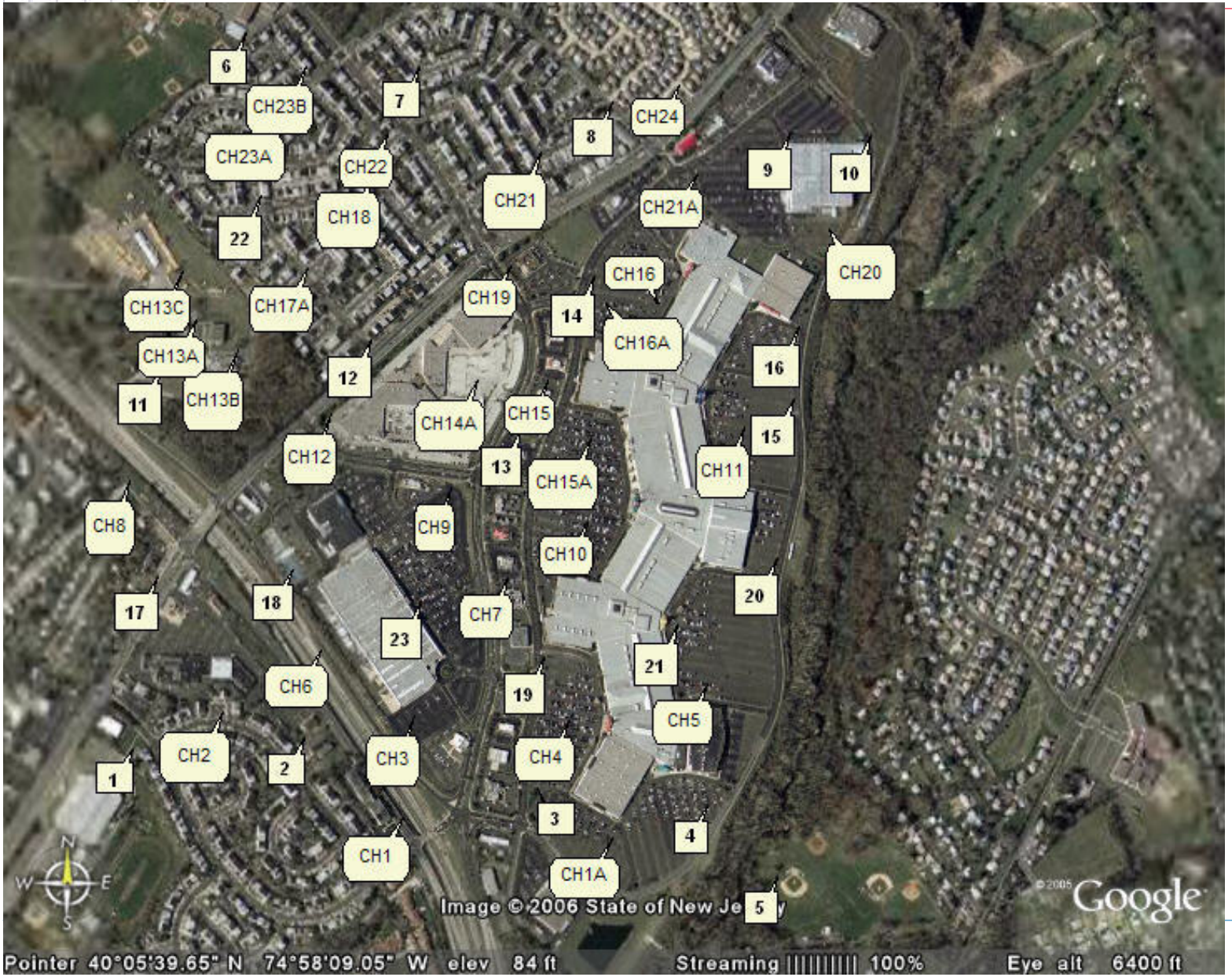
Intersection of Parking Stripes as GCPs & ChkPts

BAE SYSTEMS



Distribution and Location of GCPs & ChkPts

BAE SYSTEMS



A TOTAL OF 42 POINTS WERE USED AS GCPs AND ChkPts.

EXAMPLE OF CHOSEN POINT

BAE SYSTEMS

GCP - ChkPt

BAE SYSTEMS

FIELD SURVEY MEASUREMENT

BAE SYSTEMS

REAL TIME KINEMATIC GPS. ACCURACY OF POINTS

$\sigma_p \leq 2.0$ cm

$\sigma_Z \leq 2.5$ cm

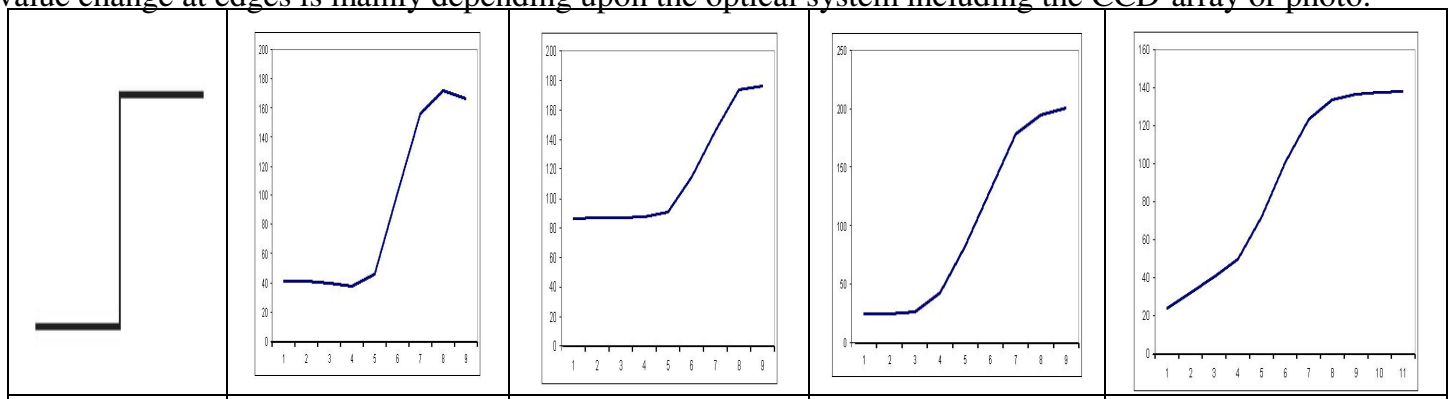
TECHNICAL DATA OF DIGITAL CAMERAS

BAE SYSTEMS

Cameras	Focal Length (mm)	Image Size x (Pixels)	Image Size y (Pixels)	Pixel Size µm	Sub-Camera Field of View-x	Sub-Camera Field of View-y	GSD (mm)	Nominal Photo Scale
DMC	120.0	7680	13824	12.0	23.1º	39.4º	54	1:4500 60%, 60%
UCD	105.2	7500	11500	9.0	35.6º	52.4º	42	1:4667 60%, 60%
UCX	100.5	9420	14430	7.2	37.3º	54.7º	37	1:5139 60%, 60%
RC30	152.3	18400	18400	12.5	74.5º	74.5º	49	1:3920 60%, 60%

Photo Flight Test over Test Field Area Franklin Mill Mall.

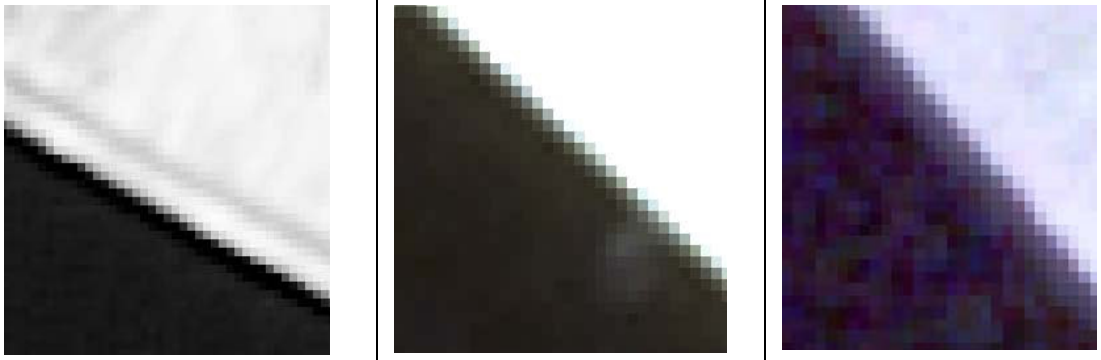
An abrupt change of brightness in the object space should cause a corresponding change of grey values in the images, but caused by the modulation transfer, the change of the grey values is continuous. The function of grey value change at edges is mainly depending upon the optical system including the CCD-array or photo.



Object	DMC	UltraCamD	UltraCamX	RC30 12.5µm pixel

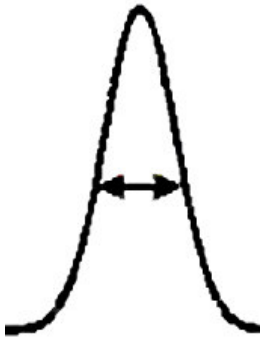
Figure 3: Grey value function perpendicular to an edge, test area Franklin Mills
vertical: grey values horizontal: relative pixel position

differentiation of grey value profile → point spread function, showing effective GSD



DMC	UltraCamX	RC30	point spread function

Figure 4: edges in the images and point spread function



INVESTIGATION OF INFORMATION CONTENTS BY EDGE ANALYSIS

BAE SYSTEMS

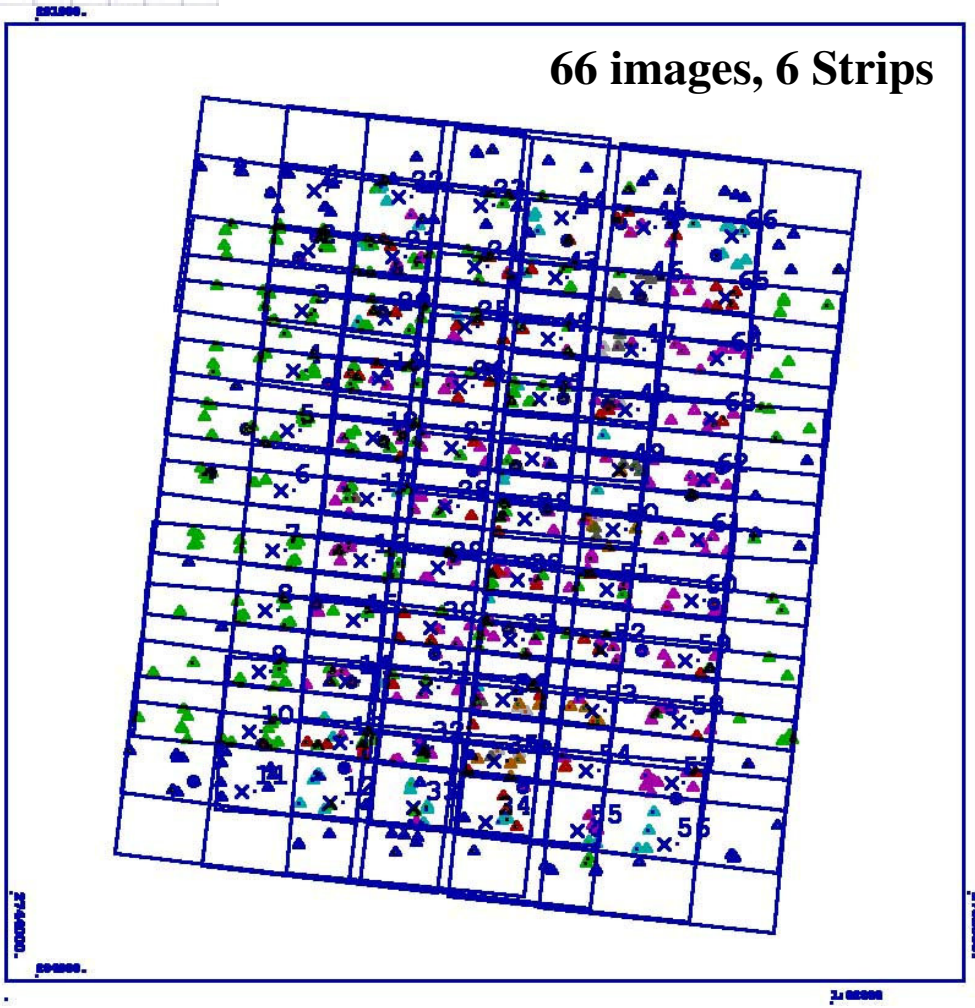
Camera	Sun Elevation	Image Type	Factor for Effective pixel size	Nominal Inage Size (pixels)	Effective Image Size	Reduction on info content
DMC	43º	Pan	0.92	7680x13824	7680x13824	-.-
UCD	27º	Pan-sharp	1.16	7500x11500	6466x9914	25.7%
UCX	27º	Pan-sharp	1.32	9420x14430	7136x10932	42.6%
RC30	46º	RGB color	1.43 2.16	18400x18400	12870x12870 (7667x7667)	51.1% (82.6%)

Factor for Effective Pixel Size and Effective Number of Pixels per Image, Franklin Mill – corresponding to information contents

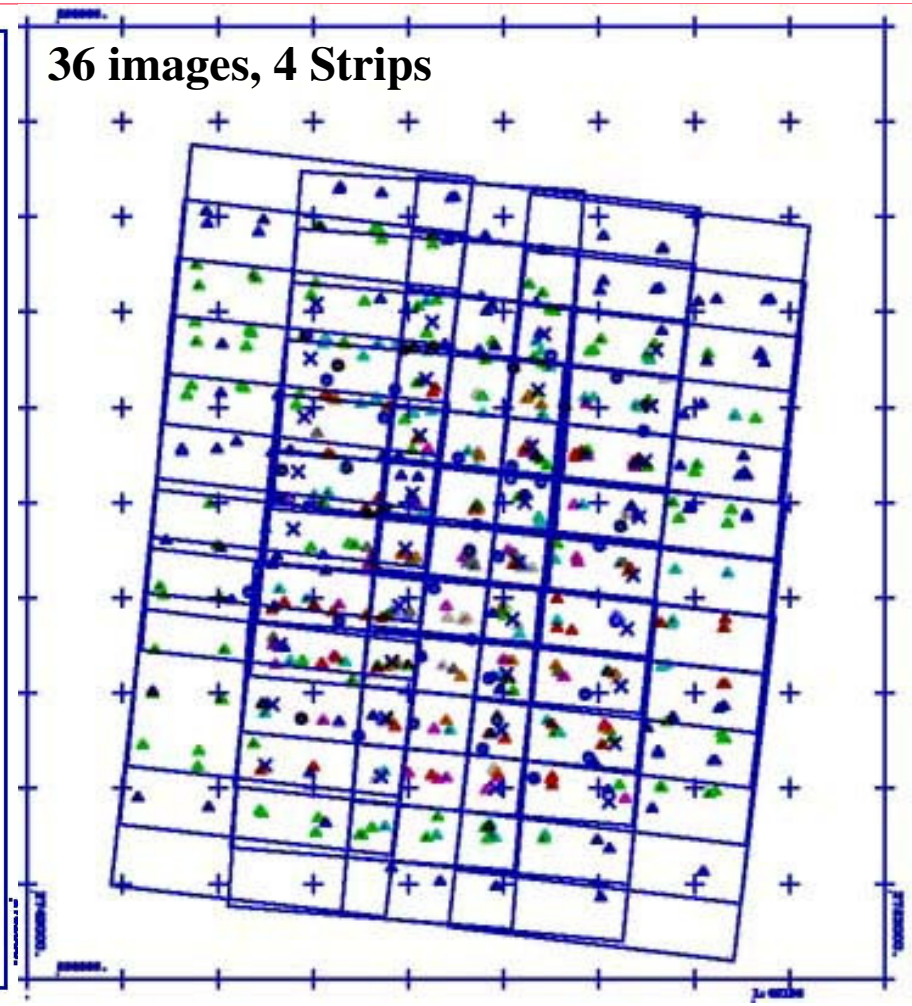
For the RC30 an additional factor of 1.5 has to be added, i.e. 1.5*12µm=27µm to account for the effect of the film grain and the lower contrast of the films as compared with the digital images. The factor 1.5 is coming from the comparison of the identification of details important for mapping (comparison of information contents of scanned aerial photo with DMC and UltraCamD. The same number of object have been found in analogue photos scanned with 20µm pixel size having 10cm GSD and in digital images having 15cm GSD. Here the pixel size of the photo is specified with 20µm; the pixel size of the digital image is unimportant (DMC and UltraCamD have been used for comparison), only the GSD of the digital image counts.

Blocks Layout and GCPs & ChkPts Distribution

BAE SYSTEMS



UltraCam$_D$ Block. p=60%, q=60%
Up to 9 images/point



RC30 Block. p=60%, q=60%.
Up to 14 images/point

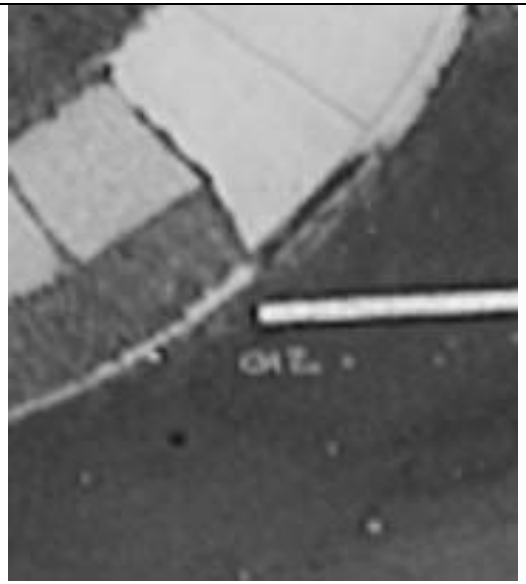
SOME PROBLEMS WITH THE GROUND CONTROL POINTS

BAE SYSTEMS

in field

in UltraCamX

in UCX bright



In DMC

In UltraCamD

In RC30

Fig. 2: control point 1002 in different images

BLOCK ADJUSTMENT OF DMC IMAGES

BAE SYSTEMS

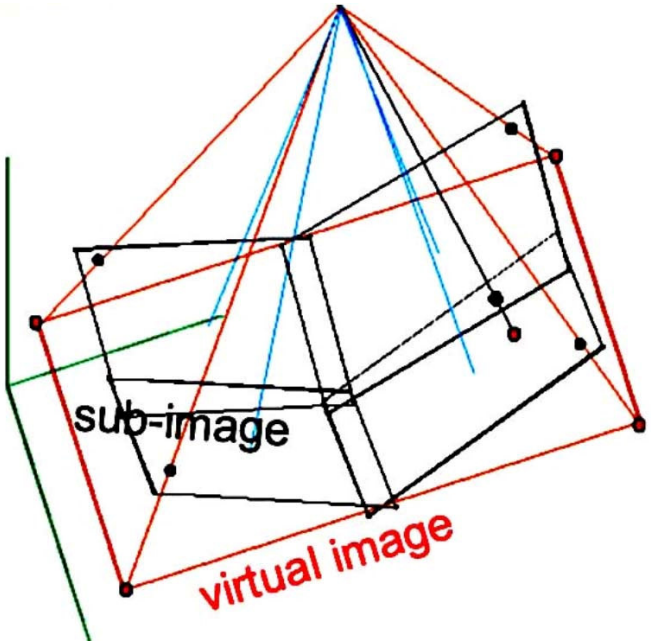
	RMSX	RMSX	RMSX	sigma0
without self calibration	1.8cm	1.4cm	1.6cm	**3.85µm**
additional parameters 1-12	1.7cm	1.4cm	1.5cm	**3.79µm**
add. parameters 1-12, 79-80	1.7cm	1.4cm	1.5cm	**3.77µm**
40 GCPs. 1.7cm=0.31GSD 1.4cm=0.26GSD				

	sigma0	15 control points			25 Check Points		
		RMSX	RMSY	RMSZ	RMSX	RMSY	RMSZ
without self calibration	**3.60µm**	1.6cm	1.6cm	1.2cm	2.0cm	1.6cm	2.3cm
add. par. 1-12	**3.55µm**	1.4cm	1.4cm	1.1cm	2.2cm	1.5cm	2.4cm
add. par. 1-12, 79-80	**3.54µm**	1.4cm	1.4cm	1.0cm	2.2cm	1.5cm	2.4cm
add. par. 1-12, 30-41,74-77	**3.53µm**	1.4cm	1.4cm	1.1cm	2.2cm	1.5cm	2.3cm
Block Adjustment with 15 GCPs. 2.2cm = 0.40 GSD 1.5cm = 0.28 GSD							

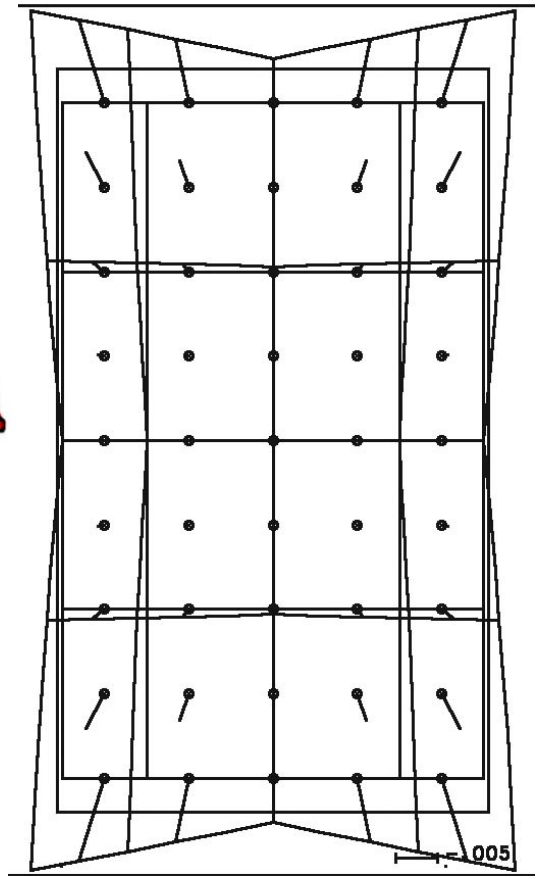
	sigma0	8 control points			32 Check Points		
		RMSX	RMSY	RMSZ	RMSX	RMSY	RMSZ
without self calibration	**3.51µm**	1.4cm	0.7cm	1.0cm	2.6cm	1.8cm	3.5cm
add. par. 1-12	**3.49µm**	1.0cm	0.6cm	0.7cm	2.5cm	1.7cm	3.4cm
add. par. 1-12, 79-80	**3.48µm**	1.1cm	0.7cm	0.6cm	2.4cm	1.7cm	3.0cm
add. par. 1-12, 30-41,74-77	**3.47µm**	1.2cm	0.7cm	0.7cm	2.4cm	1.8cm	3.2cm
Block Adjustment with 8 GCPs. 2.2cm = 0.40 GSD 1.5cm = 0.28 GSD							

SELF CALIBRATION WITH DMC

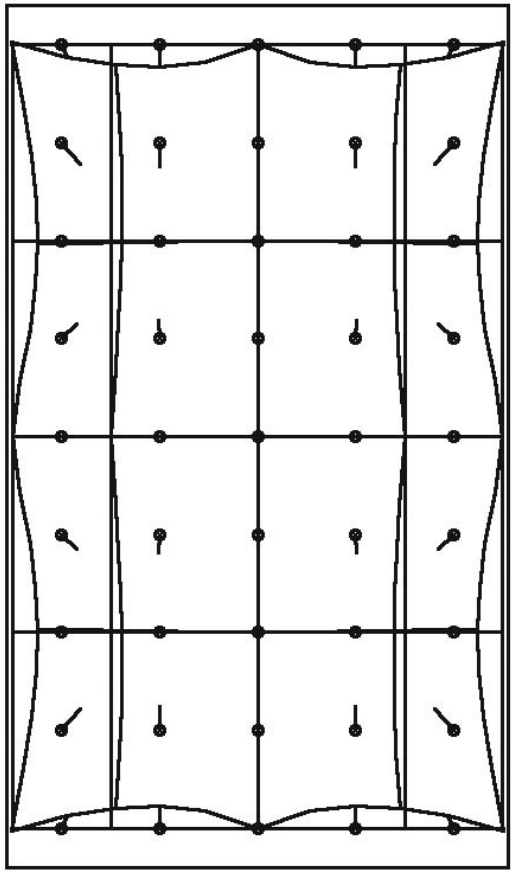
BAE SYSTEMS



Configuration of the Panchromatic DMC sub-cameras



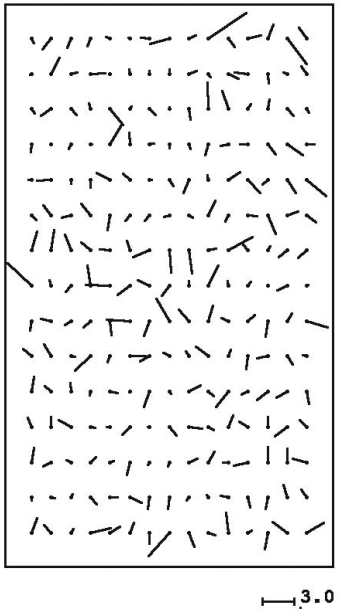
Effect of the Add Parameter 79. Common change of focal length



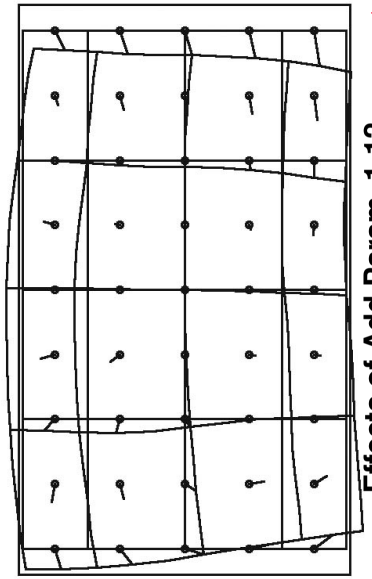
Effect of Add Parameter 80. Common radial symmetric distortion

DMC IMAGES. SELF CALIBRATION

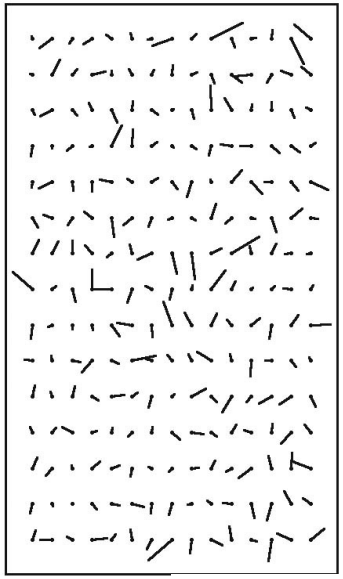
BAE SYSTEMS



Average residuals no Add Param



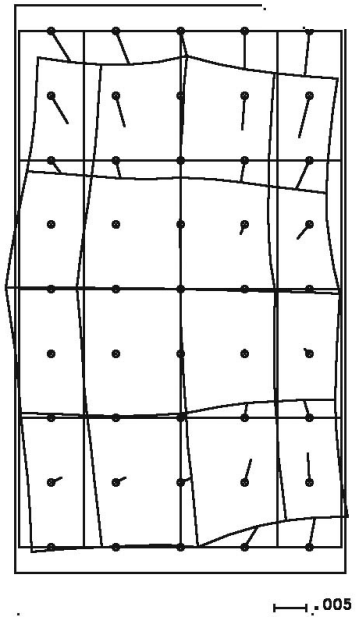
Effects of Add Param. 1-12



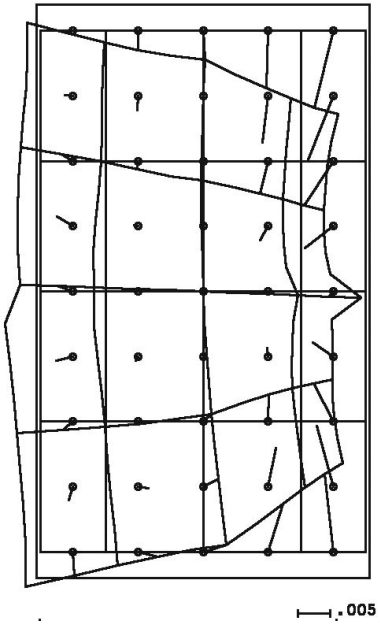
Average image residuals Add Param 1-12

Self Calibration. Effect of Standard Additional Parameters

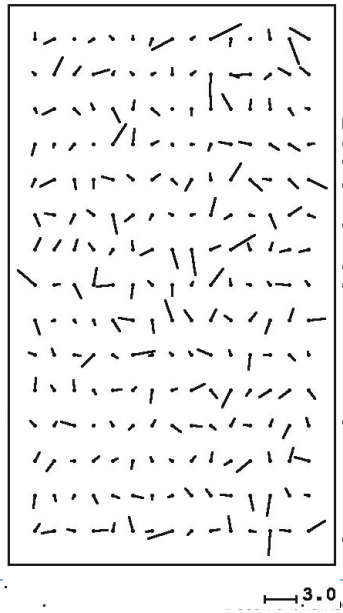
Self Calibration. Effect of Standard Add Param + Camera Specific



Add Param 1-12 + 79-80



Add param 1-12 + camera specific



Average image residuals Add Param 1-12+Camera specific

BLOCK ADJUSTMENTS OF UCD IMAGES

BAE SYSTEMS

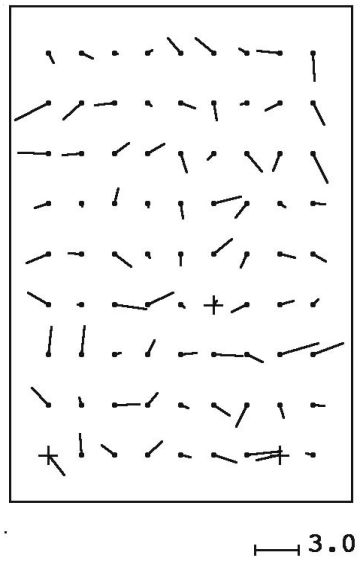
	σ_o µm	RMSX	RMSY	RMSZ
without self calibration	4.71	1.7 cm	1.8cm	2.2cm
additional parameters 1-12	4.61	1.3cm	1.7cm	2.3cm
add. Parameters 1-12, 42-73	4.53	1.2cm	1.8cm	2.1cm
UCD. Block Adjustment with 40 GCPs. 1.2cm = 0.28GSD 1.8cm = 0.49GSD				

		15 control points			26 check points		
	σ_o µm	RMSX	RMSY	RMSZ	RMSX	RMSY	RMSZ
without self calibration	4.49	2.0cm	2.2cm	1.5cm	2.9cm	2.3cm	7.2cm
additional parameters 1-12	4.36	1.2cm	1.8cm	1.5cm	2.7cm	2.1cm	7.0cm
add. Parameters 1-12, 42-73	4.30	1.1cm	1.7cm	1.5cm	2.6cm	2.0cm	6.5cm
UCD. Block Adjustment with 15 control points. 2.7cm=0.63GSD, 2.5cm=0.47GSD							

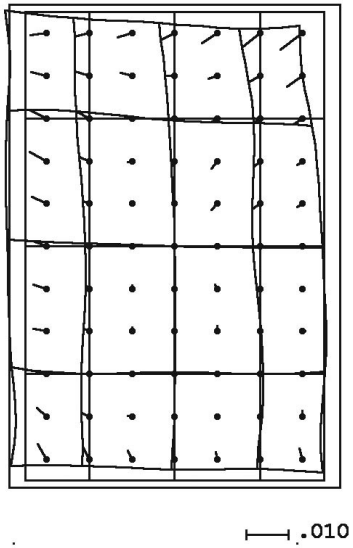
		8 control points			32 check points		
	σ_o µm	RMSX	RMSY	RMSZ	RMSX	RMSY	RMSZ
without self calibration	4.32	1.3cm	1.9cm	4.3cm	4.3cm	3.0cm	8.3cm
additional parameters 1-12	4.27	0.9cm	1.0cm	3.2cm	3.2cm	2.6cm	7.9cm
add. Parameters 1-12, 42-73	4.18	1.0cm	0.4cm	3.8cm	3.8cm	2.5cm	8.0cm
UCD. Block Adjustment with 8 control points. 3.8cm = 0.88GSD, 2.5cm=0.58GSD							

UCD IMAGES. SELF CALIBRATION

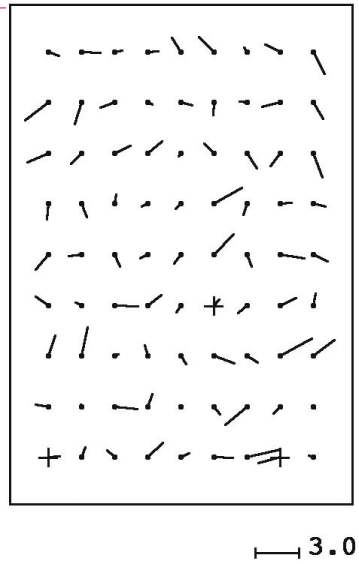
BAE SYSTEMS



Average residuals no self calibration



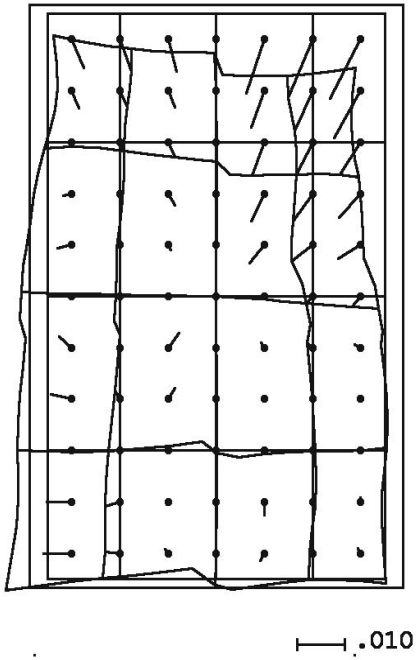
Effect of add. Param. 1-12



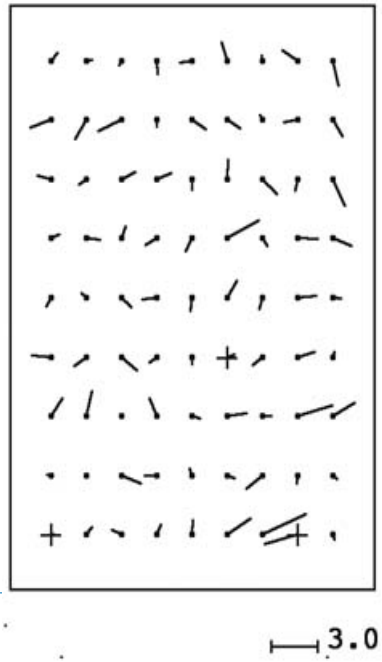
Average image residuals Add Param 1-12

Self Calibration. Effect of Standard Additional Parameters

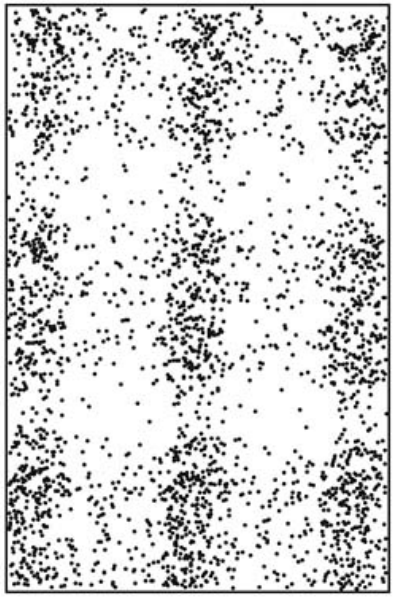
Self Calibration. Effect of Standard Add Param + Camera Specific



Effect of add param 1-12, 42-73



Average image residuals Add Param 1-12+Camera specific (42-73)



Points distribution in images – overlay of all images

BLOCK ADJUSTMENTS OF UCX IMAGES

BAE SYSTEMS

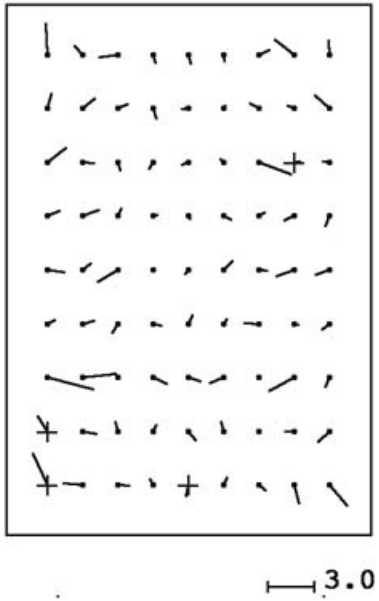
	σ_o µm	RMSX	RMSY	RMSZ
without self calibration	3.30	1.7 cm	1.6cm	1.8cm
additional parameters 1-12	3.13	1.2cm	1.4cm	1.3cm
add. Parameters 1-12, 42-73	3.11	1.2cm	1.4cm	1.1cm
UCX. Block Adjustment with 40 GCPs. 1.2cm = 0.32GSD 1.4cm = 0.38GSD				

		15 control points			27 check points		
	σ_o µm	RMSX	RMSY	RMSZ	RMSX	RMSY	RMSZ
without self calibration	3.15	2.5cm	1.6cm	2.5cm	2.5cm	1.6CM	4.7cm
additional parameters 1-12	3.03	1.2cm	0.7cm	1.5cm	1.6cm	1.3cm	3.4cm
add. Parameters 1-12, 42-73	3.04	1.6cm	1.4cm	0.9cm	2.0cm	1.4cm	3.1cm
UCX. Block Adjustment with 15 control points. 2.0cm=0.54GSD, 1.4cm=0.38GSD							

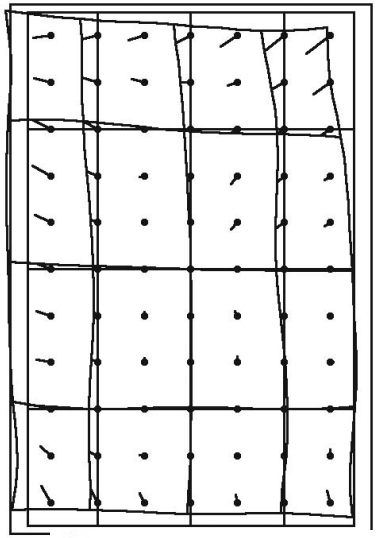
		8 control points			33 check points		
	σ_o µm	RMSX	RMSY	RMSZ	RMSX	RMSY	RMSZ
without self calibration	3.06	3.3cm	1.4cm	5.5cm	4.3cm	3.0cm	8.3cm
additional parameters 1-12	2.98	1.0cm	1.0cm	2.0cm	2.2cm	1.6cm	3.8cm
add. Parameters 1-12, 42-73	2.99	3.2cm	1.8cm	0.4cm	2.8cm	1.7cm	4.2cm
UCX. Block Adjustment with 8 control points. 2.8cm = 0.76GSD, 1.7cm=0.46GSD							

UCX IMAGES. SELF CALIBRATION

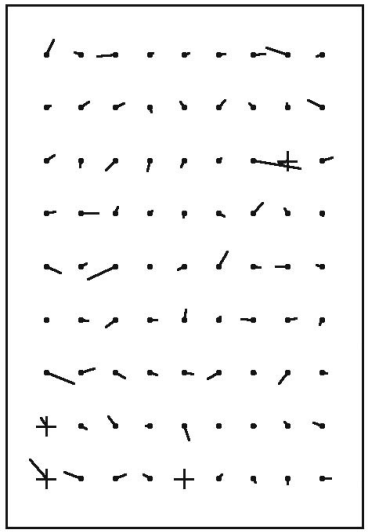
BAE SYSTEMS



Average residuals no self calibration



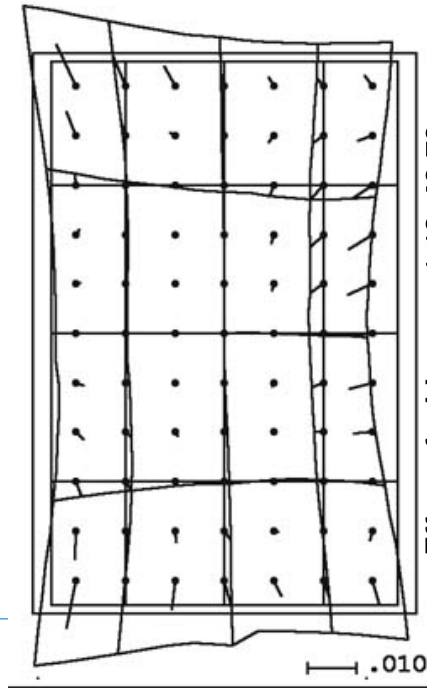
Effect of add. Param. 1-12



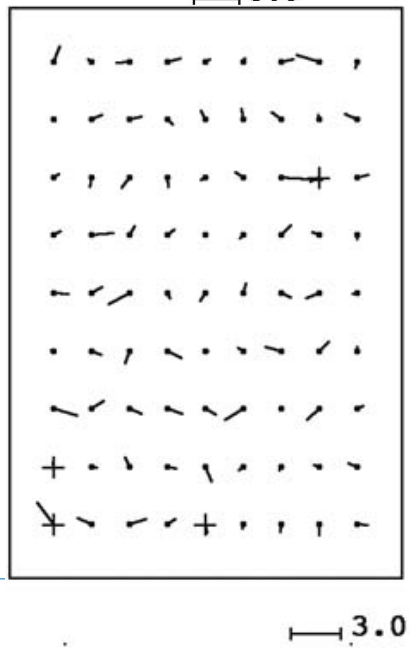
Average image residuals Add Param 1-12

Self Calibration. Effect of Standard Additional Parameters

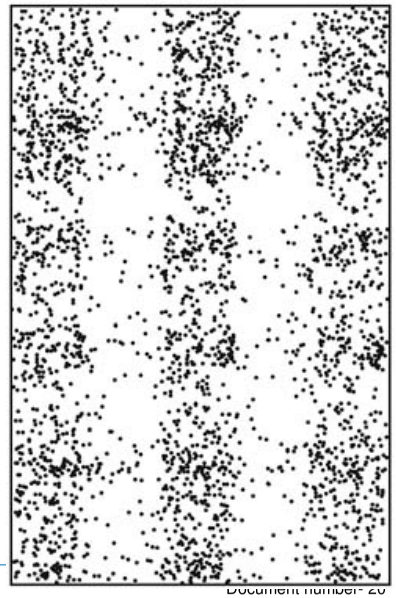
Self Calibration. Effect of Standard Add Param + Camera Specific



Effect of add param 1-12, 42-73



Average image residuals Add Param 1-12+Camera specific (42-73)



Points distribution in images – overlay of all images

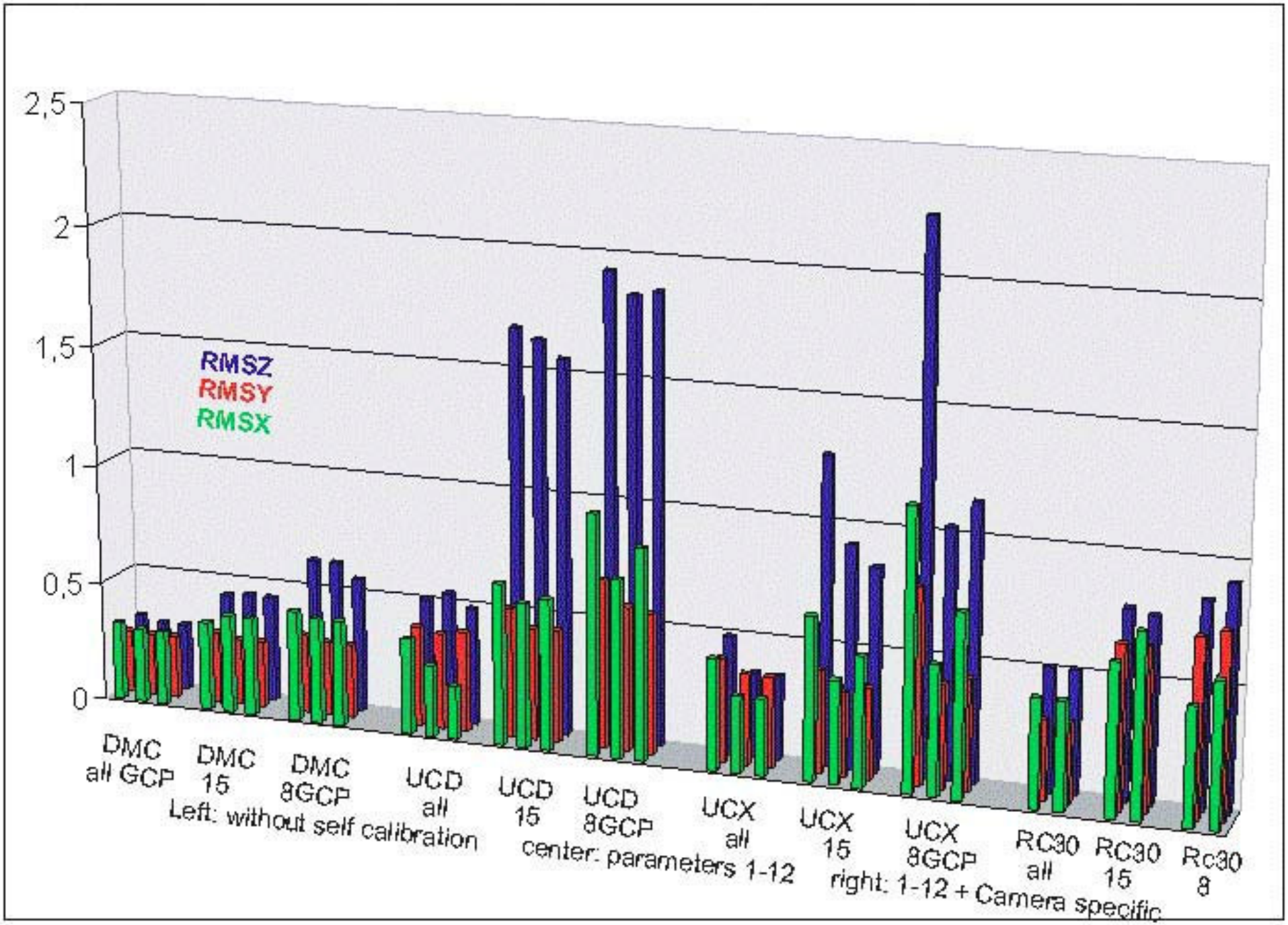
BLOCK ADJUSTMENTS OF RC30 IMAGES

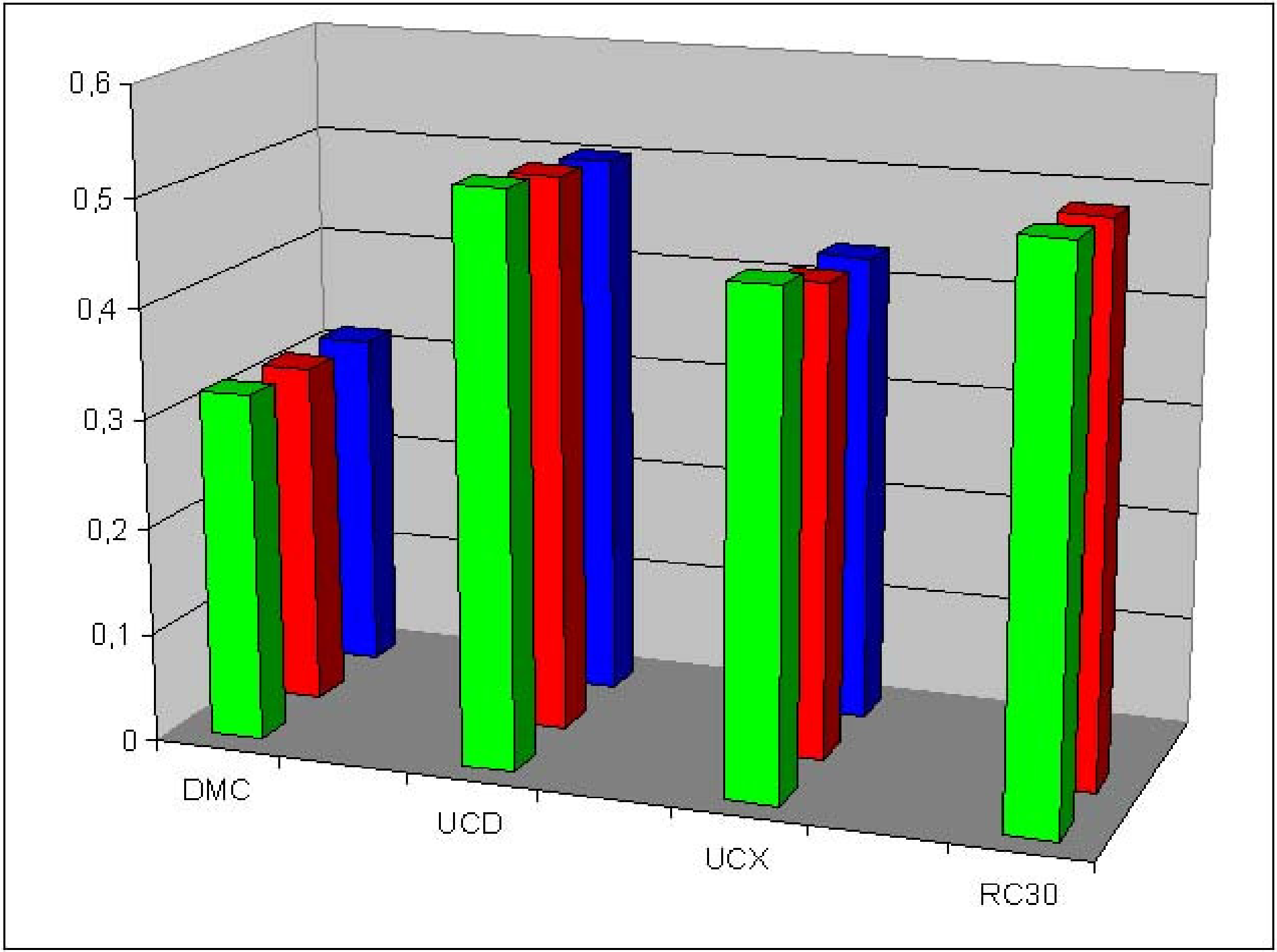
BAE SYSTEMS

	σ_o µm	RMSX	RMSY	RMSZ
without self calibration	6.44	2.2 cm	1.6cm	2.5cm
additional parameters 1-12	6.38	2.1cm	1.6cm	2.3cm
RC30. Block Adjustment with 40 GCPs. 2.1cm = 0.43GSD 1.6cm = 0.32GSD				

		15 control points			27 check points		
	σ_o µm	RMSX	RMSY	RMSZ	RMSX	RMSY	RMSZ
without self calibration	6.40	2.7cm	4.0cm	3.2cm	3.1cm	3.3cm	3.8cm
additional parameters 1-12	6.20	2.1cm	3.5cm	2.9cm	3.7cm	3.3cm	3.7cm
RC30. Block Adjustment with 15 control points. 3.7cm = 0.78GSD 3.3 = 0.70GSD							

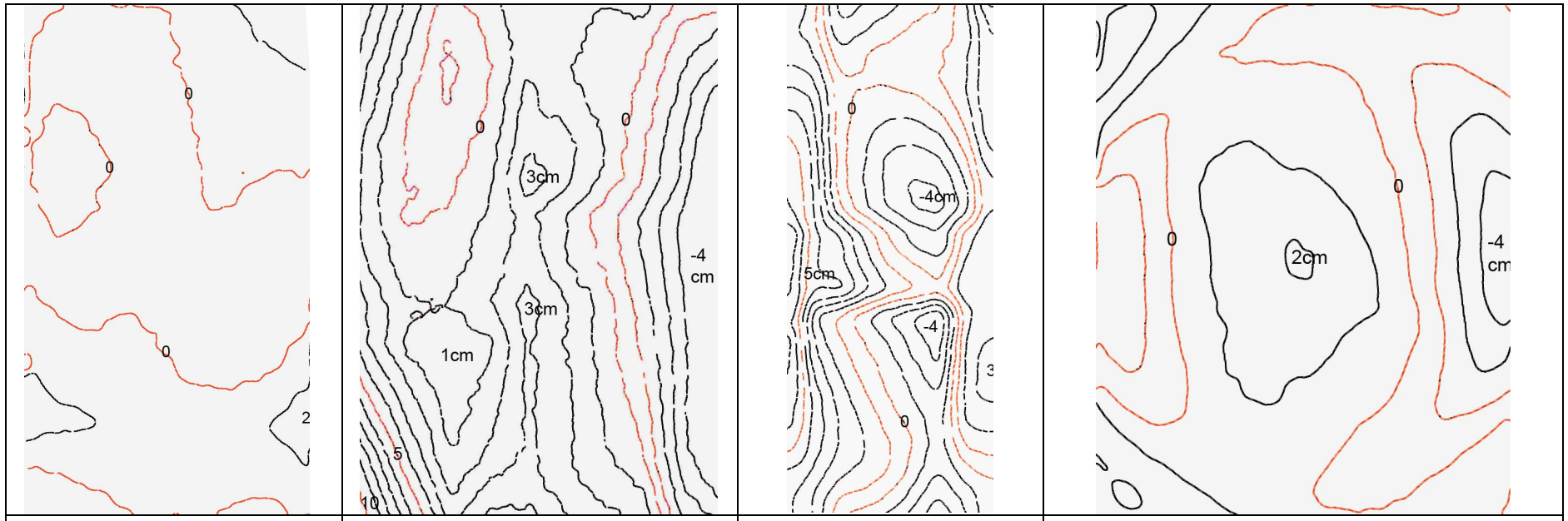
		8 control points			33 check points		
	σ_o µm	RMSX	RMSY	RMSZ	RMSX	RMSY	RMSZ
without self calibration	6.02	2.4cm	1.9cm	2.4cm	2.4cm	3.6cm	4.1cm
additional parameters 1-12	5.94	2.2cm	1.3cm	1.8cm	2.6cm	3.7cm	4.5cm
RC30. Block Adjustment with 15 control points. 2.6cm = 0.55GSD 3.7 = 0.78GSD							


2,5
2
1,5
1
0,5
0
RMSZ
RMSY
RMSX
DMC all GCP
DMC 15
DMC 8GCP
UCD all
UCD 15
UCD 8GCP
UCX all
UCX 15
UCX 8GCP
RC30 all
RC30 15
Rc30 8
Left: without self calibration
center: parameters 1-12
right: 1-12 + Camera specific


0,6
0,5
0,4
0,3
0,2
0,1
0
DMC
UCD
UCX
RC30

MODEL DEFORMATION

BAE SYSTEMS



DMC	UltraCamX	UltraCamD	RC30
Min: -1.5cm max: 2cm	Min: -4.5cm max: 9cm	Min : -5.5cm max : 8.2cm	Min : -3.0cm max : 2.8cm

Figure 11: model deformation caused by systematic image errors, based on additional parameters 1 – 12 + camera specific parameters, contour interval 1cm

DMC	UCD	UCX	RC30
$\sigma\pi_O$=27mm (1/2GSD)	$\sigma\pi_O$=21mm (1/2GSD)	$\sigma\pi_O$=18.5mm (1/2GSD)	$\sigma\pi_O$=24.5mm (1/2GSD)
H/B=3.1	H/B=3.7	H/B=3.7	H/B=1.6
σz=8.4cm	σz=7.8cm	σz=6.8cm	σz=4.0cm

CONCLUSIONS

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1. The merge of the sub-images to a virtual image respects the calibration of each one of them, by theory there should not be systematic image errors in the virtual image. In reality this is not the case. The main source of errors are caused by thermal influences. The cone, the CCD-arrays, fixed on ceramics have different thermal coefficients. Also the temperature gradient within the optics may cause geometric distortions
2. With the same GSD the DMC enables better accuracy in X, Y and Z than the wide angle RC30
3. The just 2 (79-80) camera specific additional parameters are improving the accuracy at independent check points
4. The UCD images, generated with the old matching software, have some geometric problems, reducing the accuracy. Even with the 32 camera specific parameters can not be solved and if combined with the 12 standard it may even lead to over-parameterization reducing the accuracy even more. New matching software from Microsoft respect the effects of the different thermal coefficients and thermal gradient
5. The UCX images have been merged with this new software rendering better accuracy in relation to the GSD than the UCD
6. The UltraCams H/B ratio of 3.7 leads to lower accuracies than the wide angle RC30, that in the case of the 8 GCPs only it is also influenced by the larger foot-print size of the RC30 image, causing a smaller distance of the control points in relation to the photo base for the RC30 as compared with the UCDs.
7. With 15 GCPs the UCX leads to better accuracy in X and Y than the RC30. With 8 GCPs it is reverse
8. To avoid unnecessary loss of accuracy, data acquisition in stereo-mode should be done taking into account the systematic image errors, especially for the UltraCams but also for the traditional aerial photography
9. The information content should be checked by edge analysis, determining the “Effective GSD”=Scale factor*GSD
10. For the digital cameras, information content depends on the sun elevation and the pixel size. Smaller pixels and low illumination / contrast the larger the loss of information is. The edge analysis shows that 12.5 µm is not neces.

BAE SYSTEMS

Thank you very much for your kind attention

QUESTIONS..?

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