ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Photogrammetrie pf Fernerkundung

Metric Accuracy Testing with Mobile Phone Cameras

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WHY MOBILE PHONE CAMERAS?

*) availability of small hardware:

labtops, PDAs, etc..

*) available know-how & software modules:

sequential estimation, semi-automated and automated triangulation and surface model generation and texturing

We anticipate the (future) possibilities of **on-line processing** of the acquired image data by mobile phone cameras.

This is a concept from
"**Mobile Mapping** " → to "**Mobile 3D Modeling**" (**Mobile Photogrammetry**)

Objective of the work: Geometric Calibration and accuracy validation of mobile phone cameras

CONTENT OF THE PRESENTATION:

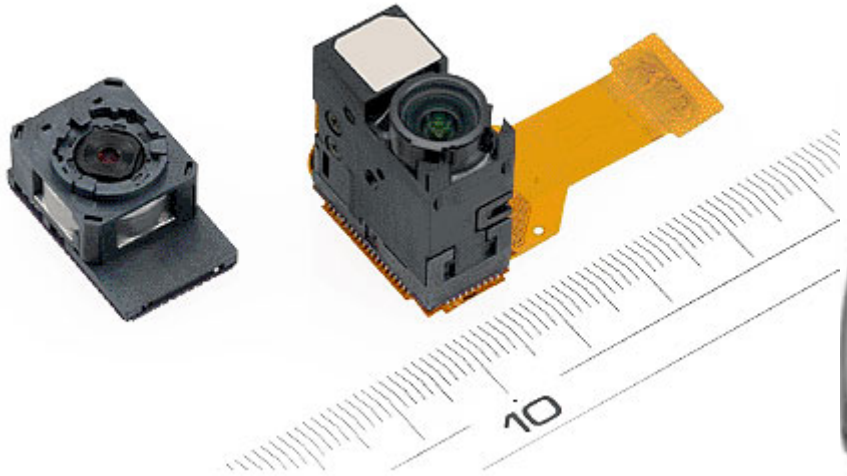
- Some applications of mobile phone cameras
- Technical specifications of the used cameras
- Calibration test field

- Accuracy tests
  - Sony Ericsson K750i - camera embedded mobile phone
  - Nokia N93 - camera embedded mobile phone
  - Sony DSC W100 - off-the-shelf digital camera
  - Sony DSC F828 - off-the-shelf digital camera

- JPEG test with Sony DSC F828
- Temporal stability test with Nokia N93
- Analysis of results & conclusions

Rapid progress in mobile phone camera technology:

Sharp (**2004**)
2 Mpixel CCD
camera module



Sharp (**2005**)
3 Mpixel CCD
camera modules

Samsung (**2006**)
10 Mpixel CCD
camera integrated
handy SCH-B600

Some applications of mobile phone cameras:

- Character / text recognition
- facial animation
- face identification / recognition
- panoramic image capturing
- context awareness
- content provision to GIS (+ GPS chip)
- LBS applications
- etc.

In spite of the availability of a broad diversity of applications,
the **metric capabilities and characteristics** of mobile phone cameras have **not** been investigated so far.

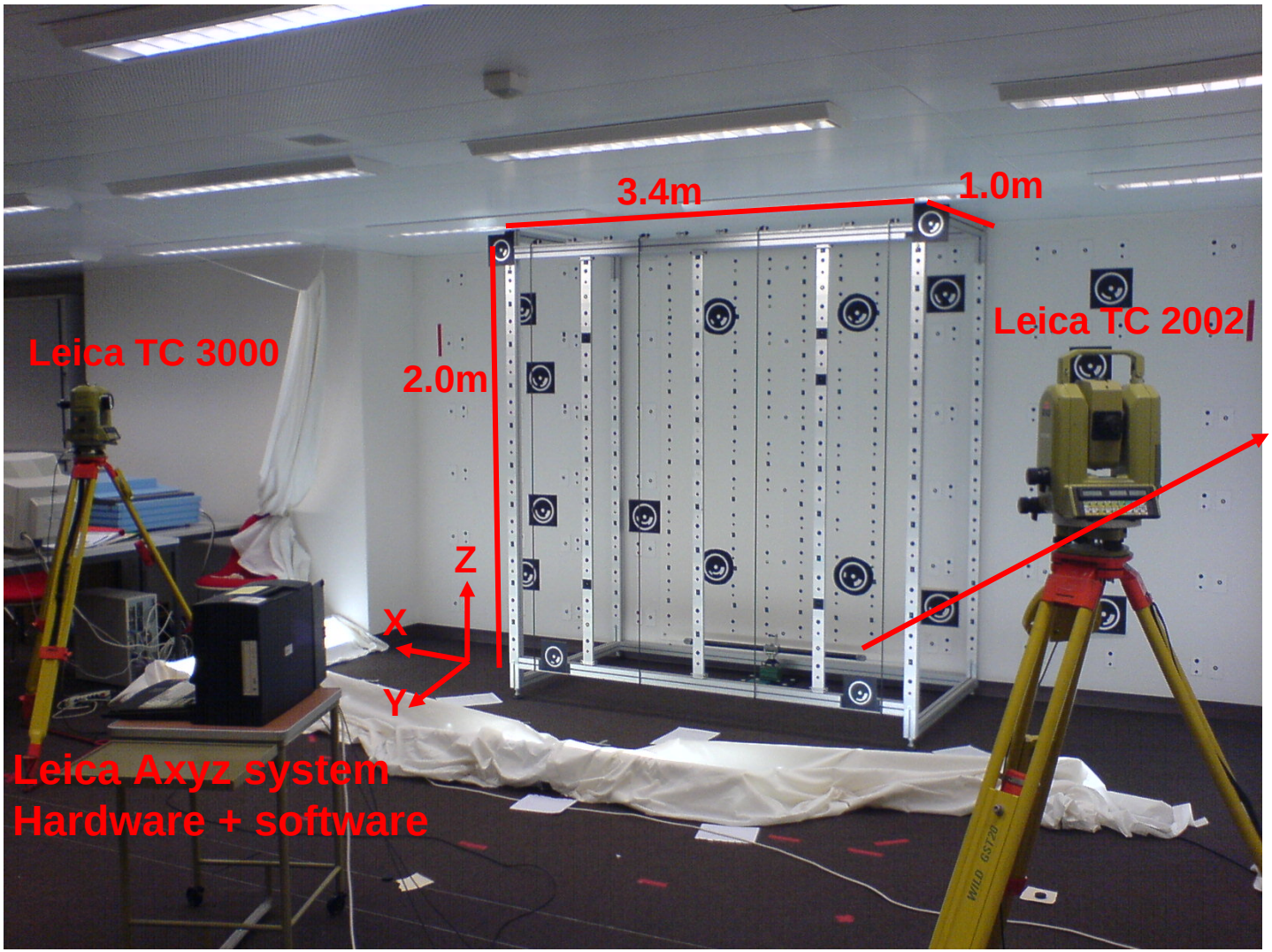
Sony Ericsson K750i

Nokia N93

Sony DSC W100

Sony DSC F828

Camera	K750i	N93	W100	F828
Sensor	CMOS 1/3.2” type 4.5 x 3.4 mm	CMOS 1/3.2” type 4.5 x 3.4 mm	CCD 1/1.8” type 7.2 x 5.3 mm	CCD 2/3” type 8.8 x 6.6 mm
Pixel size	2.8 micron	2.2 micron	2.2 micron	2.7 micron
Image format	1632 x 1224 2 mega pixel	2048 x 1536 3.2 mega pixel	3264 x 2448 8 mega pixel	3264 x 2448 8 mega pixel
Lens	Na	Carl Zeiss Vario-Tessar	Carl Zeiss Vario-Tessar	Carl Zeiss T* Vario-Sonnar
Focal length	4.8 mm	4.5 – 12.4 mm	7.9 - 23.7 mm	7.1 - 51.0 mm
Optical zoom	No	3X	3X	7X
Auto focus	Yes	Yes	Yes	Yes
Aperture	F2.8 (fixed)	F3.3 (fixed)	F2.8 - 5.2	F2.0 - 8.0
Output format	Only JPEG	Only JPEG	Only JPEG	JPG and TIFF



Test field

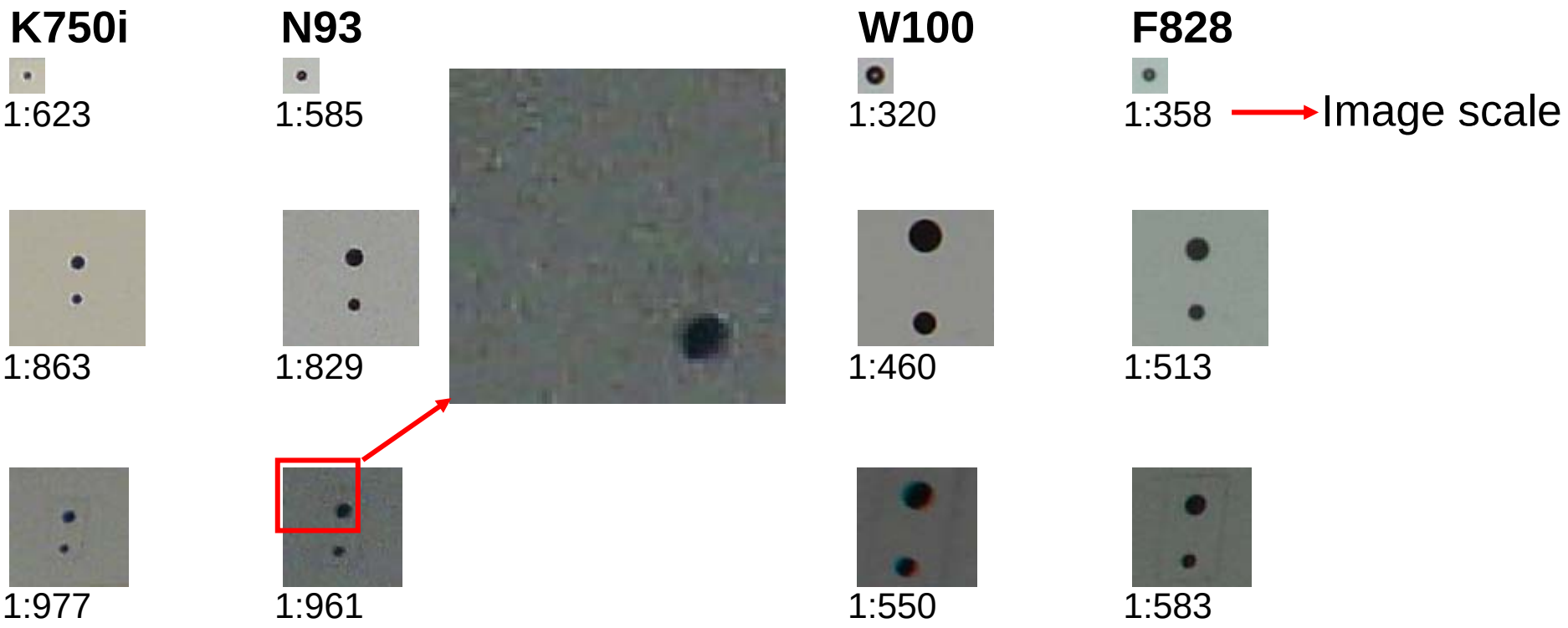
HIL C57.3,

ETH Zurich

Base for the scale:
1000.051 ±0.010 mm
by Interferometry

- 87 GCPs, the average precisions X,Y,Z: ±0.030, ±0.050, ±0.030 mm.
- **Leica Axyz system**.

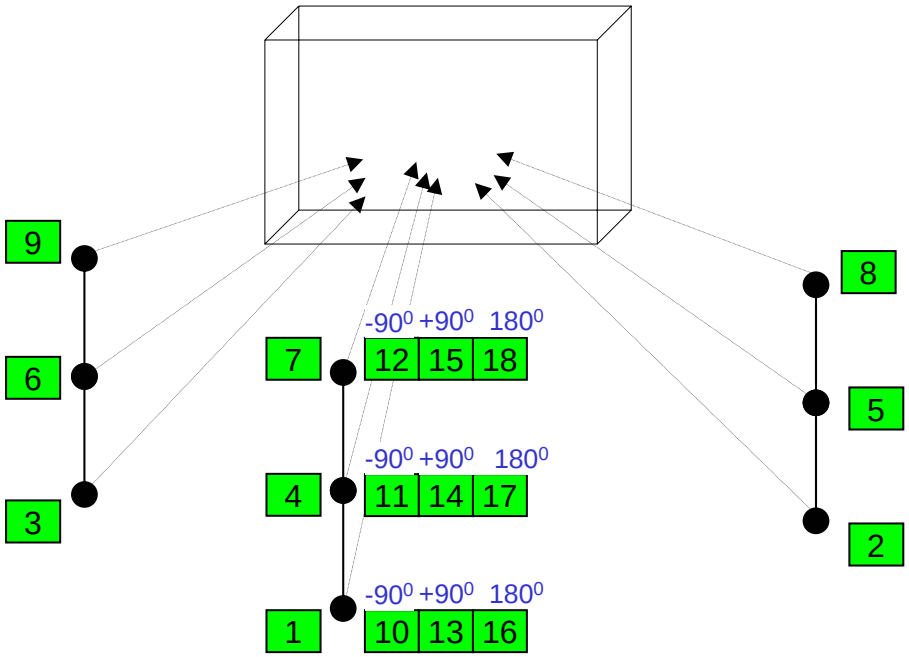
Imaging Quality:

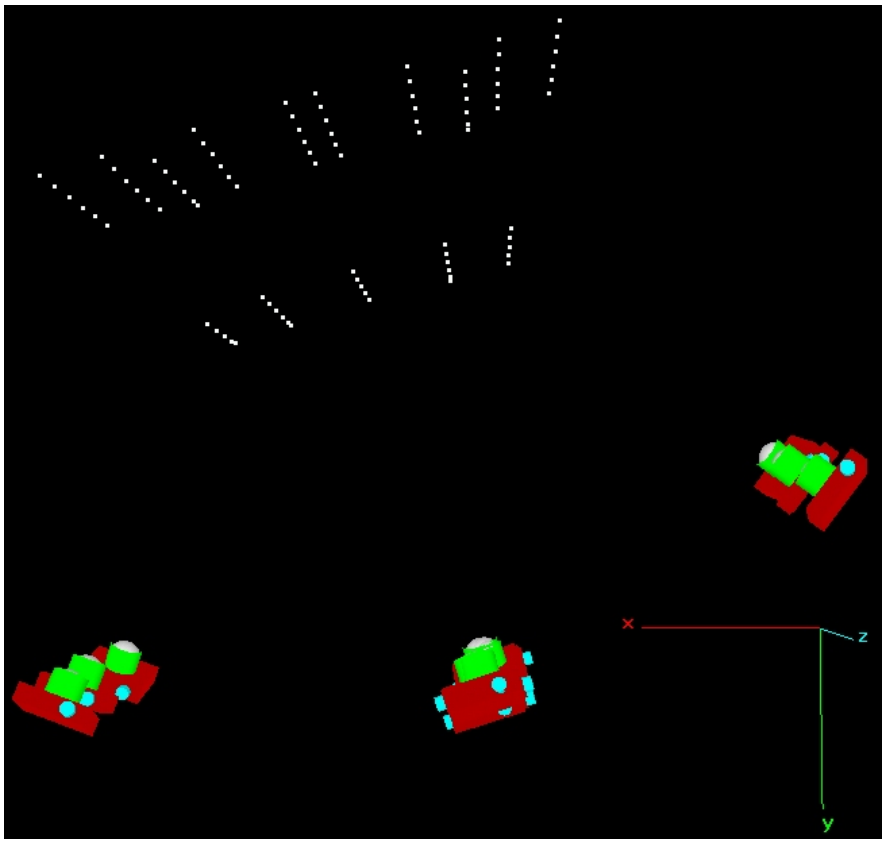


- Low-level image enhancement effects at K750i, N93 and W100.
- F828 has the best overall image quality considering all images.
- JPEG artifacts on N93 images.

- Image Measurements: **LS Template Matching**
- All process & analysis **software** are **in-house developed**

K750i: Accuracy test – network configuration





- 9 stations, convergent geometry, 18 pictures
- 9 pictures normal case
- 9 pictures rotated, 3/ 3/ 3: -90^0/ $+90^0$ / 180^0

K750i: Absolute accuracy test - #18 results

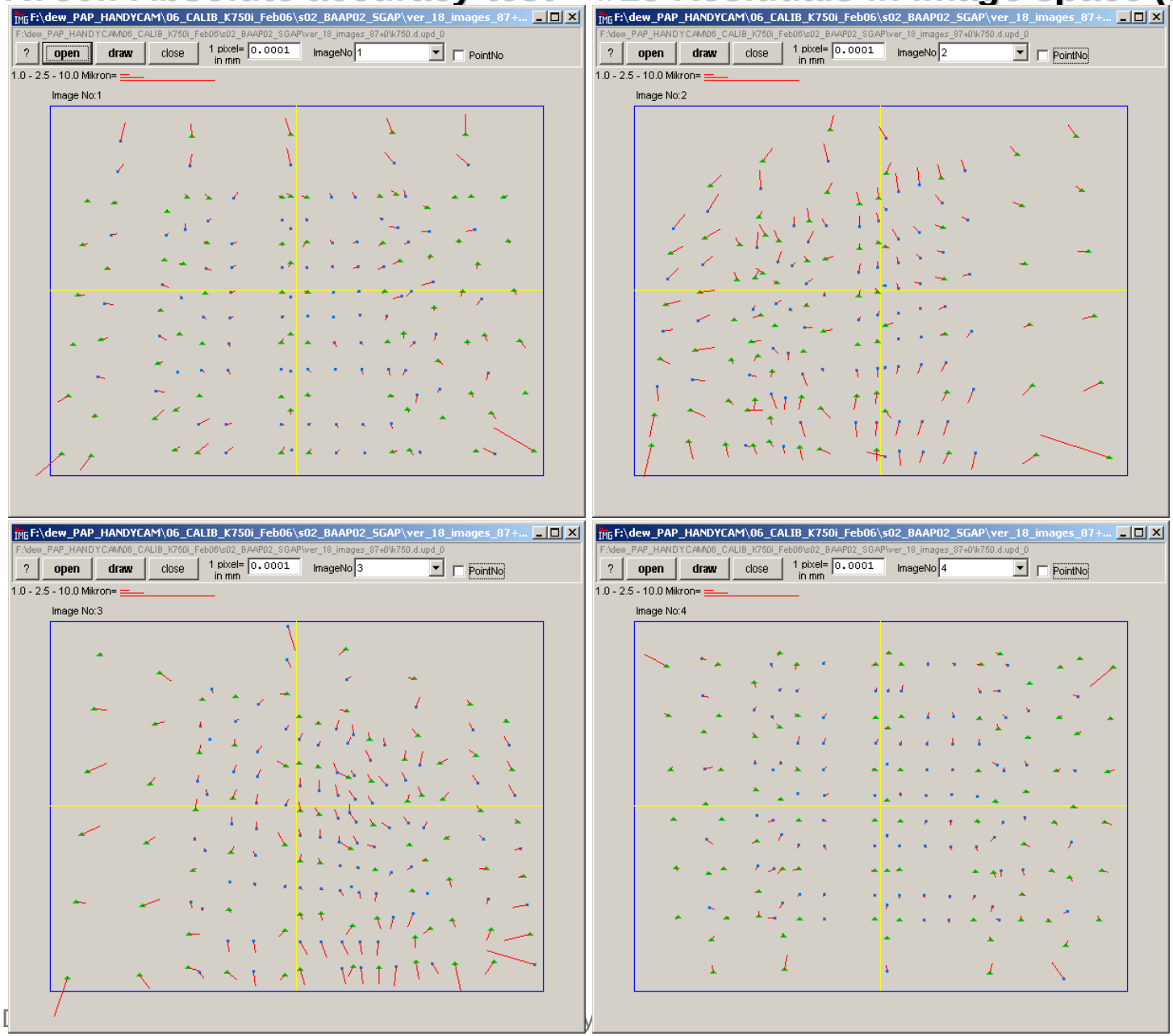
Number of images: 18 (JPEG)
Pixel size: 2.8 micron

Ver	GCP	CHK	TIE	APs	Rej	Sigma	STD-X (mm)	STD-Y (mm)	STD-Z (mm)	RMSE-X (mm)	RMSE-Y (mm)	RMSE-Z (mm)
						(μm) (pixel)	of CHK+TIE points			at CHK points		
10	87	0	90	10	0	**1.20** 0.43	**0.291**	**0.558**	**0.251**	N.A.	N.A.	N.A.

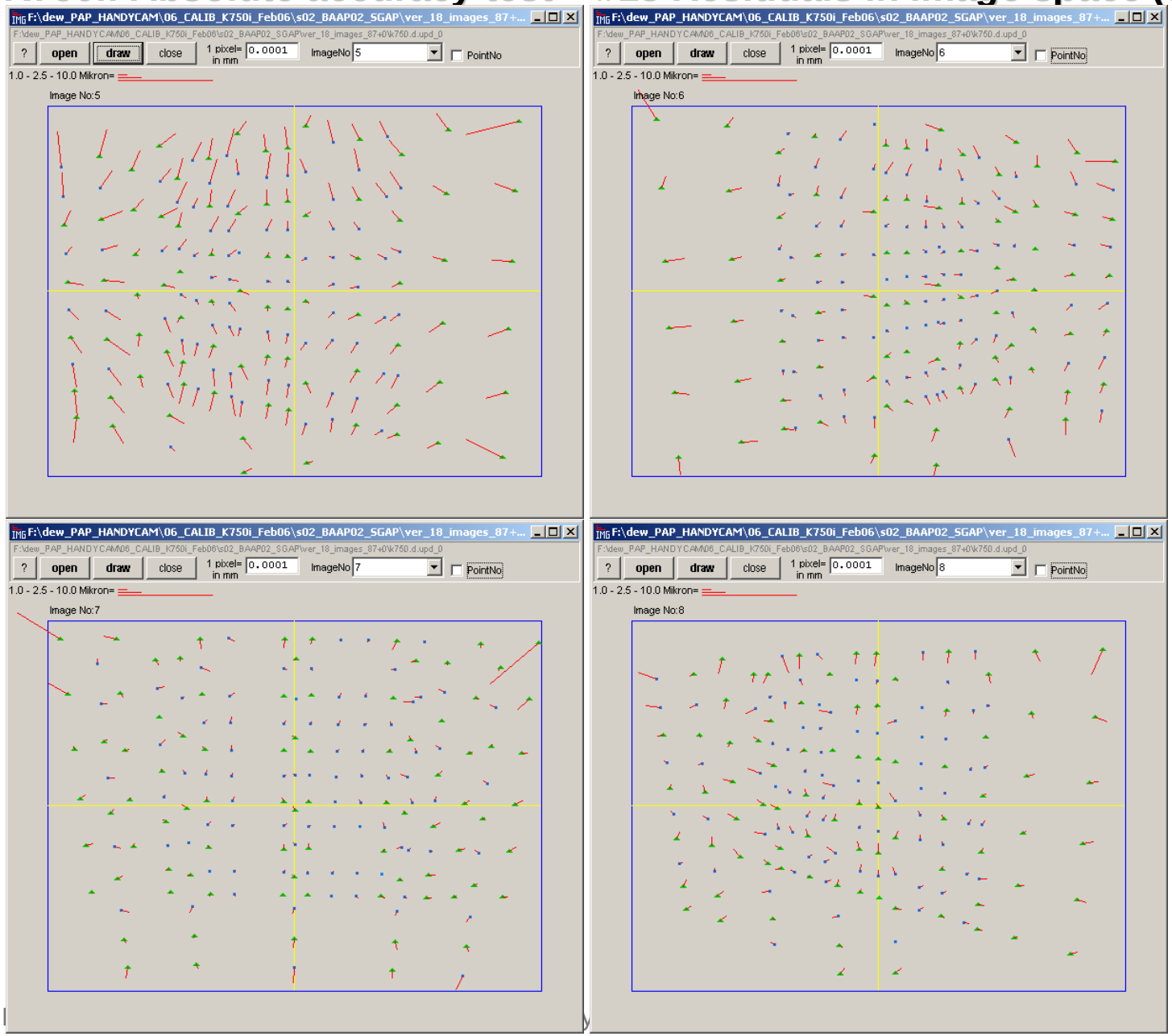
Ver : Version number
GCP : Number of control points
CHK : Number of check points
TIE : Number of tie points
APs : Number of additional parameters
Rej : Rejected rays by data-snooping,

Sigma : Standard deviation of unit weight a posteriori
STD : Average theoretical precision values of CHK/GCP coordinates
RMSE : Empirical accuracies of CHK/GCP coordinates in object space

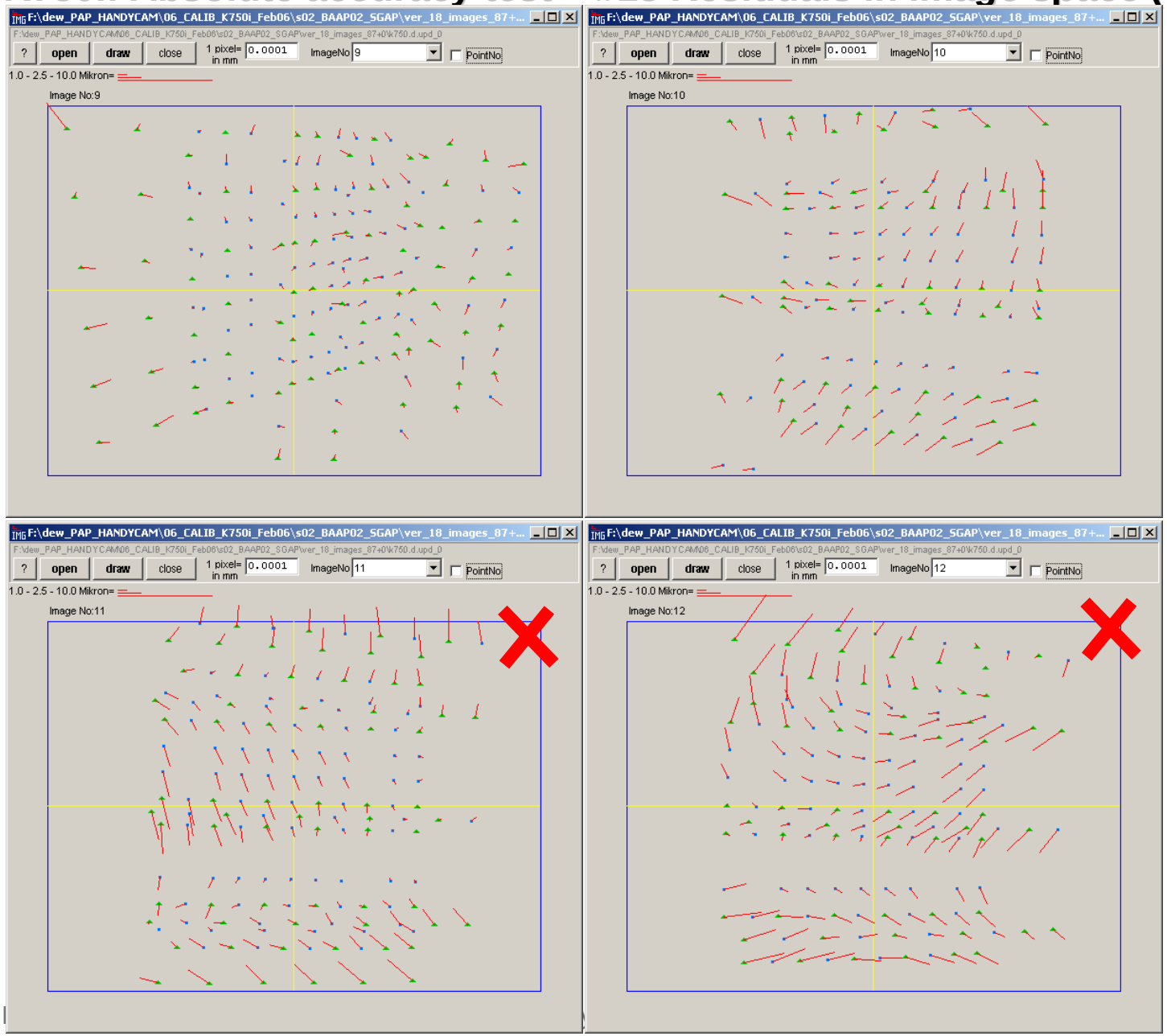
K750i: Absolute accuracy test – #18 Residuals in image space (1-4)



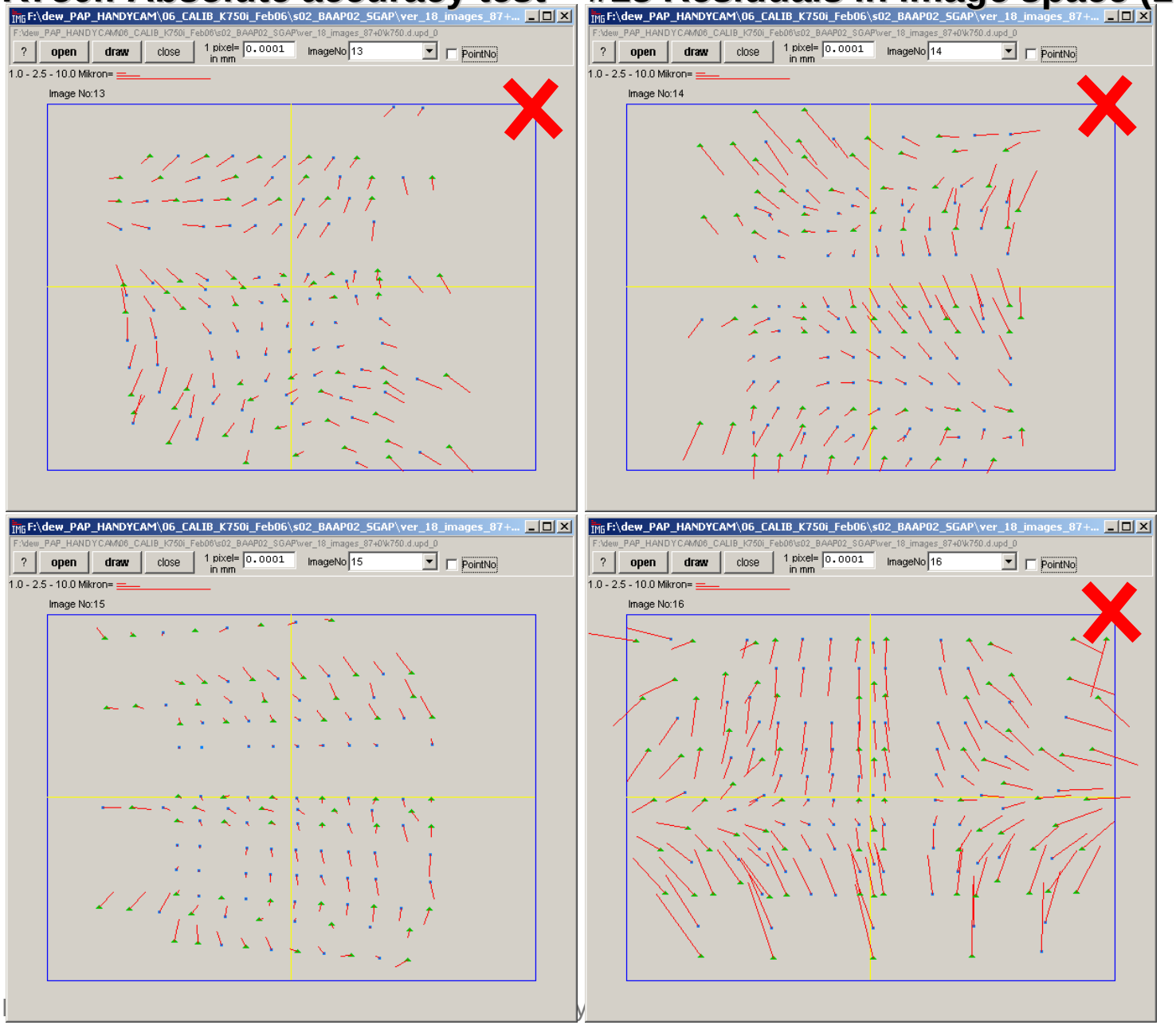
K750i: Absolute accuracy test – #18 Residuals in image space (5-8)



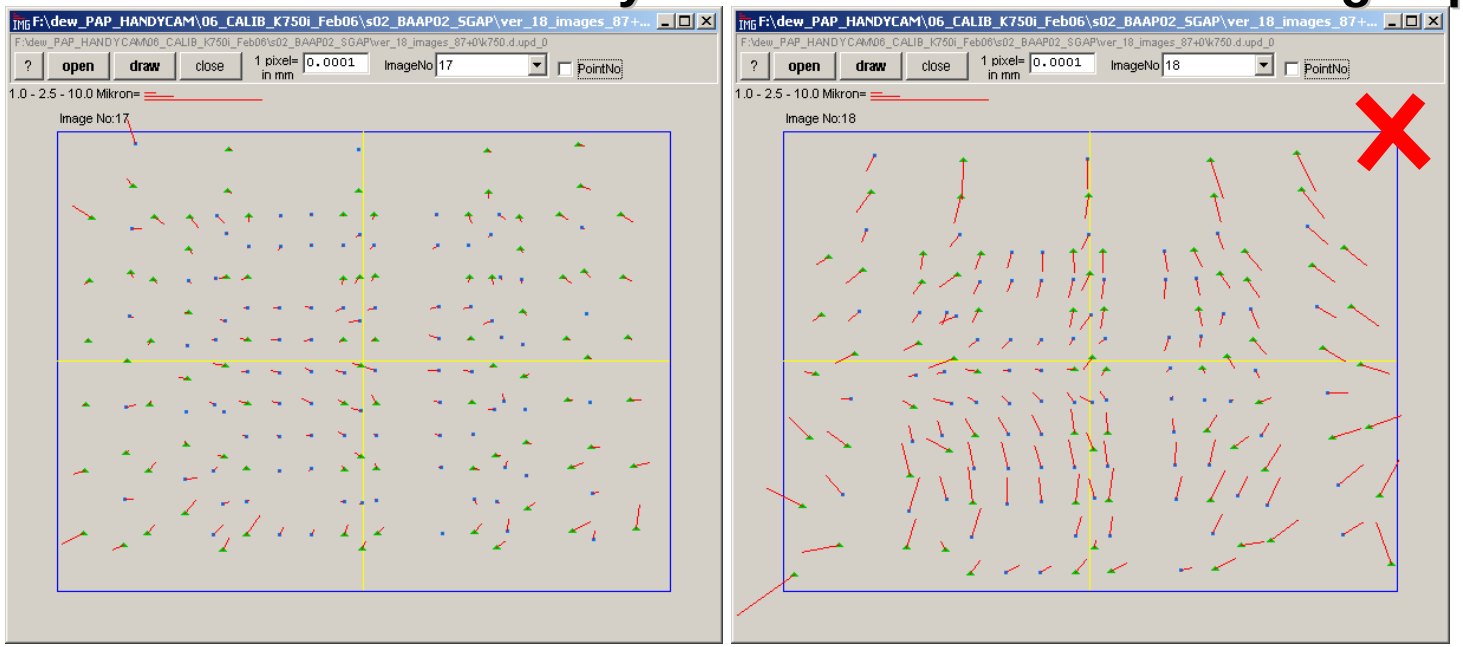
K750i: Absolute accuracy test – #18 Residuals in image space (9-12)



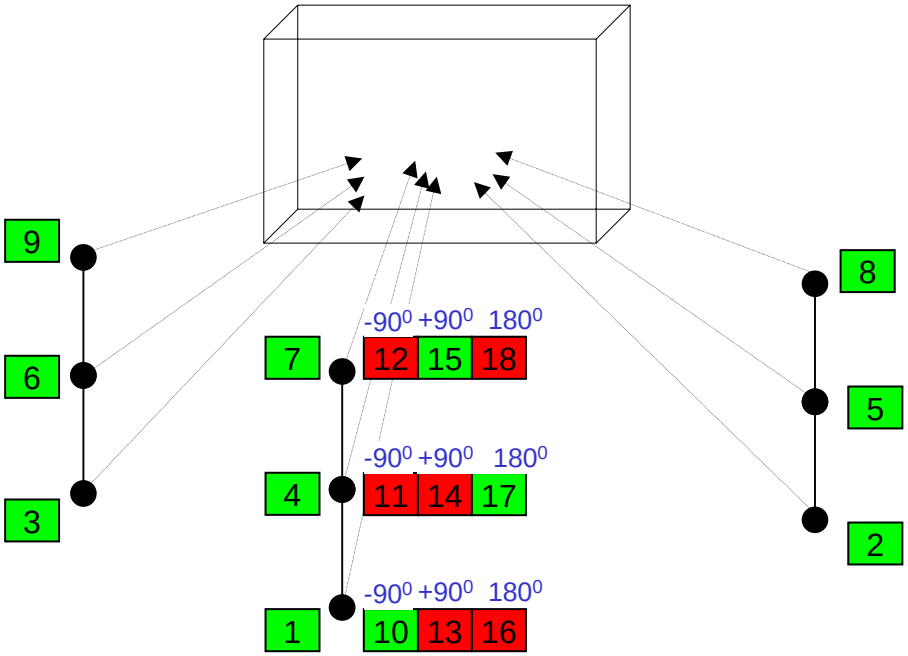
K750i: Absolute accuracy test – #18 Residuals in image space (13-16)

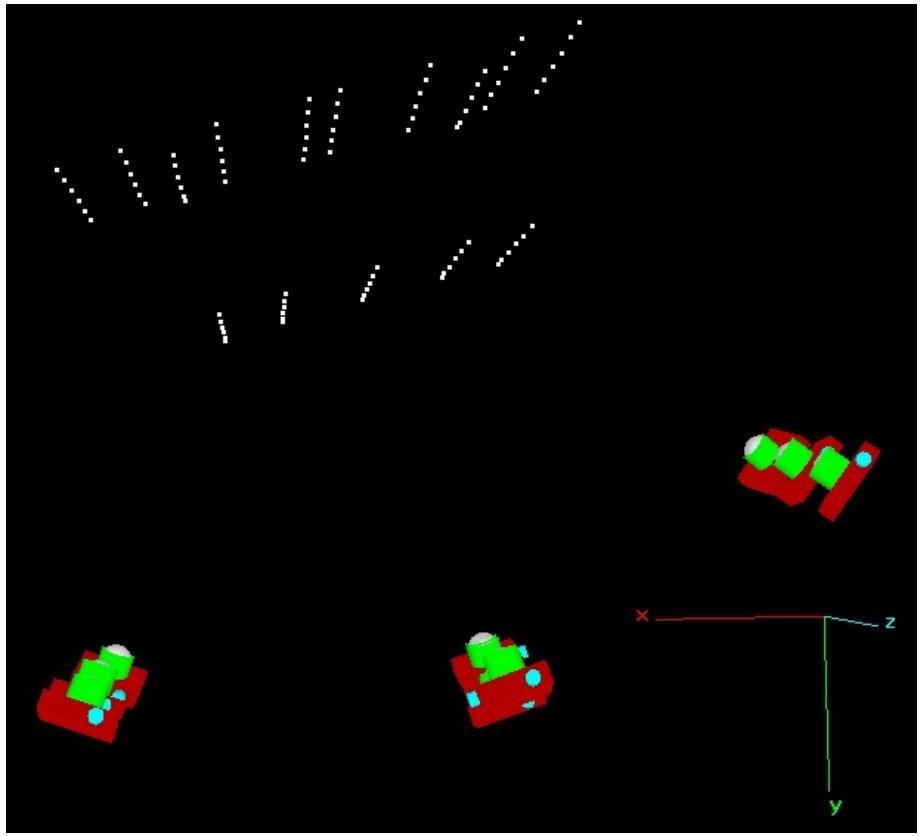


K750i: Absolute accuracy test – #18 Residuals in image space (17-18)



K750i: Accuracy test – Image rejection





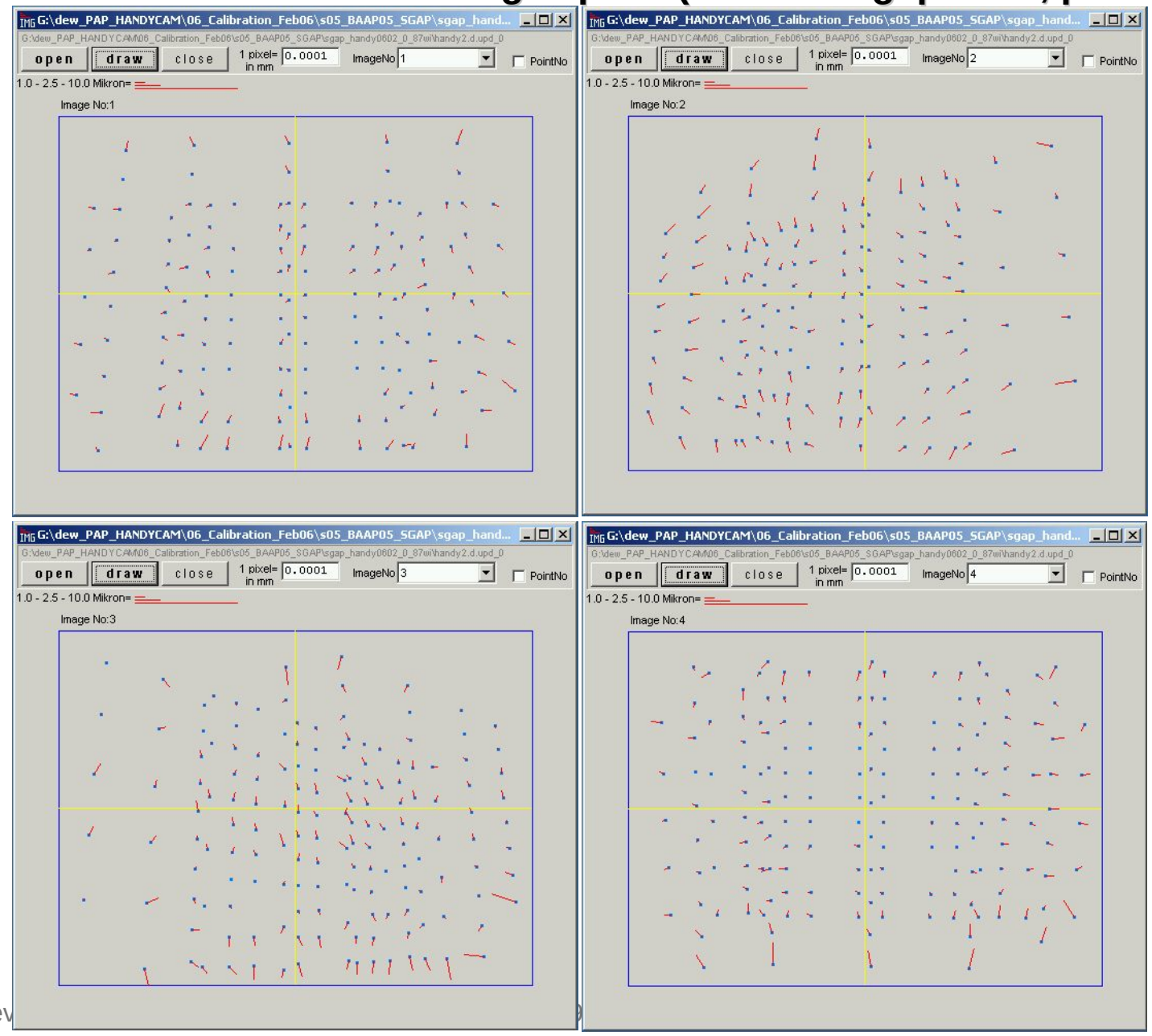
- **REDs**: Excluded images
- **GREEN**: Remained images
- 9 pictures normal case, 1/1/1: -90^0 / $+90^0$ /180^0 rotated
- NOW totally 12 pictures

K750i: Accuracy test – #12 results

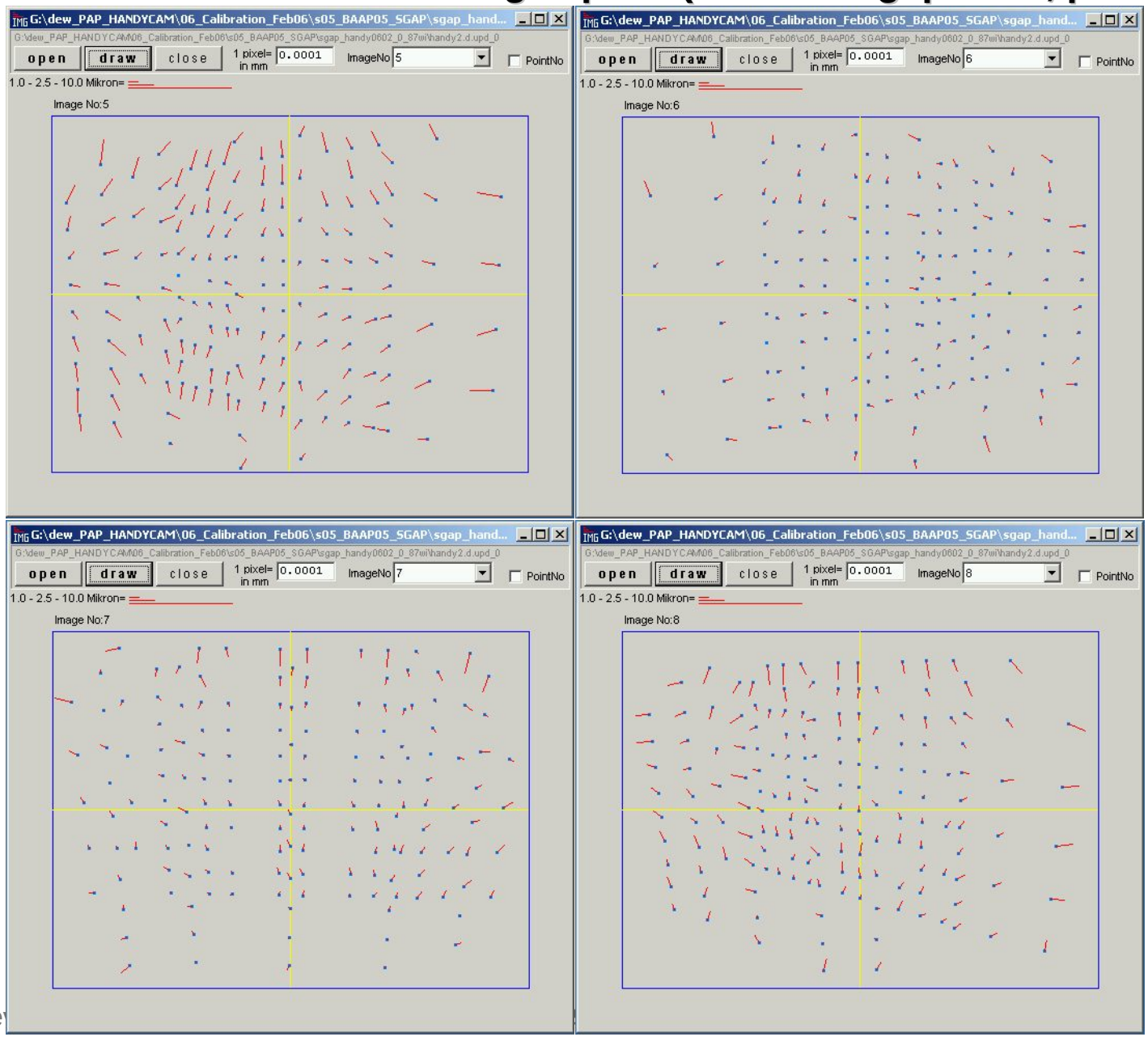
Number of images: 12 (JPEG)
Pixel size: 2.8 micron

Ver	GCP	CHK	TIE	APs	Rej	Sigma	STD-X (mm)	STD-Y (mm)	STD-Z (mm)	RMSE-X (mm)	RMSE-Y (mm)	RMSE-Z (mm)
						(μm) (pixel)	of CHK+TIE points			at CHK points		
11	**87**	0	80	10	26	**0.65** 0.23	**0.187**	**0.307**	**0.161**	Na	Na	Na
12	**87**	0	80	**44**	26	**0.64** 0.23	**0.185**	**0.304**	**0.159**	Na	Na	Na
13	**44**	43	80	10	25	**0.64** 0.23	**0.188**	**0.312**	**0.163**	**0.280**	**0.498**	**0.201**
14	**10**	77	80	10	27	**0.61** 0.22	**0.196**	**0.318**	**0.173**	**0.499**	**1.048**	**0.501**
15	**167** free	--	**--**	10	30	**0.59** 0.21	**0.174**	**0.283**	**0.151**	Na	Na	Na

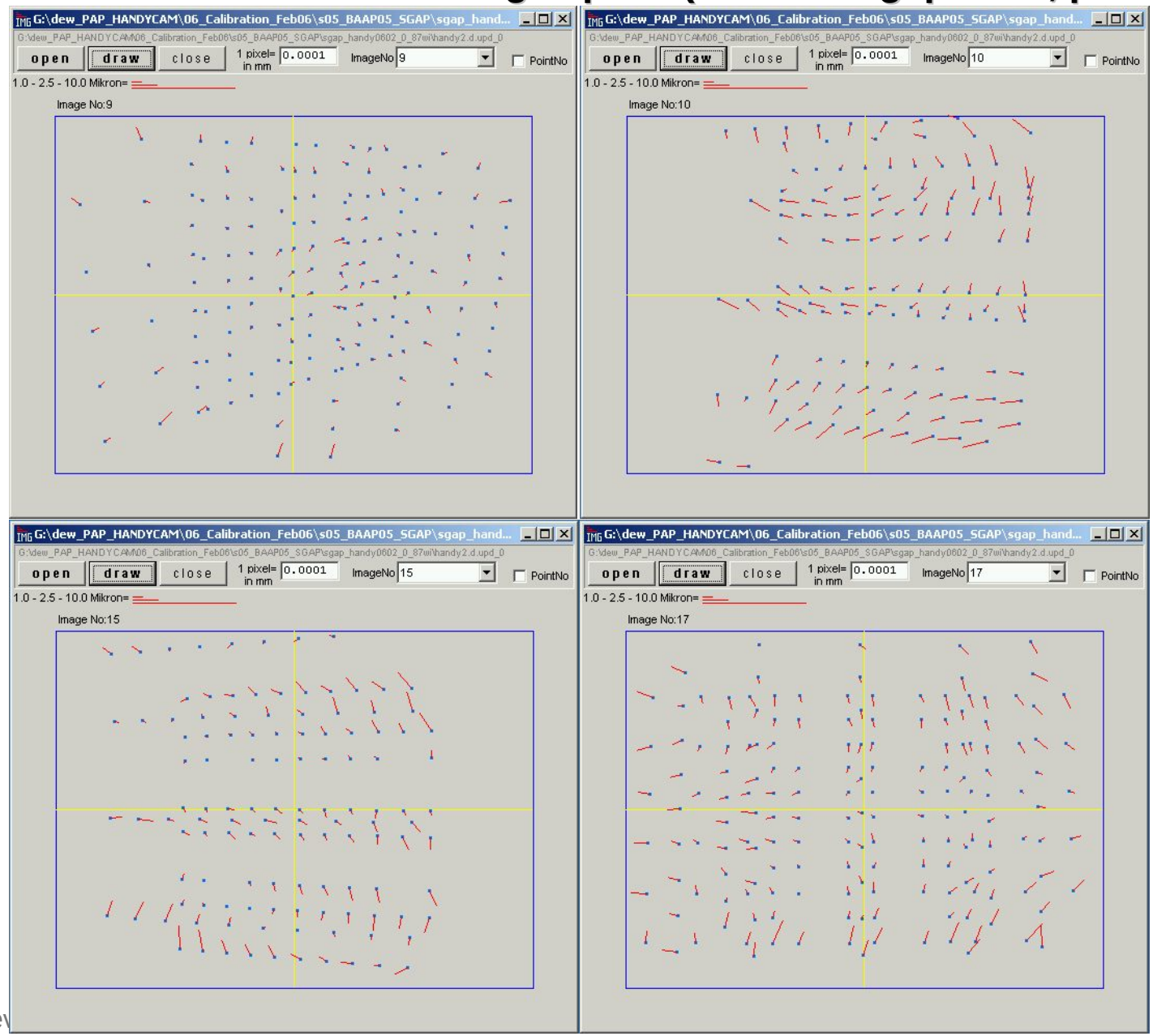
K750i: #12 - Residuals in image space (Ver.11: 87gcp/0chk, pictures 1-4)



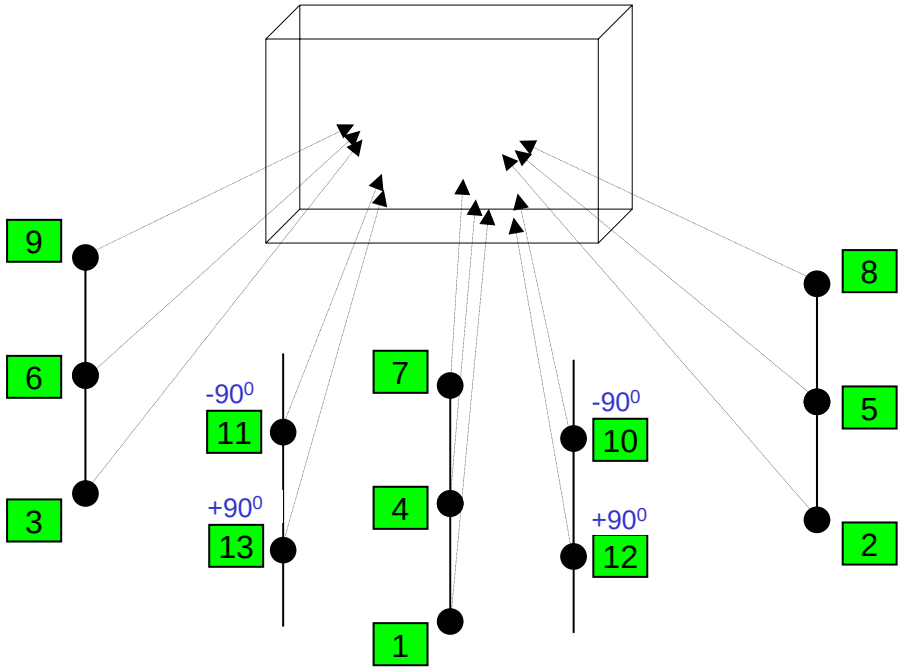
K750i: #12 - Residuals in image space (Ver.11: 87gcp/0chk, pictures 5-8)

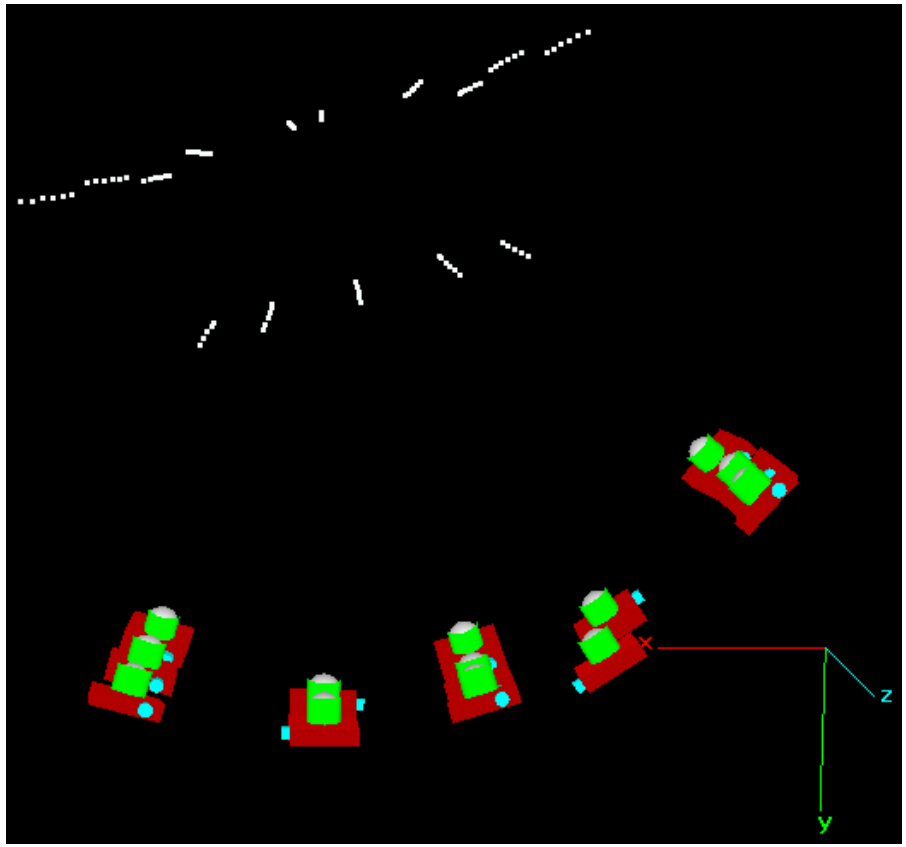


K750i: #12 - Residuals in image space (Ver.11: 87gcp/0chk, pictures 9-12)



N93: Accuracy test – Network configuration (6th February, 2007)





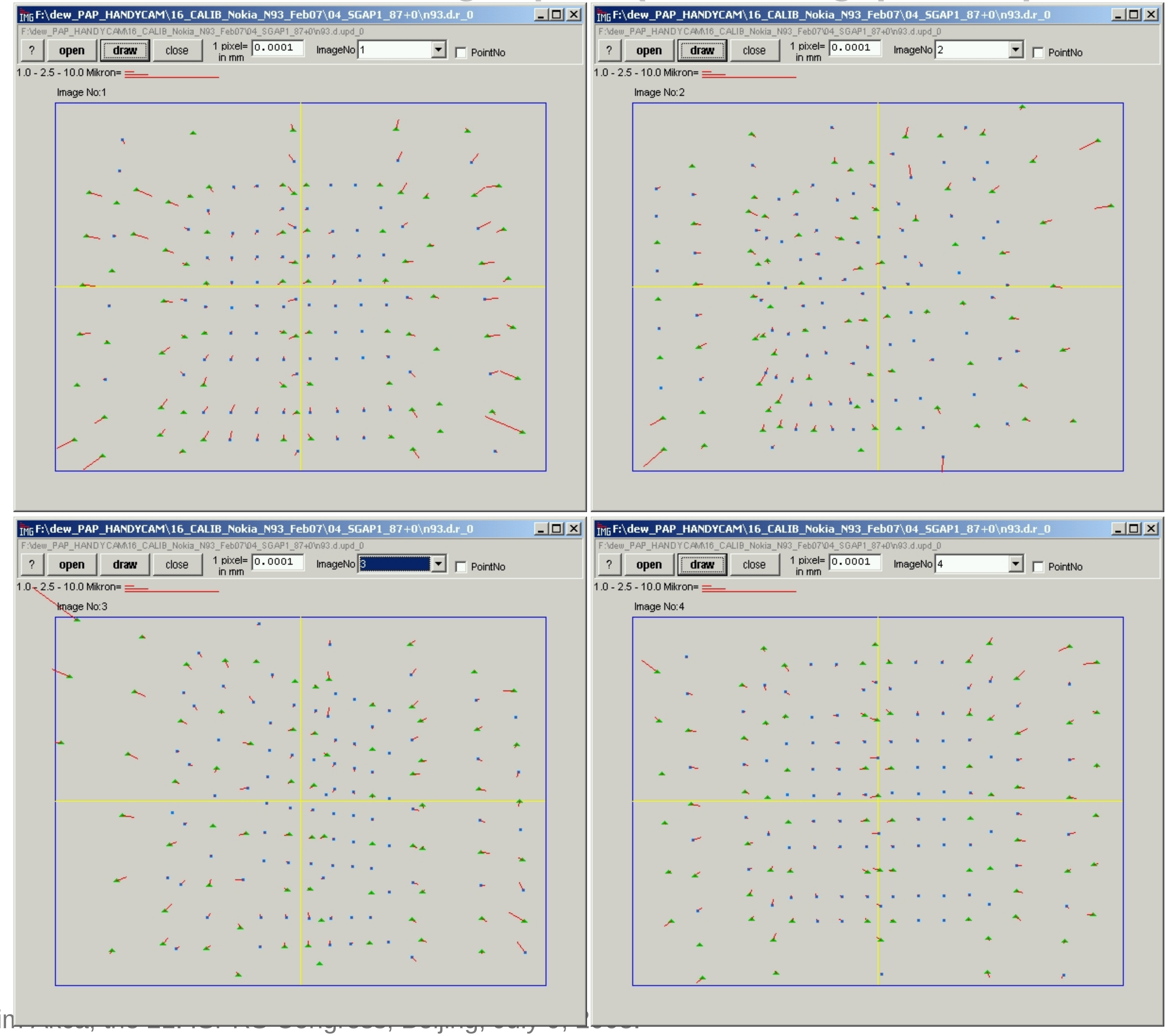
- 13 stations, convergent geometry,
- 13 pictures
- 9 pictures normal case, 2/2 pictures $+90^0$ /-90^0 rotated

N93: Accuracy test – Results (6th February, 2007)

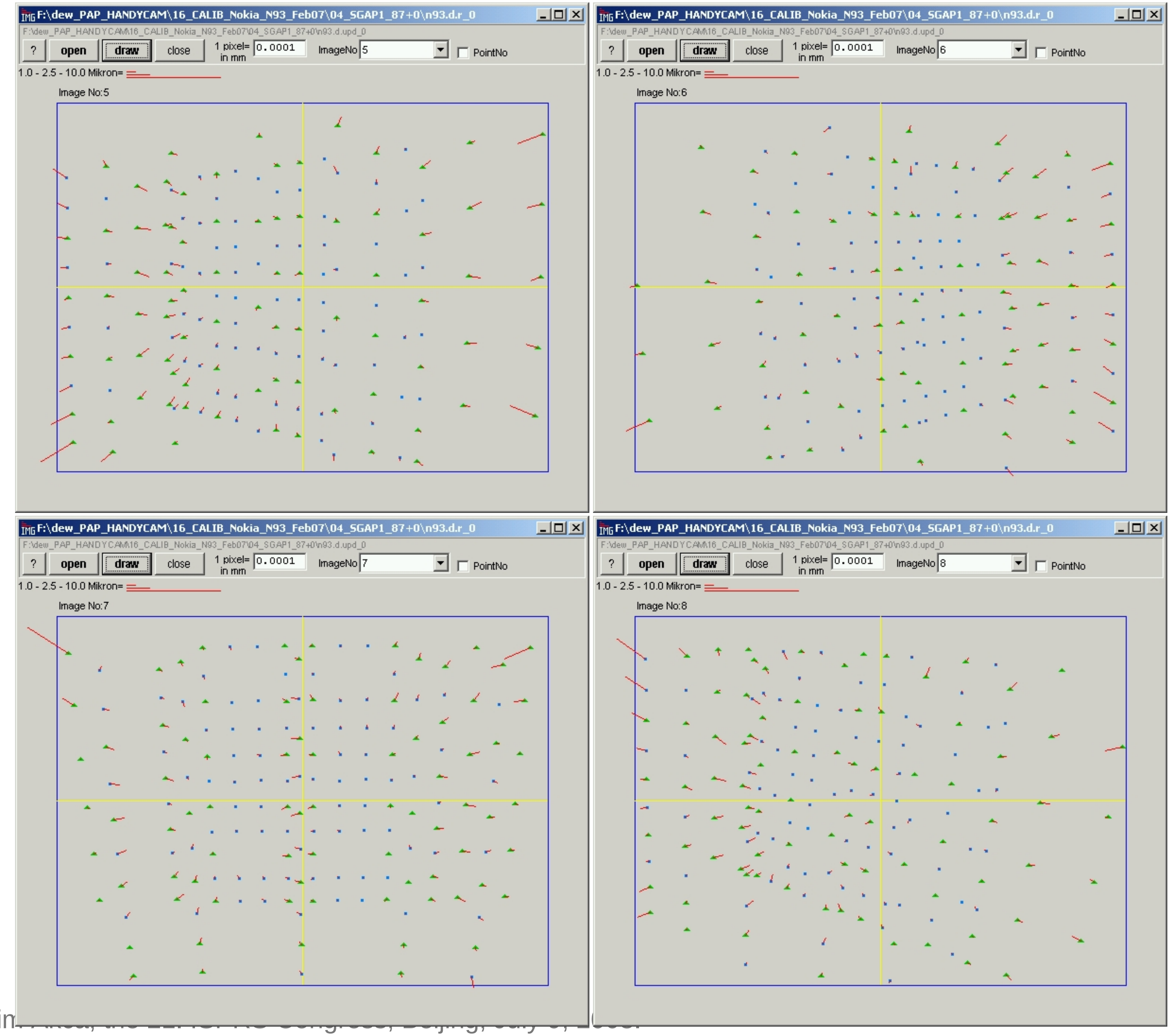
Number of images: 13 (JPEG)
Pixel size: 2.2 micron

Ver	GCP	CHK	TIE	APs	Rej	Sigma	STD-X (mm)	STD-Y (mm)	STD-Z (mm)	RMSE-X (mm)	RMSE-Y (mm)	RMSE-Z (mm)
						(μm) (pixel)	of CHK+TIE points			at CHK points		
21	**87**	0	99	10	0	**0.55** 0.25	**0.165**	**0.312**	**0.139**	Na	Na	Na
22	**44**	43	99	10	0	**0.52** 0.24	**0.157**	**0.286**	**0.133**	**0.449**	**0.617**	**0.225**
23	**10**	77	99	10	0	**0.50** 0.23	**0.161**	**0.284**	**0.140**	**0.701**	**0.816**	**0.203**
24	**186** free	--	**--**	10	0	**0.47** 0.21	**0.144**	**0.250**	**0.120**	Na	Na	Na

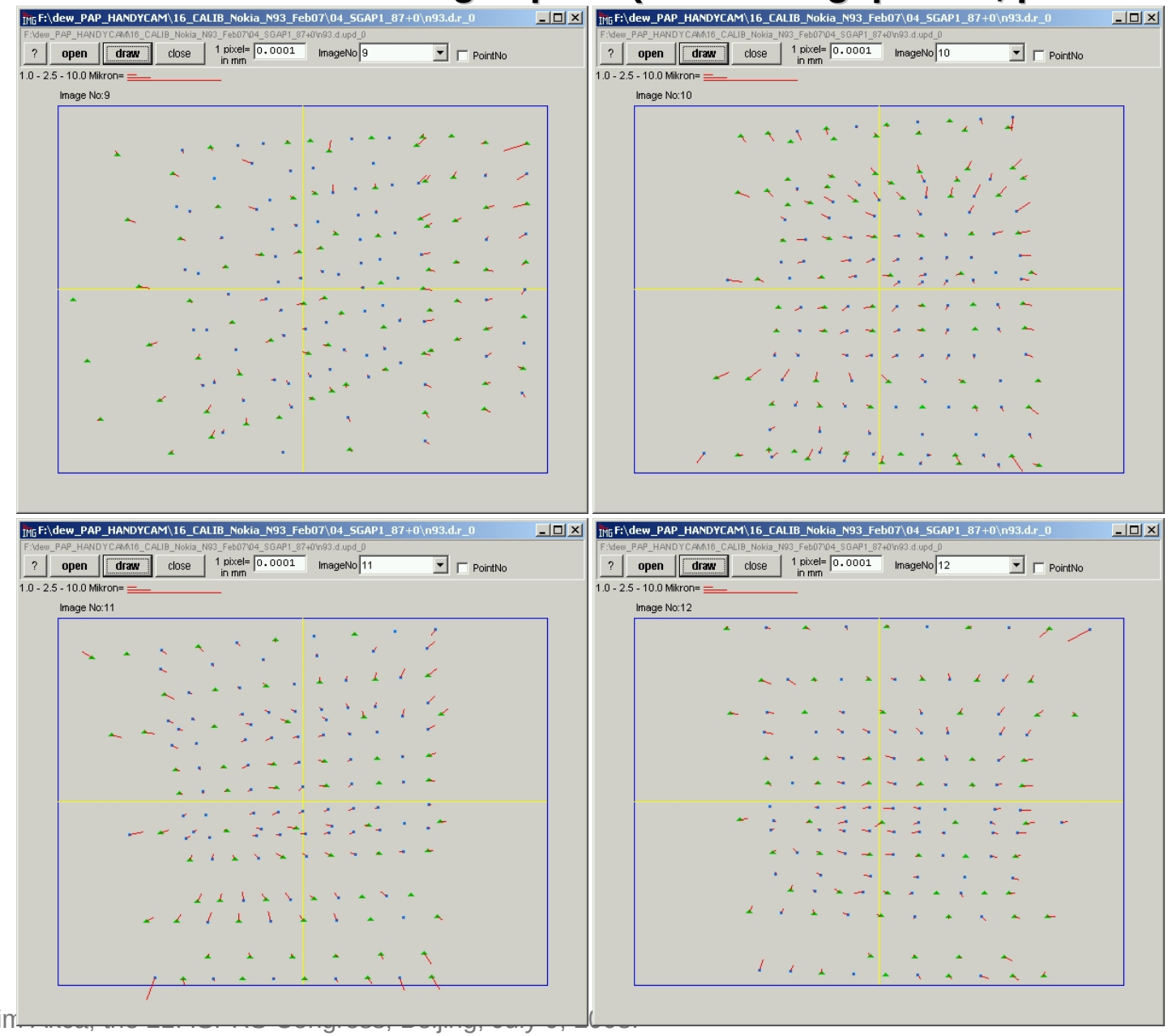
N93: #13 – Residuals in image space (Ver.21: 87gcp/0chk, pictures 1-4)



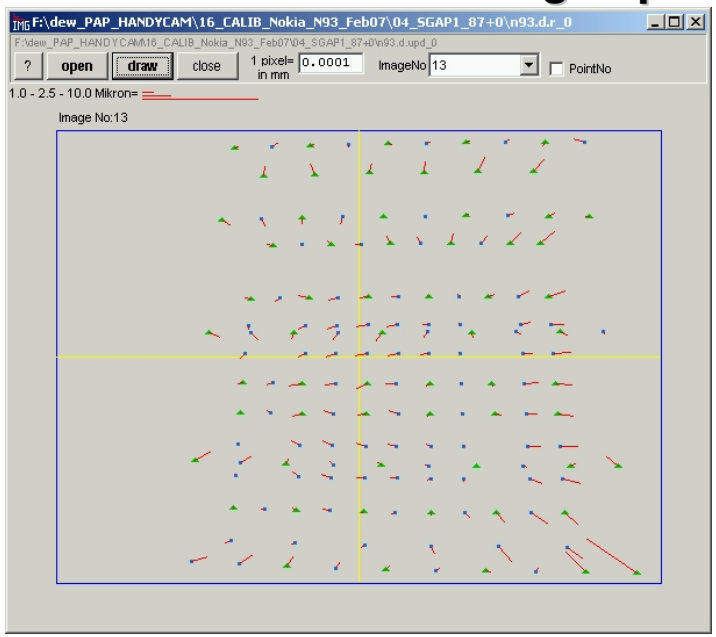
N93: #13 – Residuals in image space (Ver.21: 87gcp/0chk, pictures 5-8)



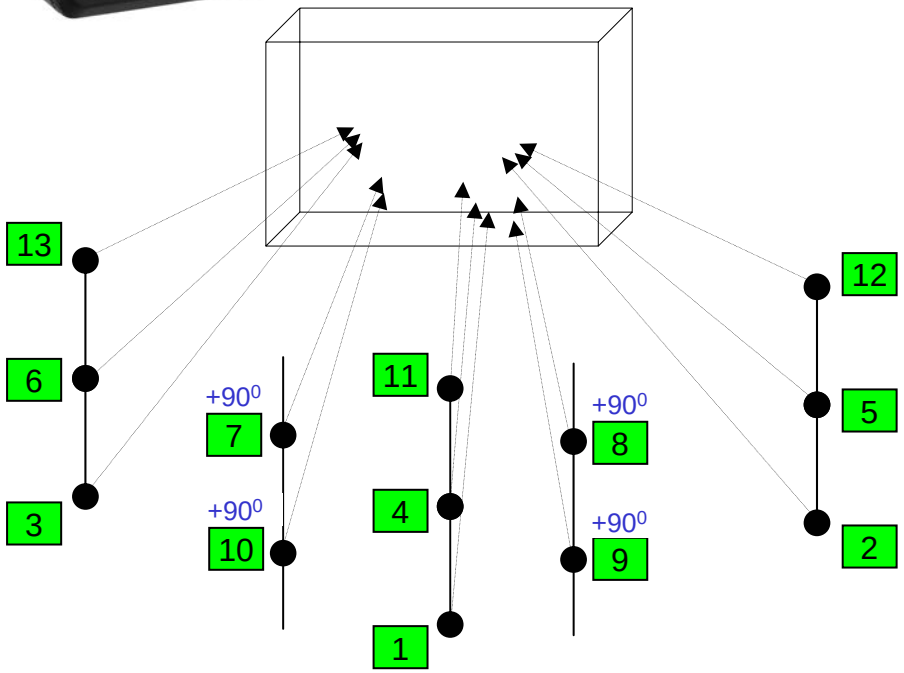
N93: #13 – Residuals in image space (Ver.21: 87gcp/0chk, pictures 9-12)

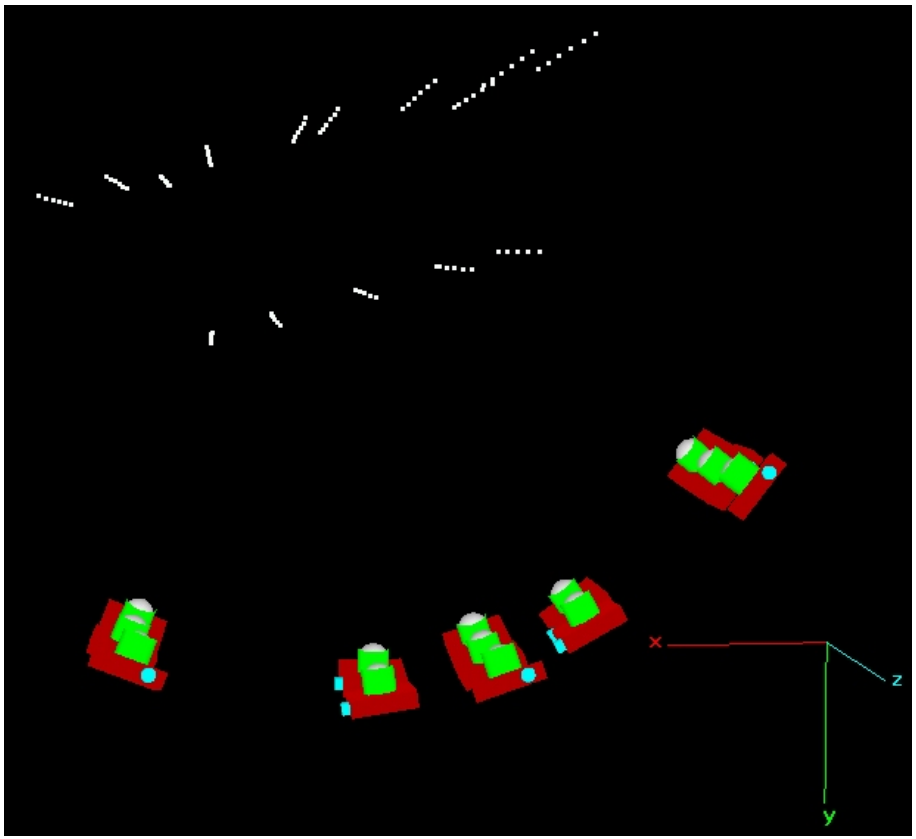


N93: #13 – Residuals in image space (Ver.21: 87gcp/0chk, picture 13)



W100: Accuracy test – Network configuration





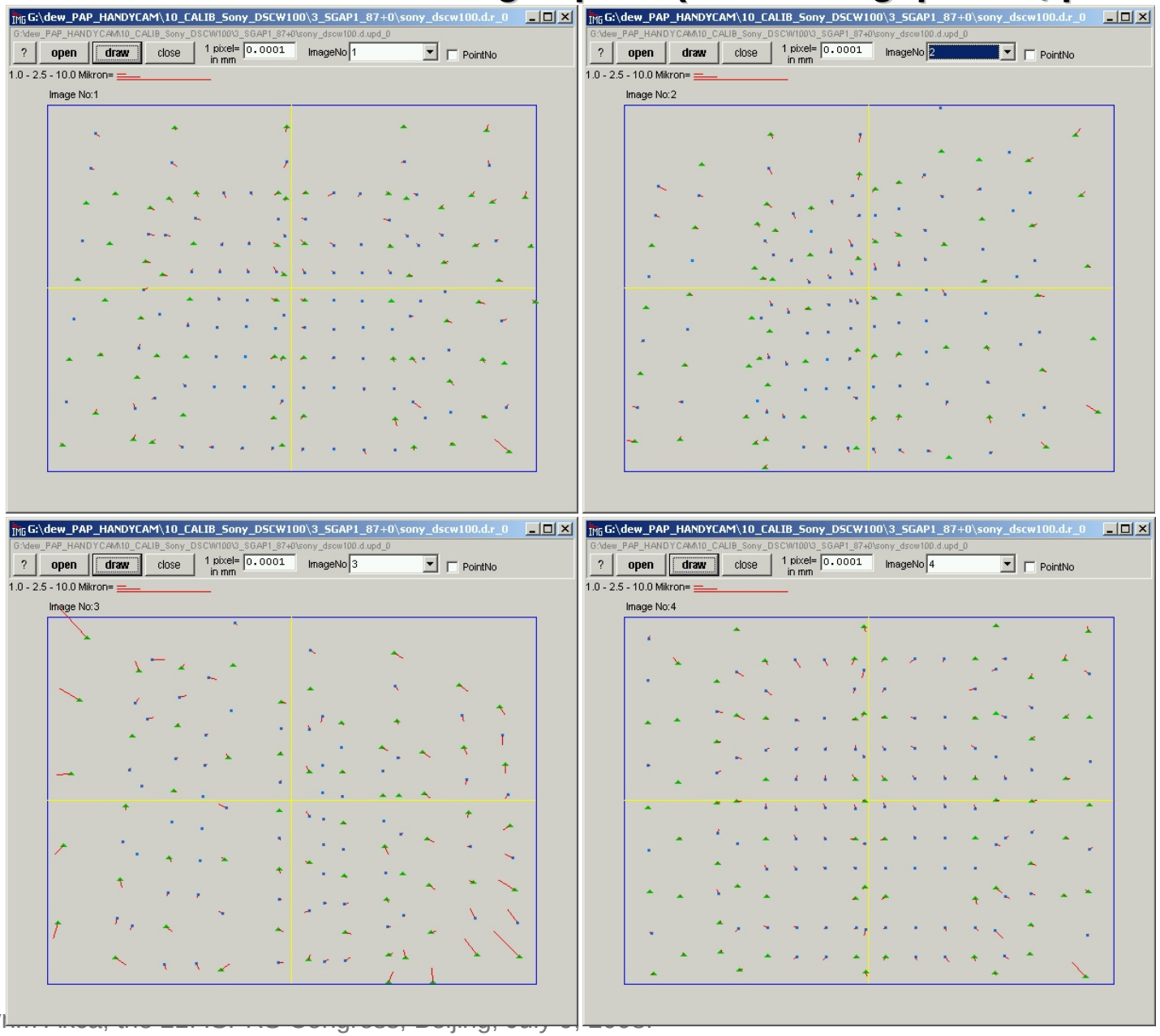
- 13 stations, convergent geometry
- 13 pictures
- 9 pictures normal case, 4 pictures +90⁰ rotated

W100: Accuracy test – Results

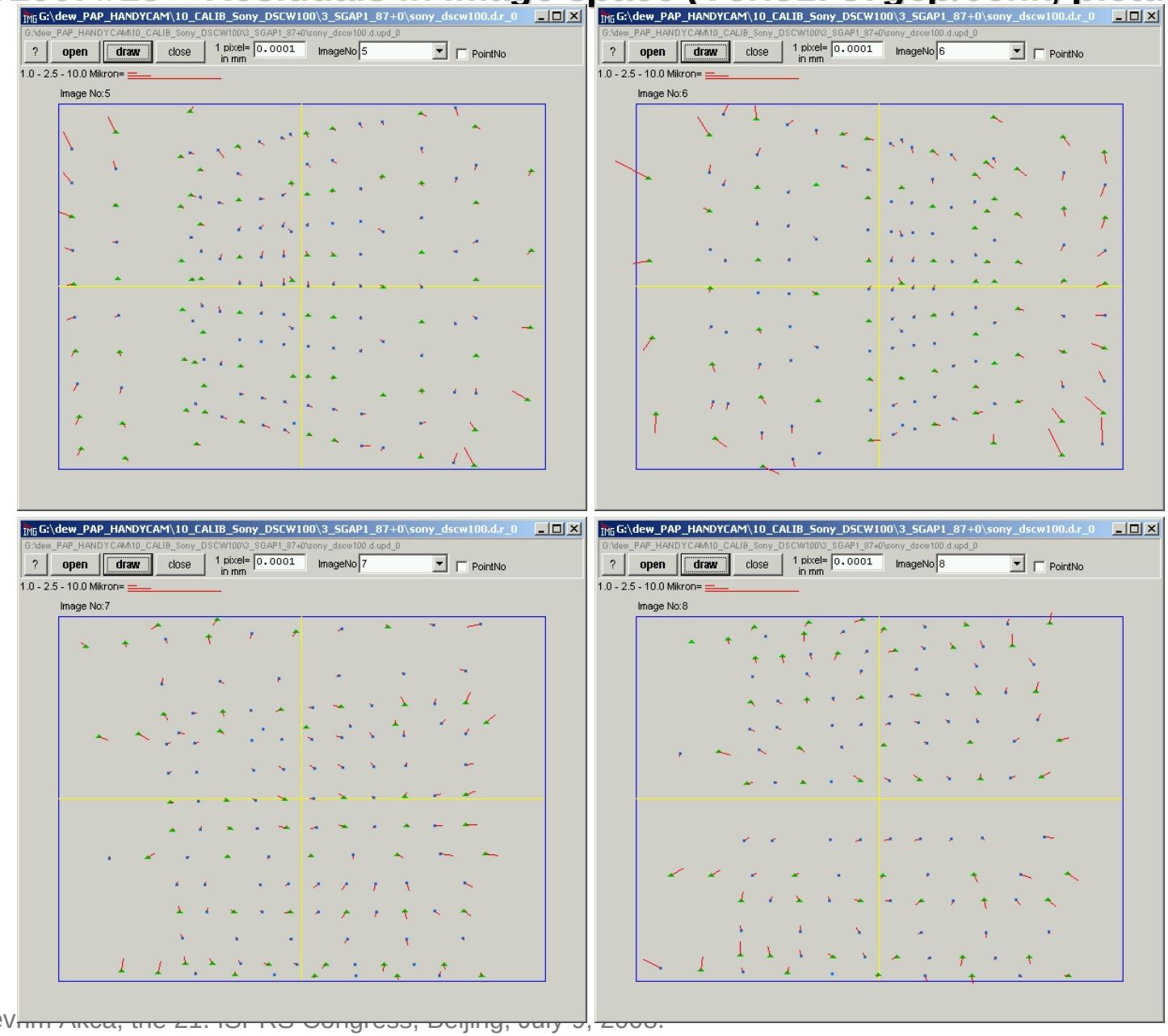
Number of images: 13 (JPEG)
Pixel size: 2.2 micron

Ver	GCP	CHK	TIE	APs	Rej	Sigma	STD-X (mm)	STD-Y (mm)	STD-Z (mm)	RMSE-X (mm)	RMSE-Y (mm)	RMSE-Z (mm)
						(μm) (pixel)	of CHK+TIE points			at CHK points		
31	**87**	0	92	10	0	**0.59** 0.27	**0.114**	**0.203**	**0.094**	Na	Na	Na
32	**44**	43	92	10	0	**0.55** 0.25	**0.104**	**0.181**	**0.084**	**0.298**	**0.369**	**0.221**
33	**10**	77	92	10	0	**0.47** 0.21	**0.100**	**0.168**	**0.085**	**0.501**	**0.421**	**0.443**
34	**179** free	--	**--**	10	0	**0.44** 0.20	**0.083**	**0.140**	**0.067**	Na	Na	Na

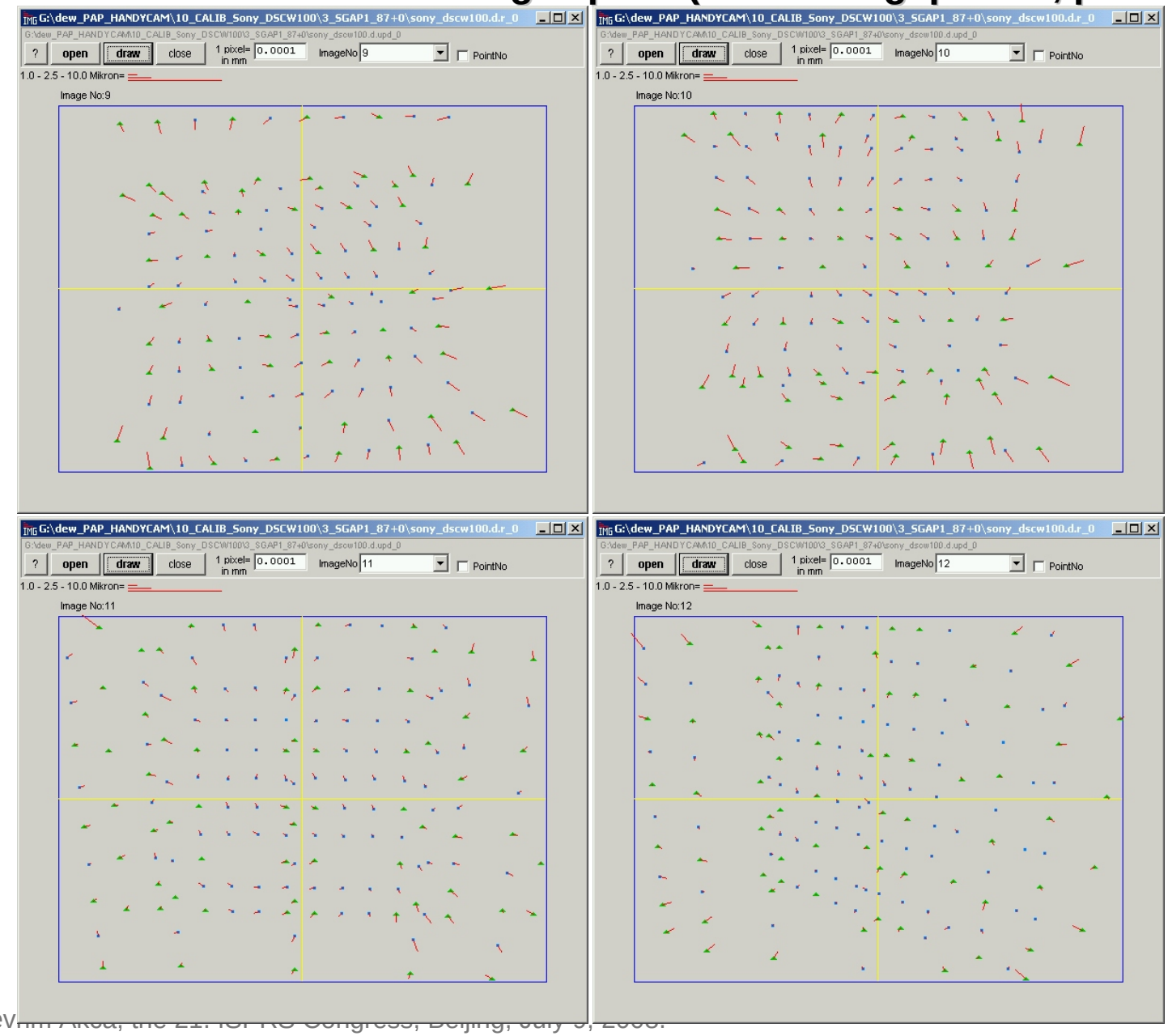
W100: #13 – Residuals in image space (Ver.31: 87gcp/0chk, pictures 1-4)



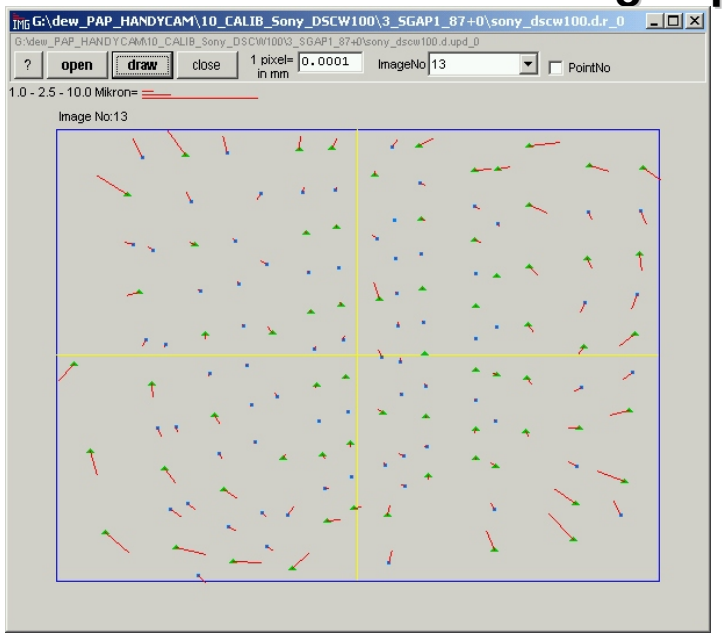
W100: #13 – Residuals in image space (Ver.31: 87gcp/0chk, pictures 5-8)



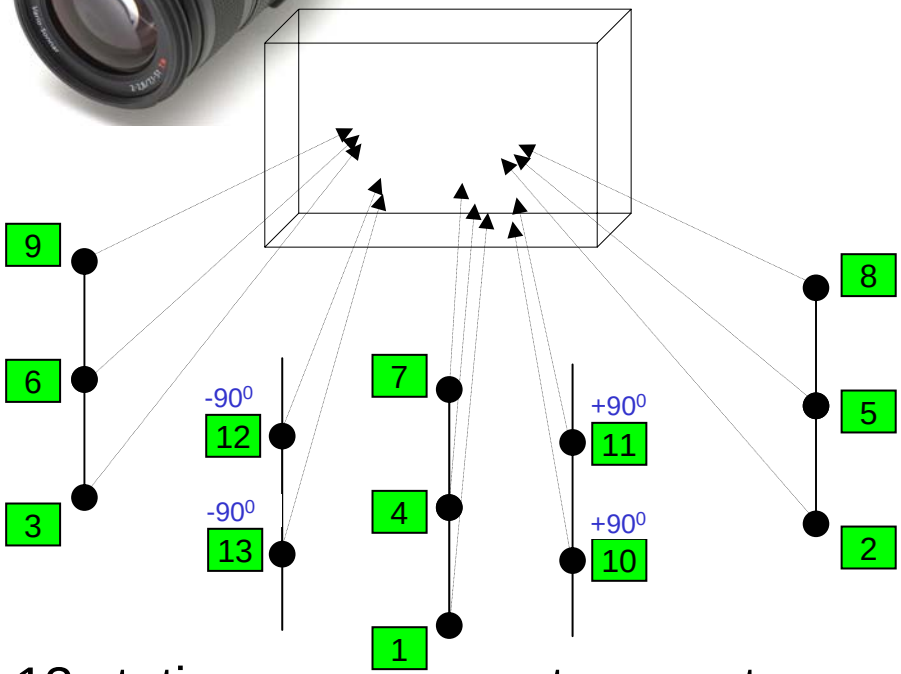
W100: #13 – Residuals in image space (Ver.31: 87gcp/0chk, pictures 9-12)

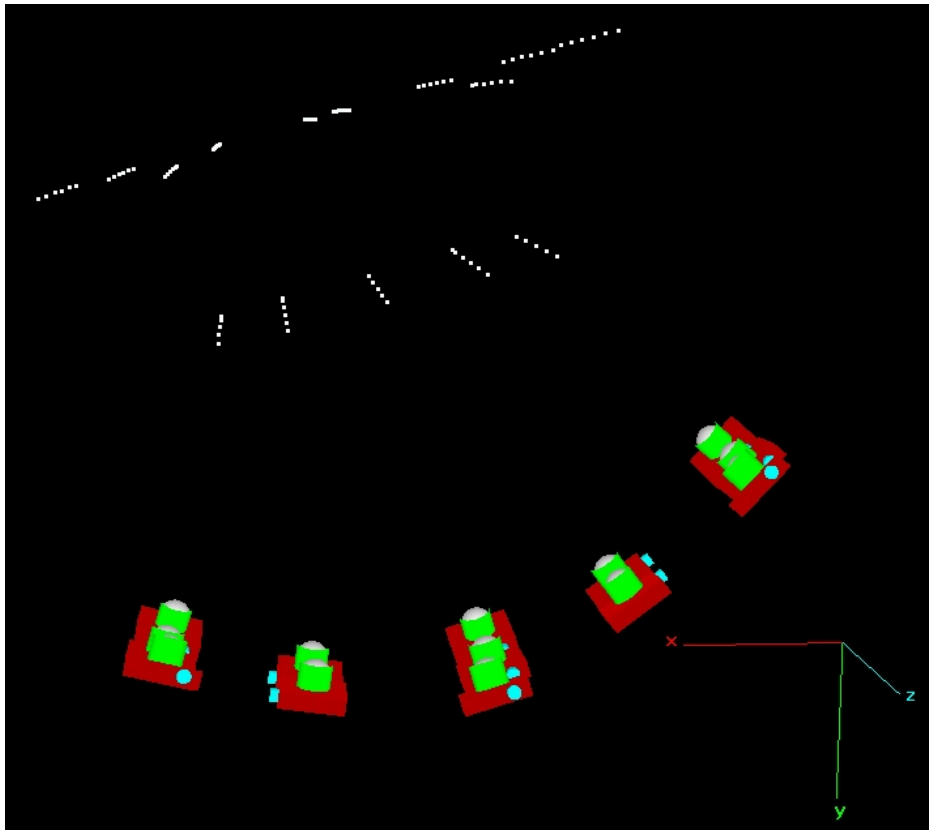


W100: #13 – Residuals in image space (Ver.31: 87gcp/0chk, picture 13)



F828: Accuracy test – Network configuration





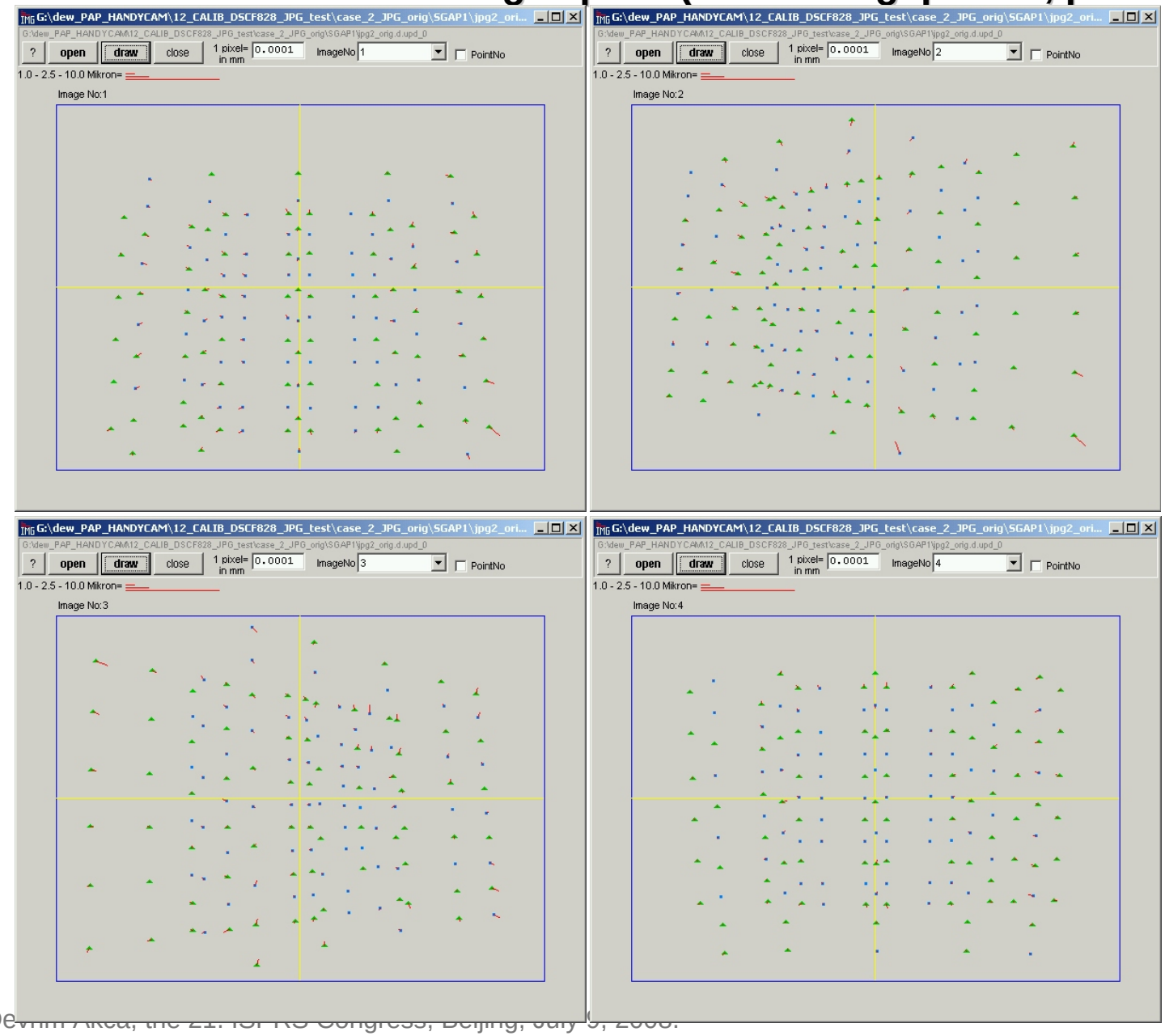
- 13 stations, convergent geometry
- 13 pictures
- 9 pictures normal case, 2/2 : $+90^0$ / -90^0 rotated

F828: Accuracy test – Results

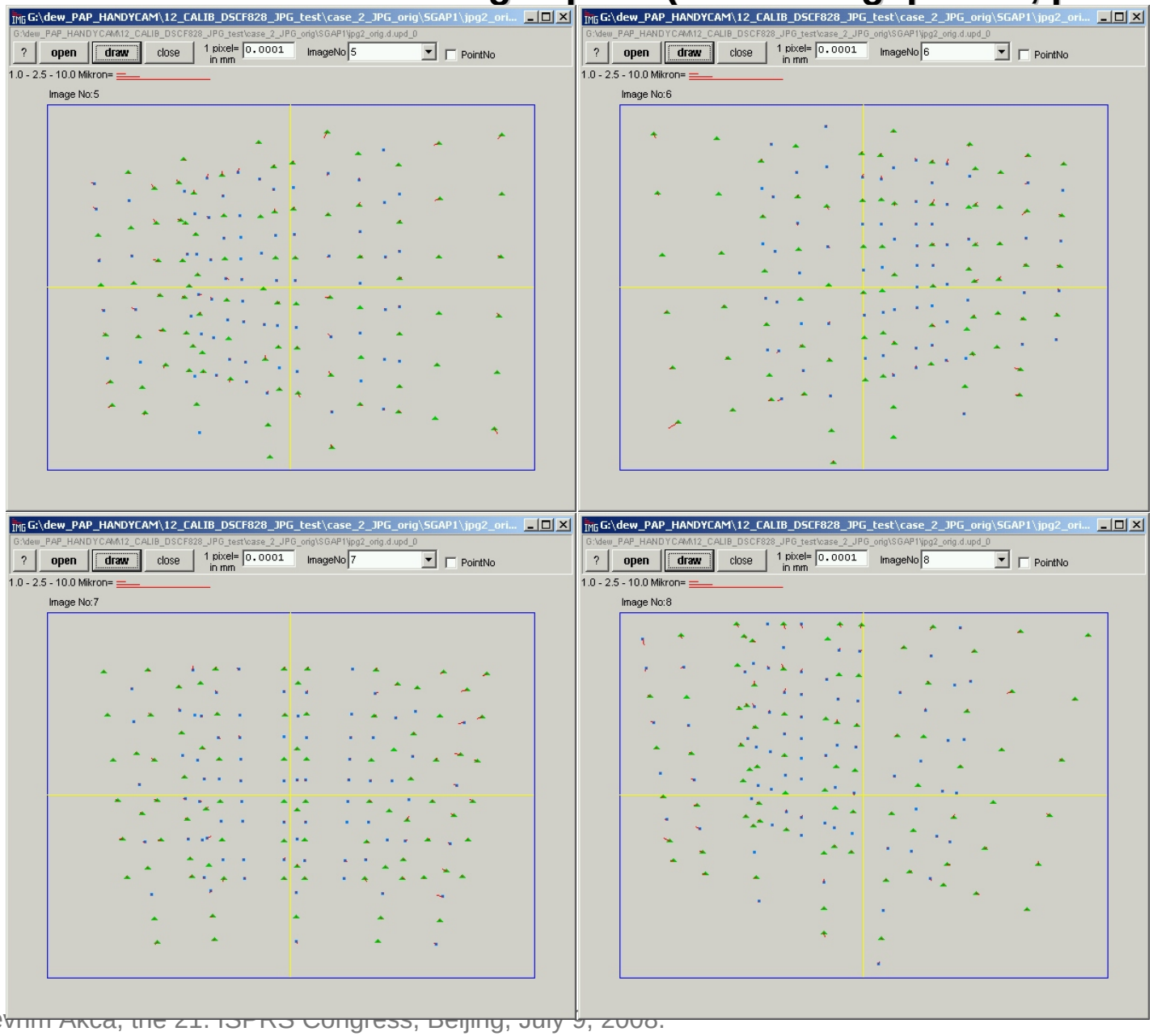
Number of images: 13 (JPEG)
Pixel size: 2.7 micron

Ver	GCP	CHK	TIE	APs	Rej	Sigma	STD-X (mm)	STD-Y (mm)	STD-Z (mm)	RMSE-X (mm)	RMSE-Y (mm)	RMSE-Z (mm)
						(μm) (pixel)	of CHK+TIE points			at CHK points		
41	**87**	0	81	10	0	**0.27** 0.10	**0.048**	**0.084**	**0.041**	Na	Na	Na
42	**44**	43	81	10	0	**0.27** 0.10	**0.047**	**0.082**	**0.040**	**0.076**	**0.125**	**0.058**
43	**10**	77	81	10	0	**0.26** 0.10	**0.049**	**0.084**	**0.043**	**0.097**	**0.144**	**0.134**
44	**168** free	--	**--**	10	0	**0.25** 0.09	**0.043**	**0.074**	**0.037**	Na	Na	Na

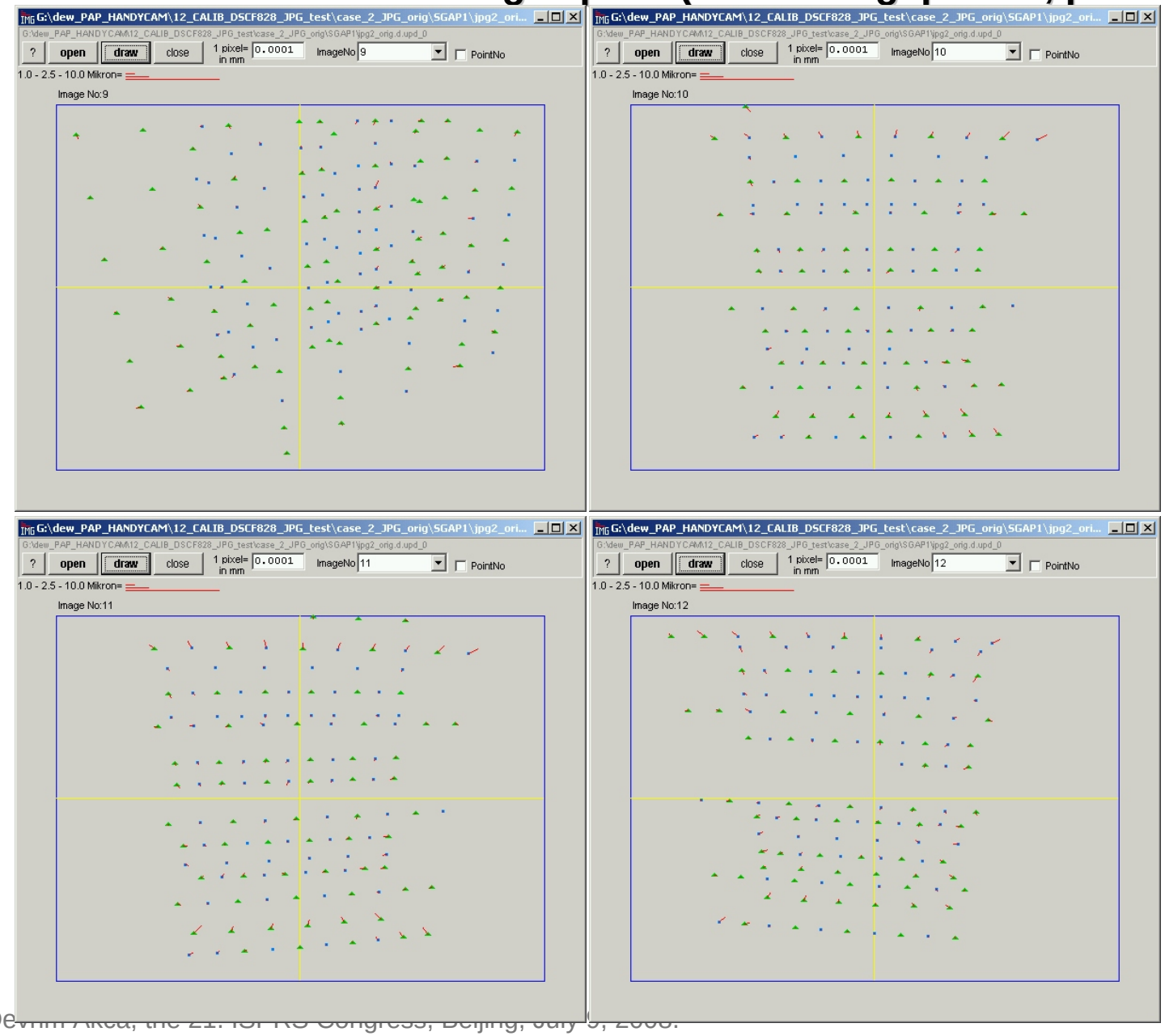
F828: #13 - Residuals in image space (Ver.41: 87gcp/0chk, pictures 1-4)



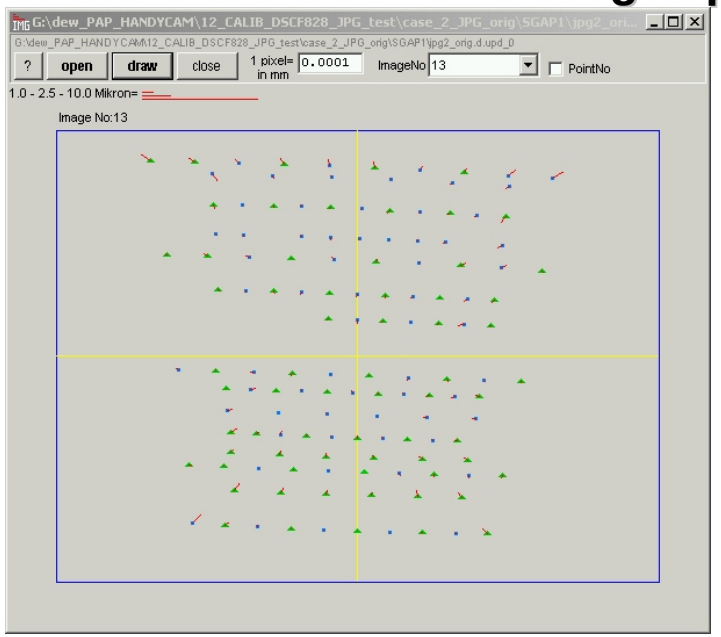
F828: #13 - Residuals in image space (Ver.41: 87gcp/0chk, pictures 5-8)



F828: #13 - Residuals in image space (Ver.41: 87gcp/0chk, pictures 9-12)



F828: #13 - Residuals in image space (Ver.41: 87gcp/0chk, picture 13)



F828: #13 – JPEG Test

Number of images: 13 (TIFF and JPEG)
Pixel size: 2.7 micron

Ver	CoR	GCP	CHK	TIE	APs	Sigma	STD-X (mm)	STD-Y (mm)	STD-Z (mm)	RMSE-X (mm)	RMSE-Y (mm)	RMSE-Z (mm)
						(μm) (pixel)	of CHK+TIE points			at CHK points		
51 **TIFF**	**Na** 23,410KB	44	43	81	10	**0.26** 0.10	**0.047**	**0.082**	**0.040**	**0.077**	**0.120**	**0.059**
52 **Q100**	**5.5** 4,265KB	44	43	81	10	**0.26** 0.10	**0.047**	**0.082**	**0.040**	**0.078**	**0.124**	**0.059**
53 **Q70**	**41.7** 562KB	44	43	81	10	**0.26** 0.10	**0.047**	**0.082**	**0.040**	**0.077**	**0.132**	**0.060**

CoR : Compression ratio

N93: Temporal Stability of the Int. Orientation (30th September, 2007)

Number of images: 13 (JPEG)

Pixel size: 2.2 micron

Same image data acquisition configuration with the version of 6th February, 2007 **!!**

Ver	GCP	CHK	TIE	APs	Rej	Sigma	STD-X (mm)	STD-Y (mm)	STD-Z (mm)	RMSE-X (mm)	RMSE-Y (mm)	RMSE-Z (mm)
						(μm) (pixel)	of CHK+TIE points			at CHK points		
61	**87**	0	99	10	0	**0.54** 0.25	**0.151**	**0.241**	**0.130**	Na	Na	Na
62	**44**	43	99	10	0	**0.52** 0.24	**0.147**	**0.234**	**0.127**	**0.381**	**0.471**	**0.203**
63	**10**	77	99	10	0	**0.49** 0.23	**0.155**	**0.245**	**0.136**	**0.574**	**0.636**	**0.222**
64	**186** free	--	**--**	10	0	**0.48** 0.21	**0.138**	**0.217**	**0.116**	Na	Na	Na

6th February, 2007

Sigma	STD-X (mm)	STD-Y (mm)	STD-Z (mm)	RMSE-X (mm)	RMSE-Y (mm)	RMSE-Z (mm)
(μm) (pixel)	of CHK+TIE points			at CHK points		
0.55 0.25	**0.165**	**0.312**	**0.139**	Na	Na	Na
0.52 0.24	**0.157**	**0.286**	**0.133**	**0.449**	**0.617**	**0.225**
0.50 0.23	**0.161**	**0.284**	**0.140**	**0.701**	**0.816**	**0.203**
0.47 0.21	**0.144**	**0.250**	**0.120**	Na	Na	Na

30th September, 2007

Ver	GCP	CHK	TIE	APs	Rej	Sigma (μm) (pixel)	STD-X (mm)	STD-Y (mm)	STD-Z (mm)	RMSE-X (mm)	RMSE-Y (mm)	RMSE-Z (mm)
							of CHK+TIE points			at CHK points		
61	**87**	0	99	10	0	**0.54** 0.25	**0.151**	**0.241**	**0.130**	Na	Na	Na
62	**44**	43	99	10	0	**0.52** 0.24	**0.147**	**0.234**	**0.127**	**0.381**	**0.471**	**0.203**
63	**10**	77	99	10	0	**0.49** 0.23	**0.155**	**0.245**	**0.136**	**0.574**	**0.636**	**0.222**
64	**186** free	--	**--**	10	0	**0.48** 0.21	**0.138**	**0.217**	**0.116**	Na	Na	Na

N93: Temporal Stability of the Int. Orientation (30th September, 2007)

*) We compared the **tie point coordinates** of the
Ver.21 (February 2007) and
Ver.61 (September 2007) results:

The **means of the differences** (February'07 – September'07)
are
+0.043, **+0.002** and **+0.004 mm** (for the X, Y and Z axes, respectively).

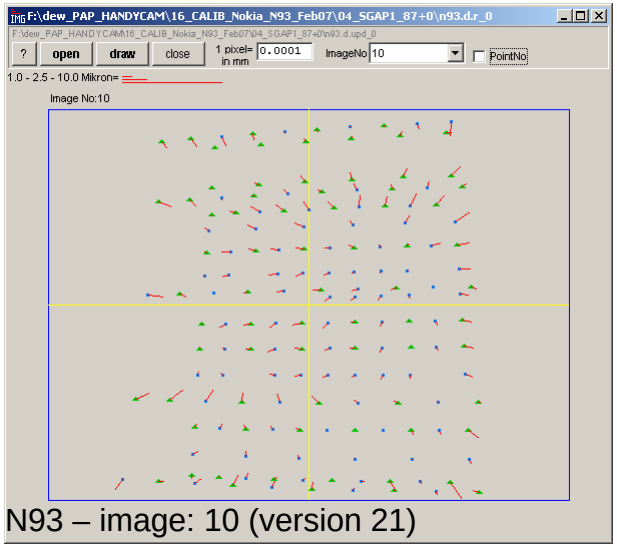
The **standard deviations of the coordinate differences**
are
± 0.089, **± 0.169** and **± 0.106 mm** (for X, Y and Z axes, respectively).

N93: Temporal Stability of the Int. Orientation (30th September, 2007)

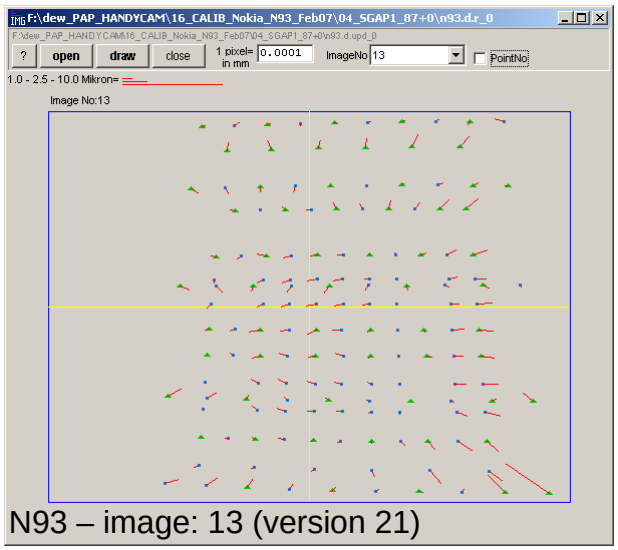
) The **change of the principal point locations (x0 & y0) and the **focal length** (c) between
Ver.21 (of February 2007) and
Ver.61 (of September 2007) are
only
-1.2, **+1.0** and **-1.8 microns**, respectively.

The corresponding **standard deviations of the differences**
(calculated according to the law of error propagation without considering the correlations)
are
± 1.1, **± 0.8** and **± 0.6 microns**, respectively.

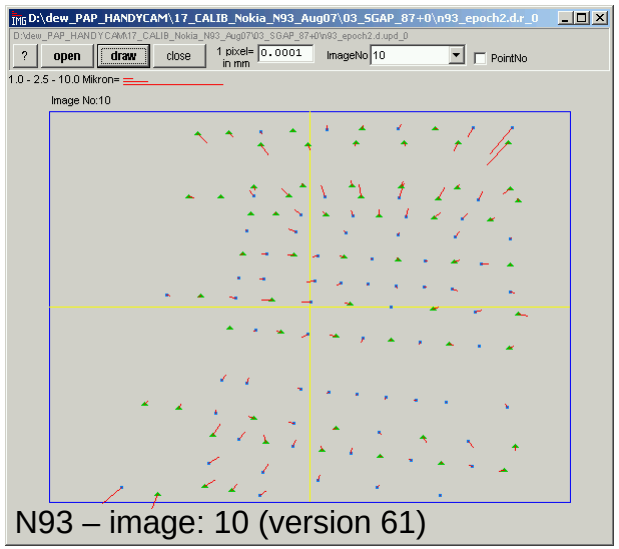
N93: Temporal Stability of the Int. Orientation (30th September, 2007)



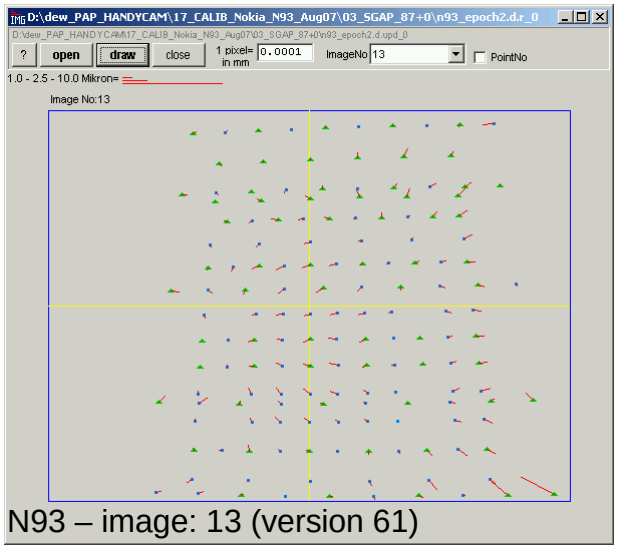
N93 – image: 10 (version 21)



N93 – image: 13 (version 21)

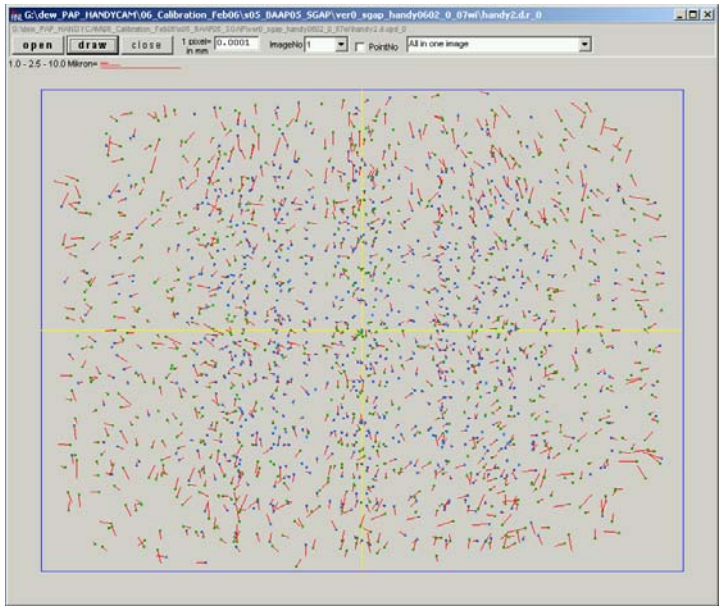


N93 – image: 10 (version 61)



N93 – image: 13 (version 61)

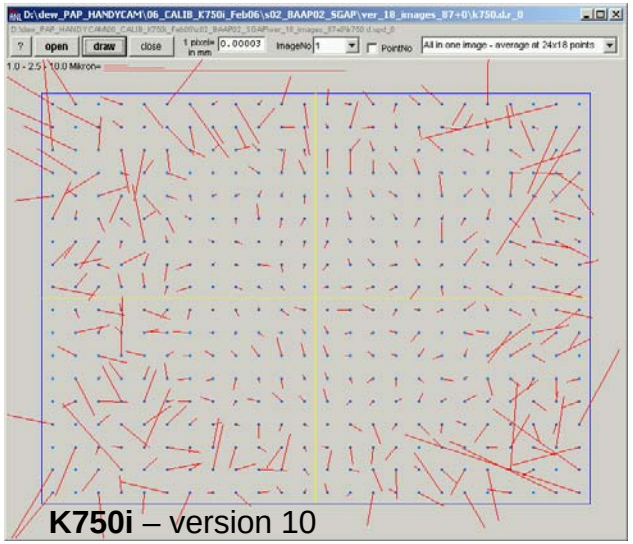
Image Residual Analysis



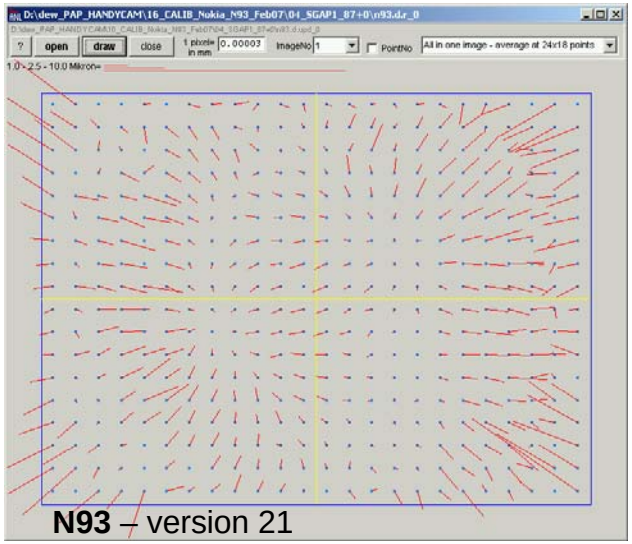
- Project all residuals to one image plane

- Average at pre-defined grid locations

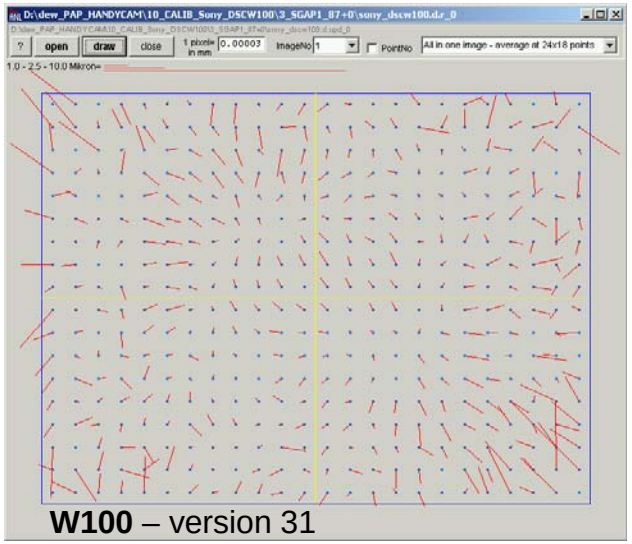
Image Residual Analysis



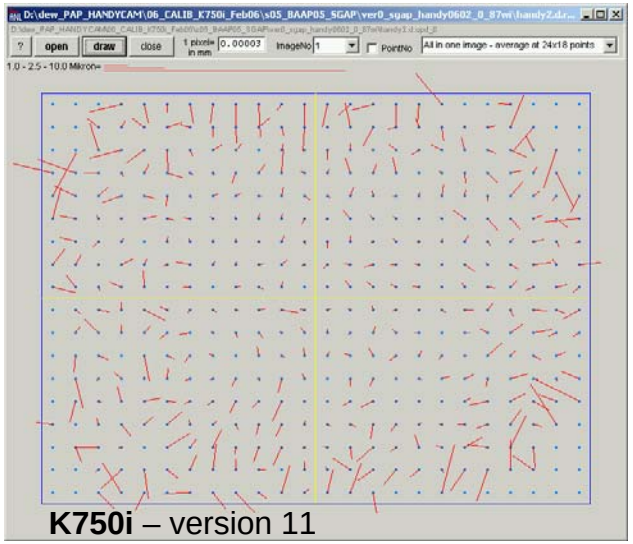
K750i – version 10



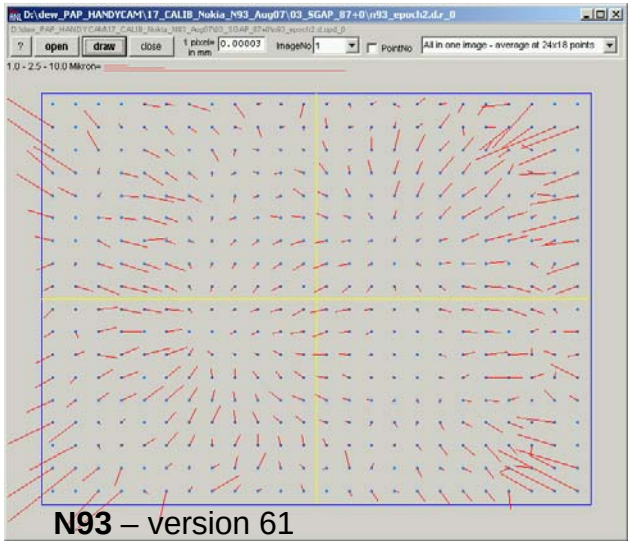
N93 – version 21



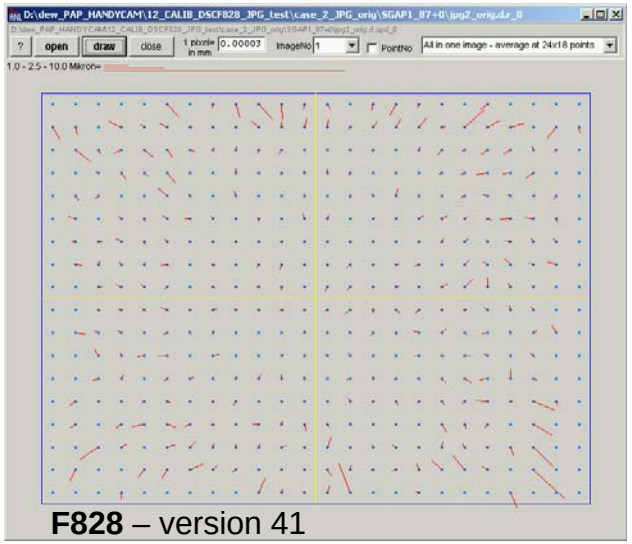
W100 – version 31



K750i – version 11



N93 – version 61



F828 – version 41

Results & Conclusions

- We have found;
  - + **unwanted effects** from image enhancement in K750i, N93 and W100
  - + JPEG **compression artifacts** in N93
- In spite of giving the worst results, K750i still can offer **sub-mm accuracy**.

- Sigma0 of image observations
  - + K750i, N93 and W100 → **1/5 pixel**
  - + F828 → **1/10 pixel**
- Only in the case of F828, residuals in (almost) random distribution

- The other cameras (esp. K750i), strong **image-variant systematic errors**
- **Block-invariant APs cannot** compensate the systematic errors in the individual images.

- So far, we cannot explain the reasons.

Maybe: image enhancement procedure or any other electronic shortcomings.

Results & Conclusions

Ver	GCP	CHK	TIE	APs	Rej	Sigma	STD-X (mm)	STD-Y (mm)	STD-Z (mm)	RMSE-X (mm)	RMSE-Y (mm)	RMSE-Z (mm)
						(μm) (pixel)	of CHK+TIE points			at CHK points		
14 **K750i**	**10**	77	80	10	27	**0.61** 0.22	0.196	0.318	0.173	**0.499**	**1.048**	**0.501**
23 **N93-I**	**10**	77	99	10	0	**0.50** 0.23	0.161	0.284	0.140	**0.701**	**0.816**	**0.203**
63 **N93-II**	**10**	77	99	10	0	**0.49** 0.23	0.155	0.245	0.136	**0.574**	**0.636**	**0.222**
33 **W100**	**10**	77	92	10	0	**0.47** 0.21	0.100	0.168	0.085	**0.501**	**0.421**	**0.443**
43 **F828**	**10**	77	81	10	0	**0.26** 0.10	0.049	0.084	0.043	**0.097**	**0.144**	**0.134**

Results & Conclusions

- Nevertheless, **relative accuracies** (10 GCP versions):

+ K750i	in-plane: 1 : 8 000	**depth: 1 : 3 000**
+ N93	in-plane: 1 : 9 000	**depth: 1 : 4 000**
+ W100	in-plane: 1 : 8 000	depth: 1 : 7 000
+ F828	in-plane: 1 : 34 000	depth: 1 : 21 000

- JPEG compression **does not have a significant effect** on the metric system accuracy.
For a factor of 42 compression rate, RMSE-Y degraded 9%.

- N93, **interior orientation is stable over time**, even the systematic error pattern!!

- Mobile phone cameras **are offering** an interesting option for doing "**mobile photogrammetry**" in terms of **accuracy**, **costs** and **flexibility**.

Future Work

→ **Radiometric analysis**
- Image noise analysis
- MTF analysis by Siemens starts method
- Linearity analysis

→ **3D modeling**

谢谢您的关注

Thank you for your attention

www.photogrammetry.ethz.ch