EuroCOW 2012 - The European Calibration and Orientation Workshop

Institut of Geomatics / EuroSDR / ISPRS

unesp

2012, February 08-10, Castelldefels, Spain

Correlation Analysis Between Inner Orientation Parameters of Digital Cameras and Temperature

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Introduction / Motivation

- The modern digital imaging sensors are based on semiconductor devices and the most common sensors are CCD (*Charge Couple Device*) and CMOS (*Complementary Metal Oxide Semiconductor*).

- In despite of the architecture of each sensor they are affected by temperature changes.

- For this kind of sensors, to produce results with low noise level the ideal is to work with low temperatures.

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- For this kind of sensors, to produce results with low noise level the ideal is to work with low temperatures.

- The use of medium format cameras is growing for different applications, including aerial imaging.

- Some aspects that are important to consider: stability of the IOPs and temperature effects in the IOPs.

Introduction / Motivation

- Some works related to this subject (stability and/or temperature):

Dahler (1987) and Gulch (1986)	
Jacobsen and Wegmann (2002)	
Habib and Morgan (2005)	
Mitishita et al (2009)	
Smith and Cope (2010)	
Ladstädter et al. (2008)	

Introduction / Motivation

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Dahler (1987) and Gulch (1986)	The effects of temperature on the measurements.
Jacobsen and Wegmann (2002)	Variation of the focal length of two metric cameras - based on Meier (1978).
Habib and Morgan (2005)	Stability of the IOPs was studied.
Mitishita et al (2009)	The results do not indicate that variations in the estimated IOPs were caused by the temperature.
Smith and Cope (2010)	Effects of variation of temperature for one SLR camera.
Ladstädter et al. (2008)	TDM to compensate some effects for the UltraCam camera.

Introduction / Motivation

Optical specifications for high performance photogrammetric cameras (Eckardt et al, 2000):

Spatial channel	Wide angular field of view (FoV) High spatial resolution over the whole FoV equally along and across track Telecentric on imaging side Large depth of focus
Radiometric channel	Fast lens (F-number 4) High transmission Homogenous irradiance distribution across the FoV Minimised optical crosstalk between pixels
Spectral channel	Panchromatic channel Narrow band spectral channels from blue (400 nm) to infrared (900 nm)
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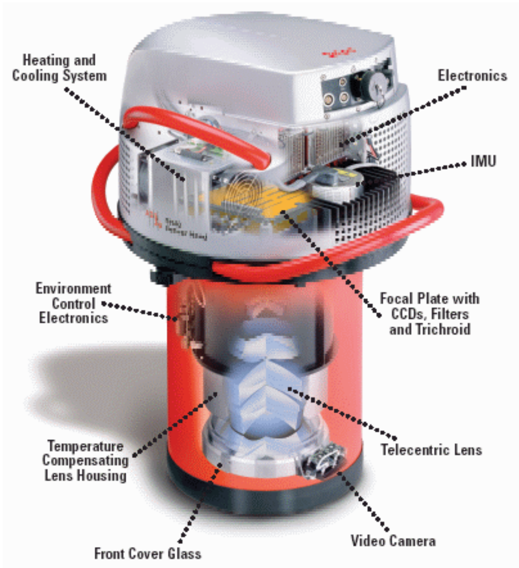
Resources used in some digital cameras



Airborne Digital Sensor 80 (ADS 80) and also ADS 40 cameras has a device to control the temperature.
Leica Geosystems

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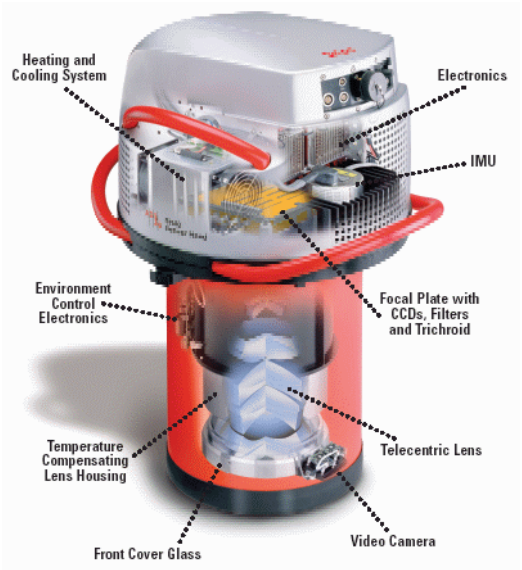

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Some models use a DDC - *Double Duration Circuit*. (HASSELBLAD, 2004).

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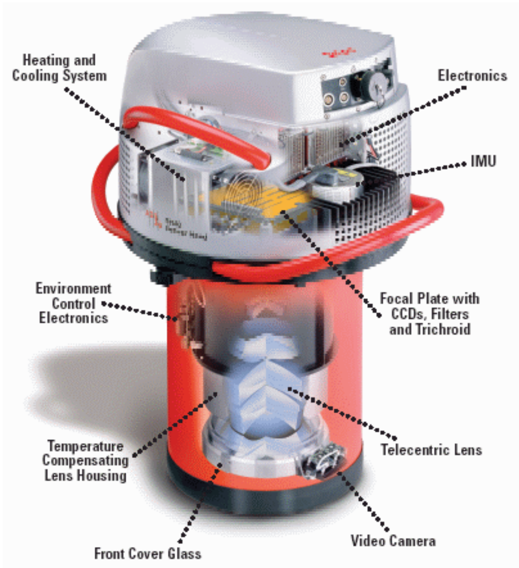

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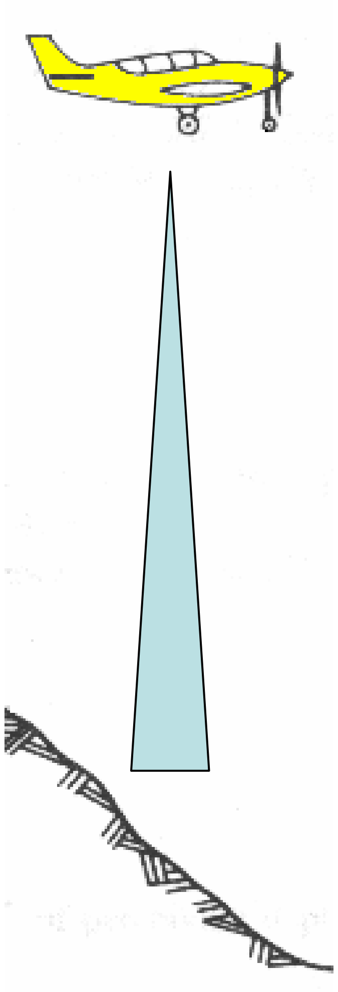
The Vexcel $UltraCam_X$ camera uses in the post-processing the TDM – Temperature Dependent Model.
It is necessary: $T_{Calibration}$ and $T_{Flight\ Mission}$.

Introduction / Motivation



Vertical thermal gradient*.

$$\frac{dT}{dh} \approx -1^{o}C/153{,}9m$$

* ALLSTAR Network (2008).

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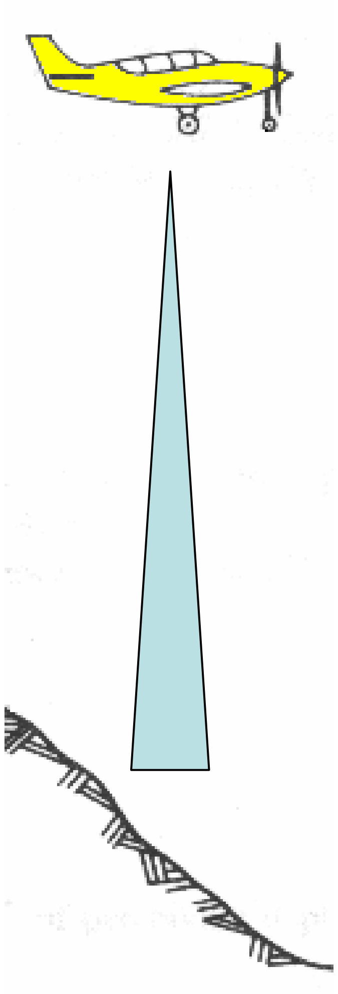

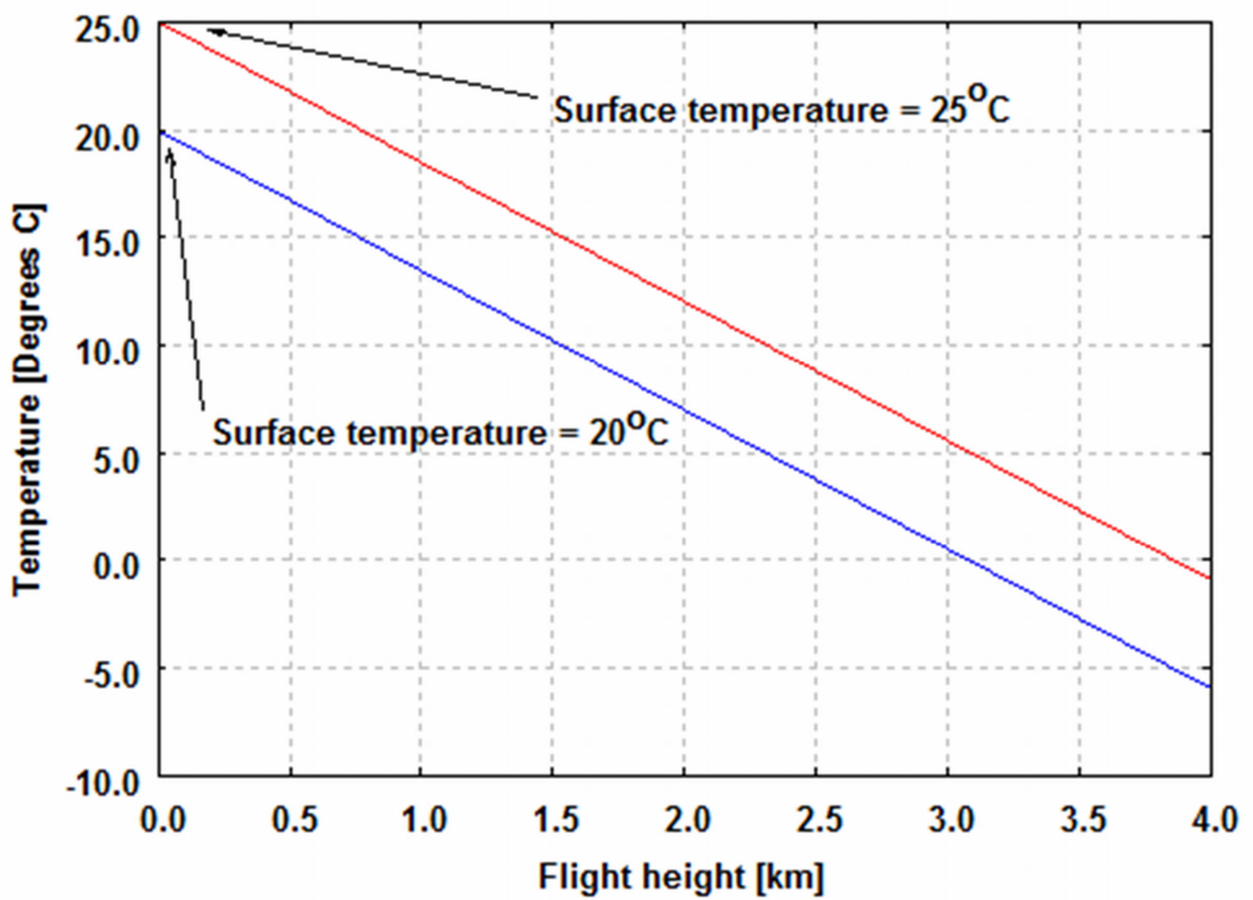

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Objective

To evaluate the effects of temperature changes on the IOPs of two digital medium format cameras and to perform a correlation analysis between the IOPs and temperature.

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- Acquisition of images (convergent arrangement) at different temperatures (4 acquisition were taken);

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- Selection of the images to be measured;
- Measurement of coordinates (with subpixel quality);
- Calibration of each set of images at different temperatures for two groups of IOPs:

IOP Group 1 - f, x_0, y_0, k_1, k_2
IOP Group 2 - f, x_0, y_0, k_1, k_2, P_1, P_2

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- Computation of the Pearson´s Correlation Coefficient (ρ) between temperature and each IOP.

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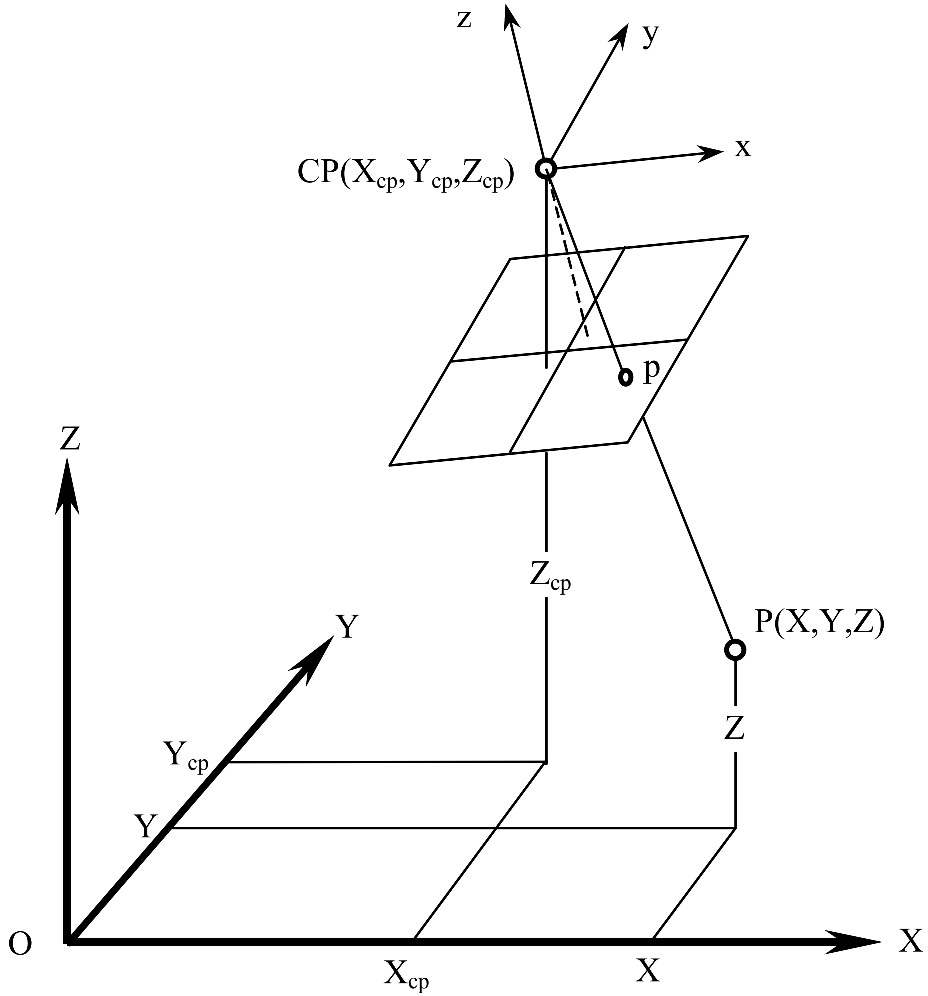
> - **One pre-processing step using control points was performed for each set of images, for both cameras;**
> - **The points with residuals greater than 1.5 pixels were verified and measured again.**

Mathematical model used in the calibration process



$$x' = x_0 + \Delta x - f\,\frac{\vec{m}_1 \times (\vec{X} - \vec{X}_{cp})}{\vec{m}_3 \times (\vec{X} - \vec{X}_{cp})}$$

$$y' = y_0 + \Delta y - f\,\frac{\vec{m}_2 \times (\vec{X} - \vec{X}_{cp})}{\vec{m}_3 \times (\vec{X} - \vec{X}_{cp})}$$

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$$\begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} = \begin{bmatrix} \delta x_r \\ \delta y_r \end{bmatrix} + \begin{bmatrix} \delta x_d \\ \delta y_d \end{bmatrix} + \begin{bmatrix} \delta x_a \\ \delta y_a \end{bmatrix}$$

Affinity (A, B) or In-plane distortion (b_1, b_2)

Descentring distortions (P_1, P_2)

Radial distortion parameters (k_1, k_2, k_3)

Softwares used in the experiments

CC – Camera Calibration (Galo, 1993; Galo et al, 2006)

CMC – Multi-Camera Calibration (Ruy, 2008; Ruy et al, 2009)

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CC – Camera Calibration (Galo, 1993; Galo et al, 2006)

IOP can be chosen, allows the inclusion of constraints in any parameter and self-calibration (with minimum constraints). In the last version the significance analysis was included. The LSM is based on the parametric model.

CMC – Multi-Camera Calibration (Ruy, 2008; Ruy et al, 2009)

IOP can be chosen, allows the use of constraints for the orientations for dual-configuration. The LSM is based on the combined model.

Cameras used in the experimets

a)

b)

a) Fuji FinePix S3 Pro

f=28mm

b) CCD of the Fuji FinePix camera (CCD SR II)

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c)

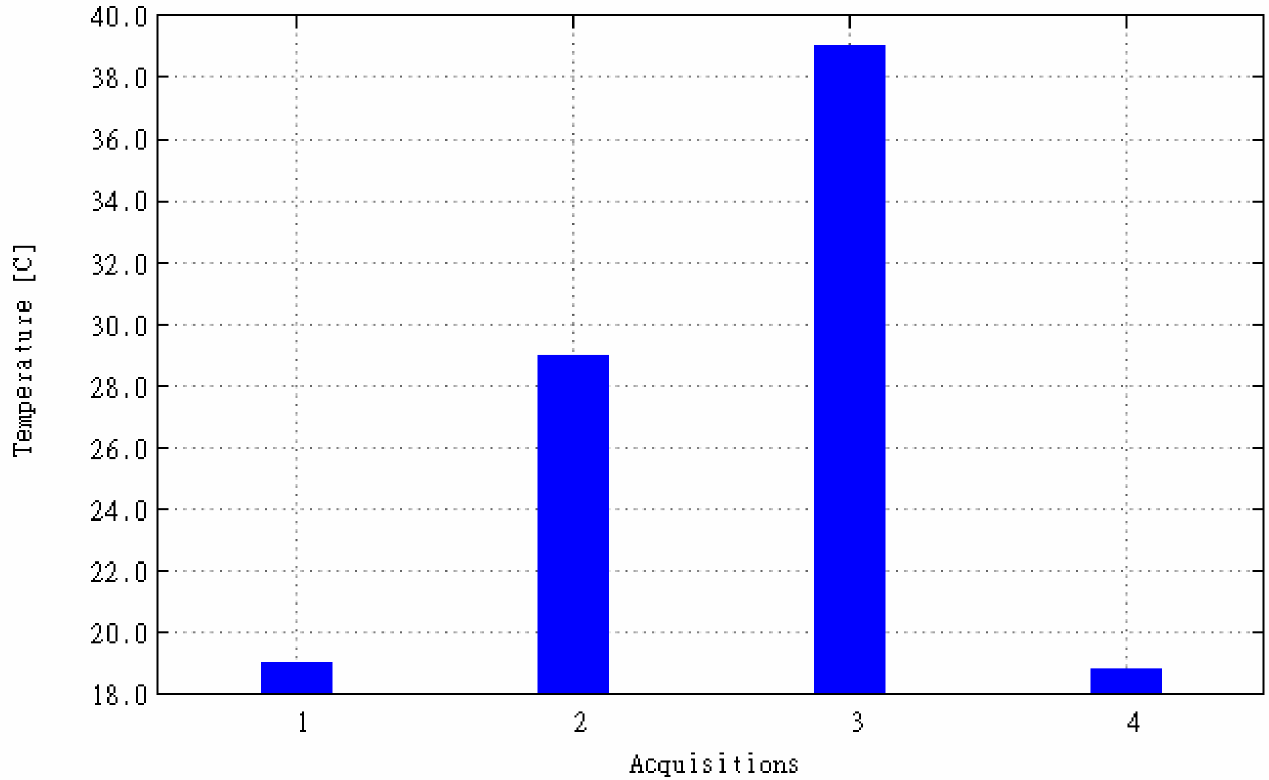
c) Hasselblad H3D 50

f=35 mm

Change the temperature and image acquisition

- The cameras were first placed in a temperature-controlled room overnight;
- The first set of images was taken at a low temperature, early in the morning.

Change the temperature and image acquisition



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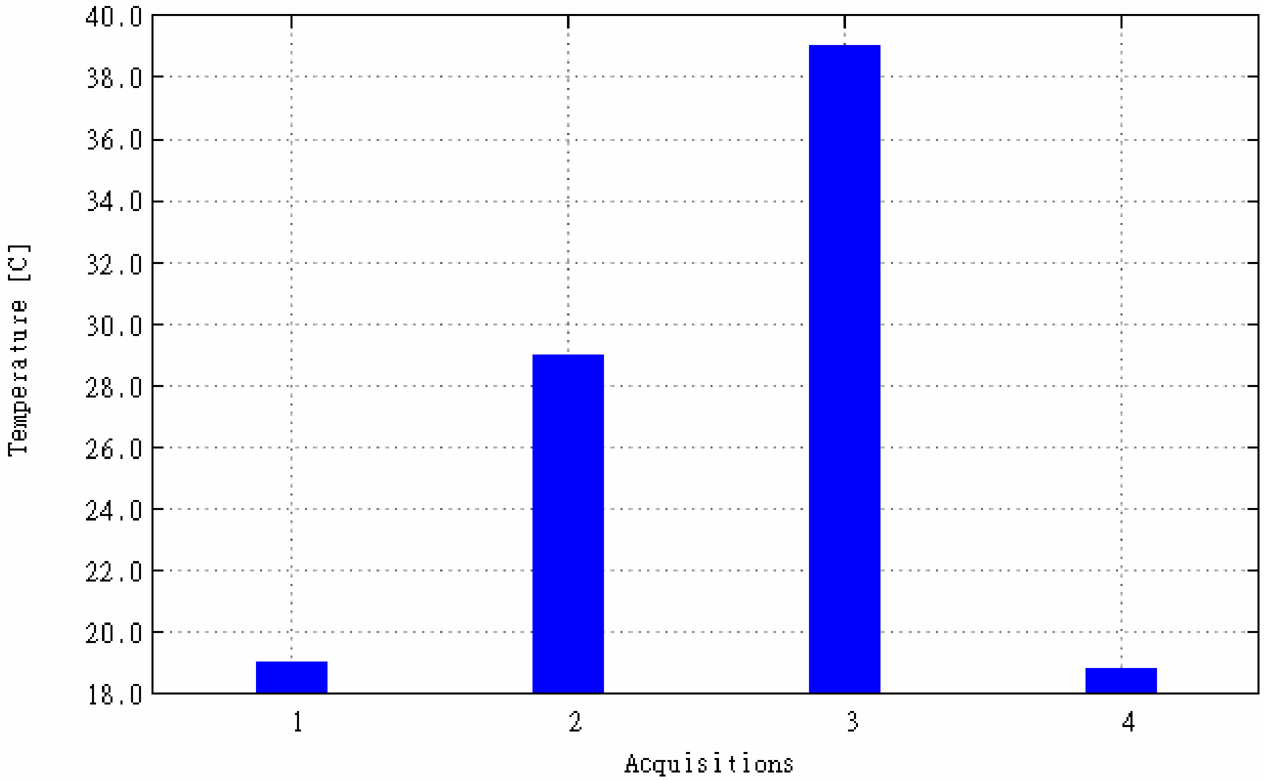
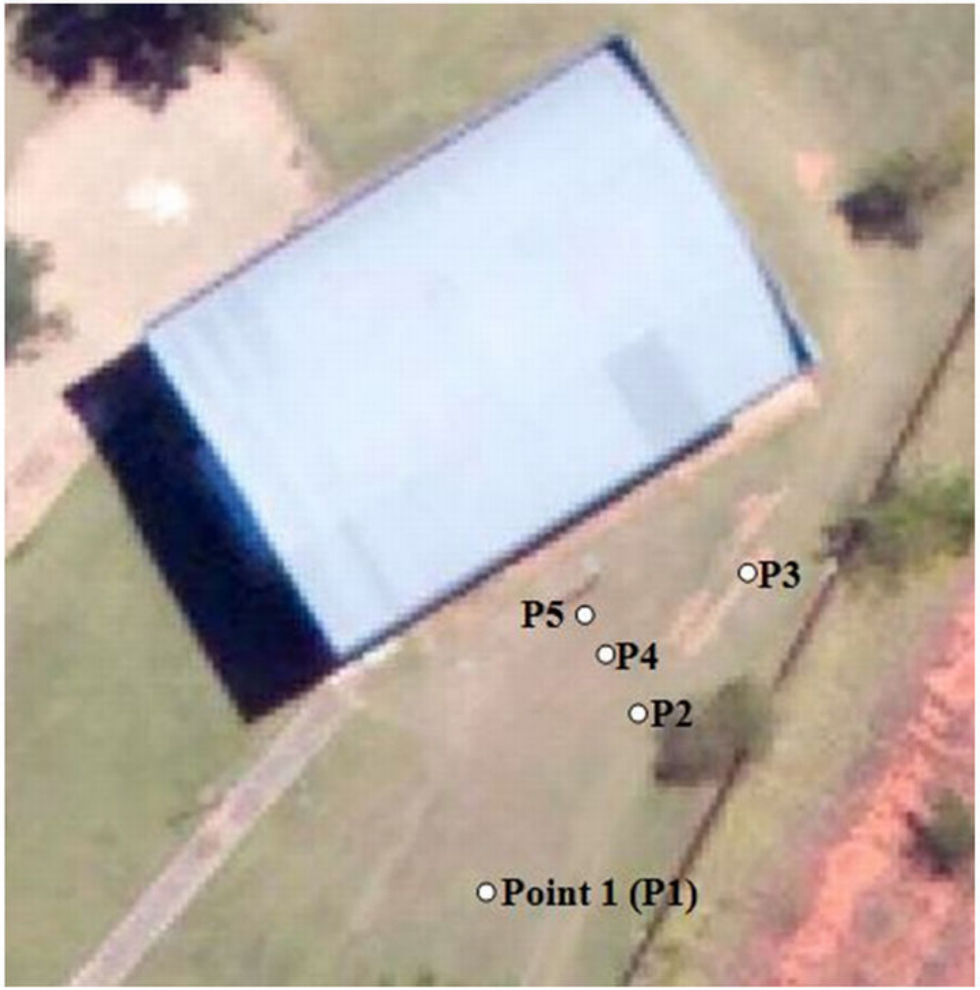


8:15h	12:00h	16:45h	8:25h

1st Day | 2nd Day

Change the temperature and image acquisition



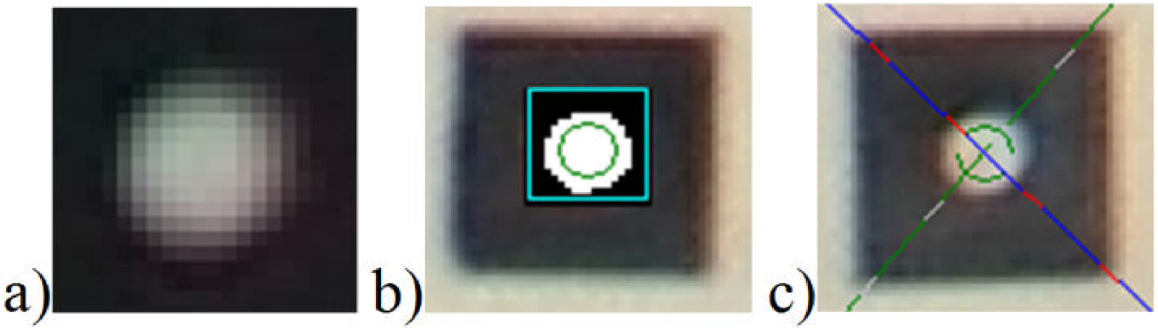
From each point P1, P2, P3 and P4 four images were acquired (rotated ~90º).

From the point P5 one image was acquired.

Nine images were selected to be measured.

The test field and one set of images

Point measurement



The points (a) were measured by computing the centroid (b).

For some points not well defined, the position was estimated by intersecting two lines (c), using MID* program.

* Author: Dr. **Mário Reiss**, UFRGS – Universidade Federal do Rio Grande do Sul, Porto Alegre RS.

Strategies adopted in the IOP estimation

Constraints applied in the self-calibration:

- Position and orientation in one camera station (6 constraints);
- Distance constraints (2). The distances were directly measured with a precision calliper (PANTEC 2000mm / 80", Reading ± 0,020mm);

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- Position and orientation in one camera station (6 constraints);

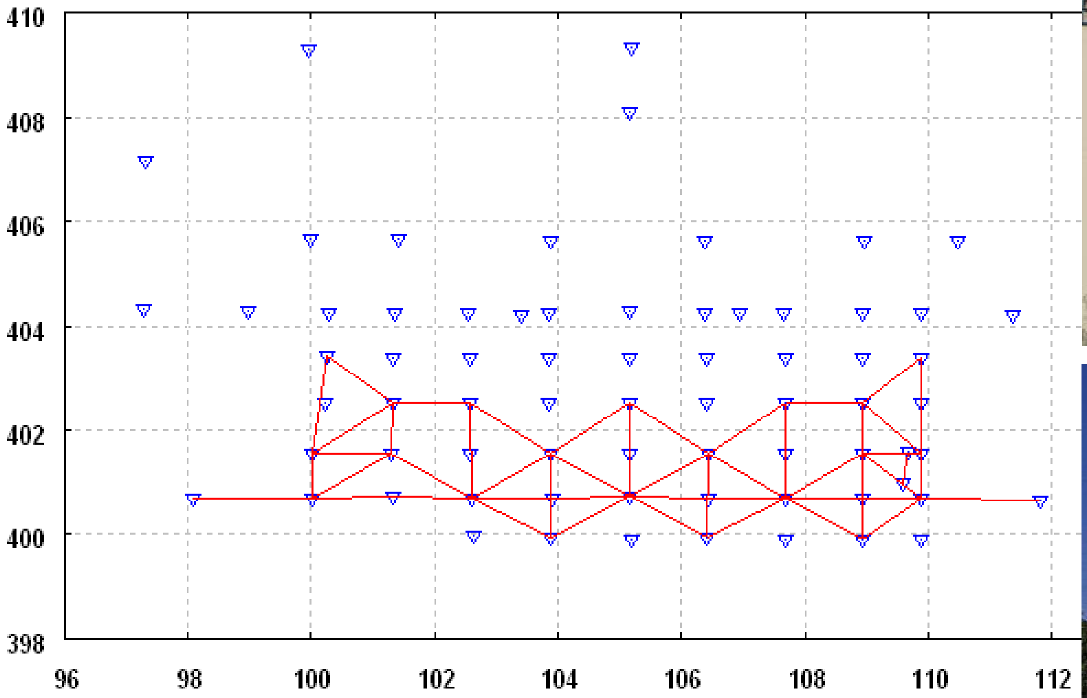
- Distance constraints (2). The distances were directly measured with a precision calliper (PANTEC 2000mm / 80", Reading ± 0,020mm);

- The approximate coordinate of one ground point was given with the following variances (this information is used only to have one approximate Z coordinate):

$$\sigma_X = 2\text{ m} \quad \sigma_Y = 2\text{ m} \quad \sigma_Z = 1\text{ m}$$

- The other points were considered free in adjustment.

Quality control



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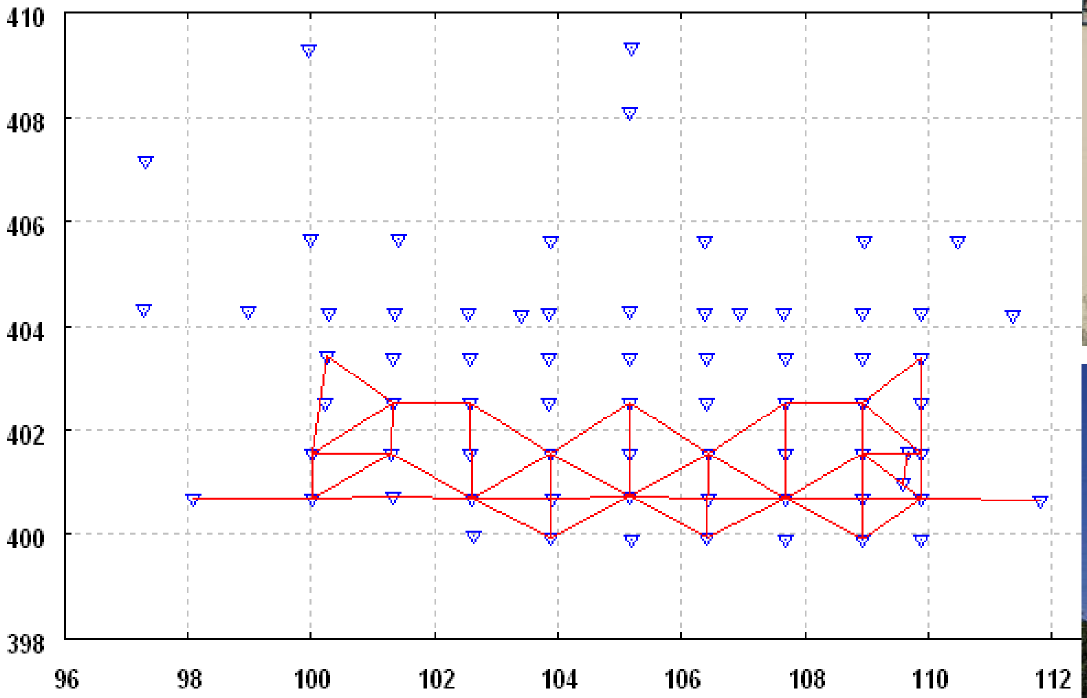

- RMSE for distance discrepancies (for CC software);

- RMSE for GCP (for CMC software).

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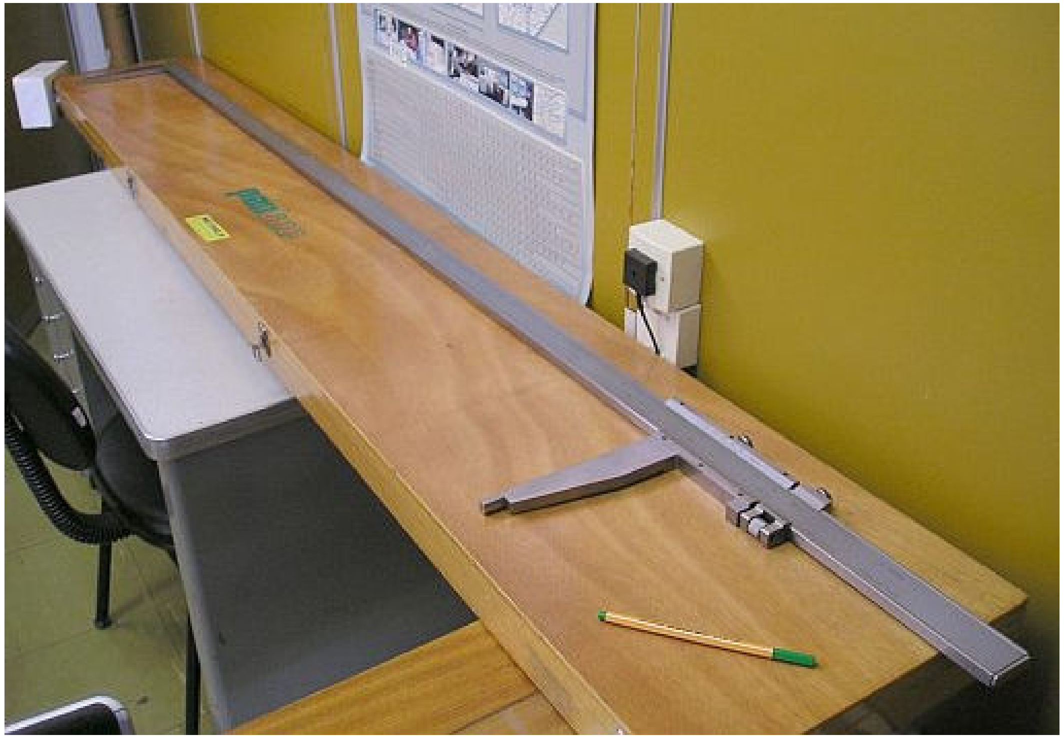

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Results and Analyses

IOP and statistics for each acquisition for the Fuji FinePix Camera

IOP	Acquisition 1	Acquisition 2	Acquisition 3	Acquisition 4
c (mm)	28.4787 $\pm$ 0.83 x 10^{-2}	28.4598 $\pm$ 0.1351 x 10^{-1}	28.5222 $\pm$ 0.1768 x 10^{-1}	28.4657 $\pm$ 0.2435 x 10^{-1}
x_0 (mm)	0.2302 $\pm$ 0.39 x 10^{-2}	0.2637 $\pm$ 0.5360 x 10^{-2}	0.2545 $\pm$ 0.6997 x 10^{-2}	0.1870 $\pm$ 0.6963 x 10^{-2}
y_0 (mm)	-0.0865 $\pm$ 0.54 x 10^{-2}	-0.0522 $\pm$ 0.8065 x 10^{-2}	-0.0825 $\pm$ 0.1048 x 10^{-1}	-0.1005 $\pm$ 0.1028 x 10^{-1}
k_1 (mm^{-2})	-0.1465523 x 10^{-3} $\pm$ 0.11 x 10^{-5}	-0.1453770 x 10^{-3} $\pm$ 0.1943 x 10^{-5}	-0.1406433 x 10^{-3} $\pm$ 0.2846 x 10^{-5}	-0.1411886 x 10^{-3} $\pm$ 0.2388 x 10^{-5}
k_2 (mm^{-4})	0.1971801 x 10^{-6} $\pm$ 0.65 x 10^{-8}	0.1699899 x 10^{-6} $\pm$ 0.1203 x 10^{-7}	0.1560215 x 10^{-6} $\pm$ 0.1625 x 10^{-7}	0.1734235 x 10^{-6} $\pm$ 0.1571 x 10^{-7}
P_1 (mm^{-1})	0.3975759 x 10^{-4} $\pm$ 0.17 x 10^{-5}	0.3662160 x 10^{-4} $\pm$ 0.2465 x 10^{-5}	0.2892082 x 10^{-4} $\pm$ 0.3302 x 10^{-5}	0.1892078 x 10^{-4} $\pm$ 0.3368 x 10^{-5}
P_2 (mm^{-1})	0.1193519 x 10^{-4} $\pm$ 0.19 x 10^{-5}	0.2163877 x 10^{-4} $\pm$ 0.2688 x 10^{-5}	0.1054321 x 10^{-4} $\pm$ 0.3608 x 10^{-5}	0.1500472 x 10^{-4} $\pm$ 0.3536 x 10^{-5}
df	699	787	864	703
χ^2_S	143.01	239.81	457.80	380.33
χ^2_t	747.32	838.25	917.68	751.46
np	484	525	565	486

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For all acquisitions the χ^2 **tests** were **accepted** for **confidence level of 90%**.

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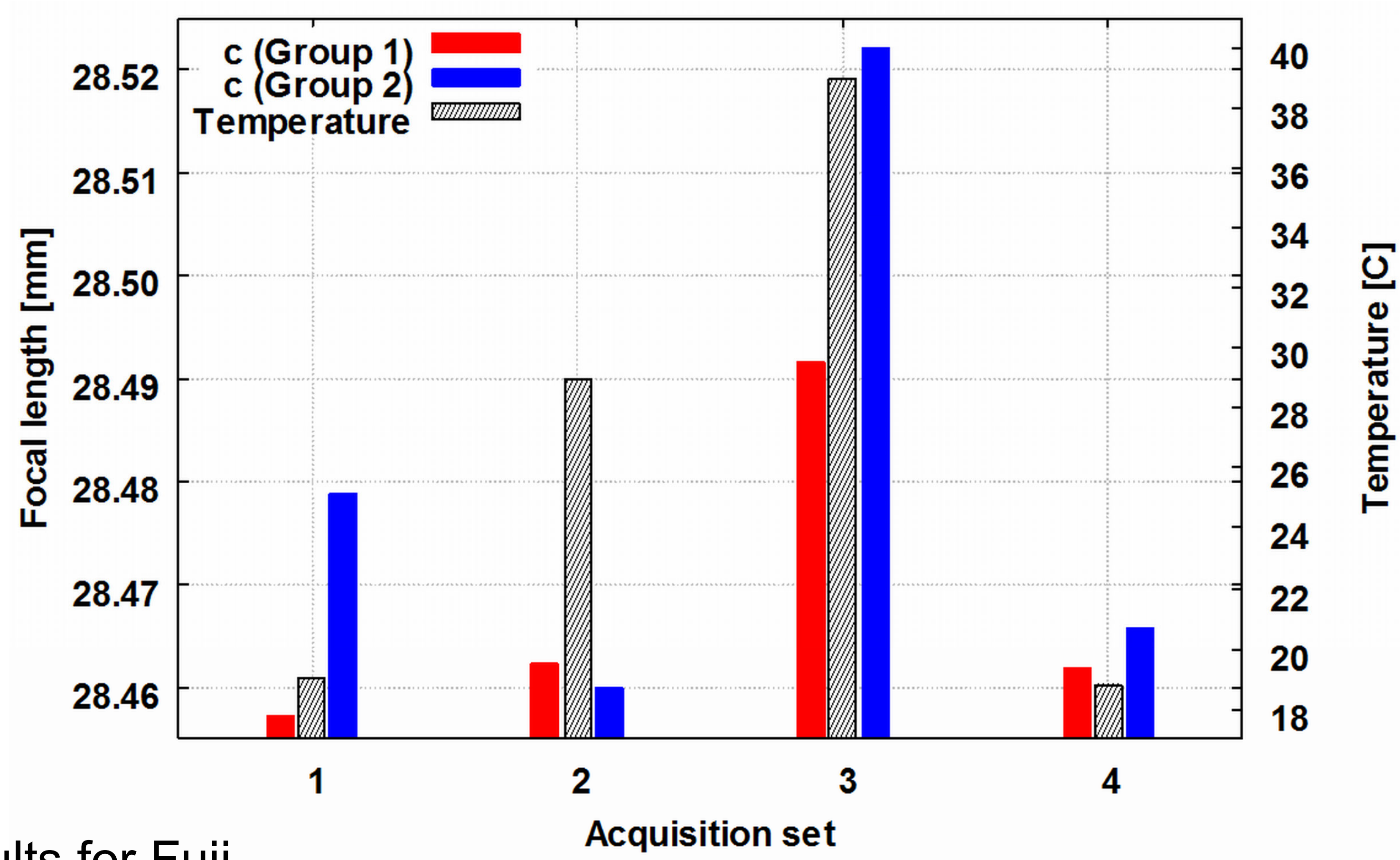
Estimated focal length considering IOP groups 1 (c, x_0, y_0, k_1, k_2) and 2 (c, x_0, y_0, k_1, k_2, P_1, P_2) and the temperatures for each camera



Results for Fuji FinePix camera.

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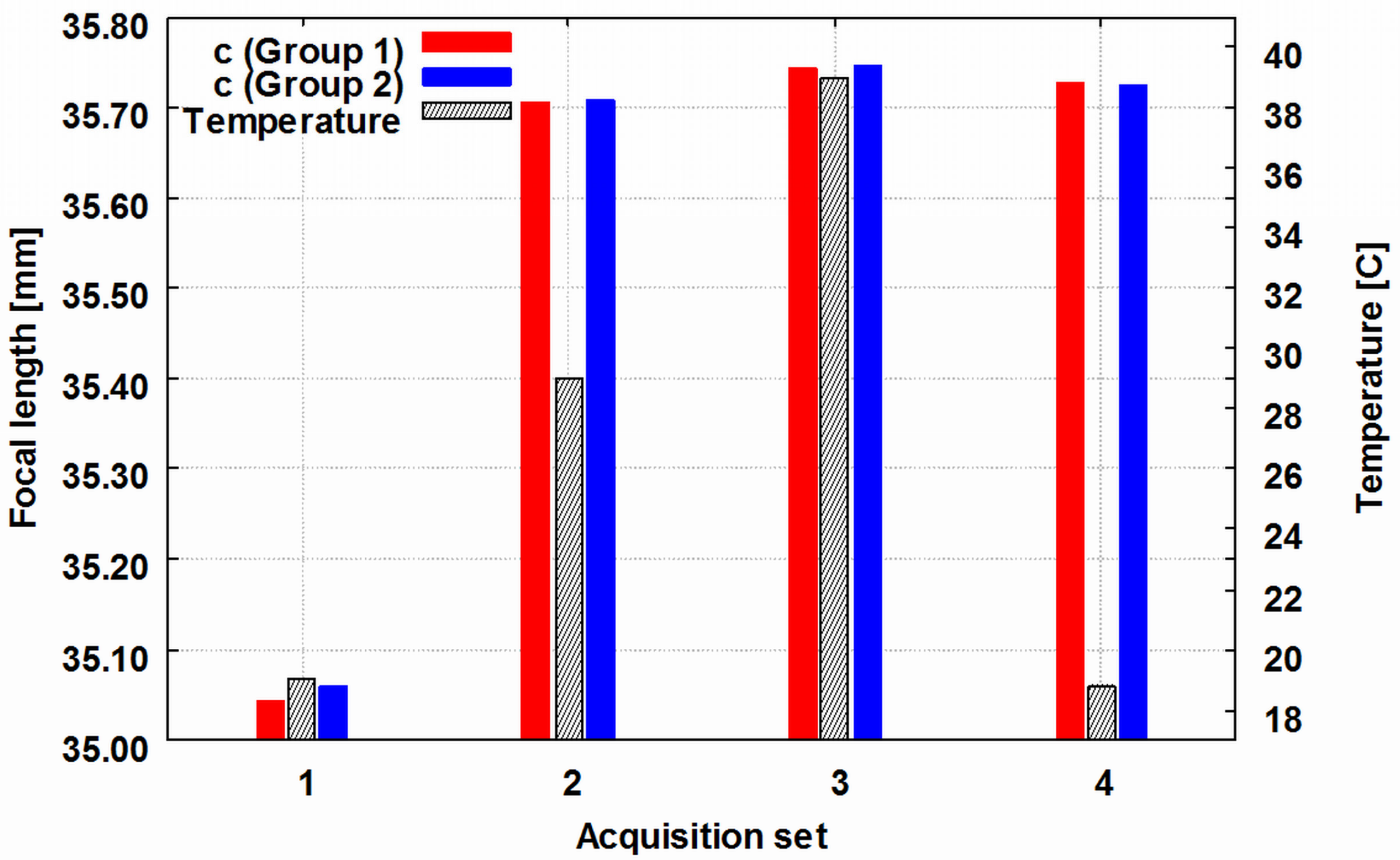

Results for
Hasselblad camera.

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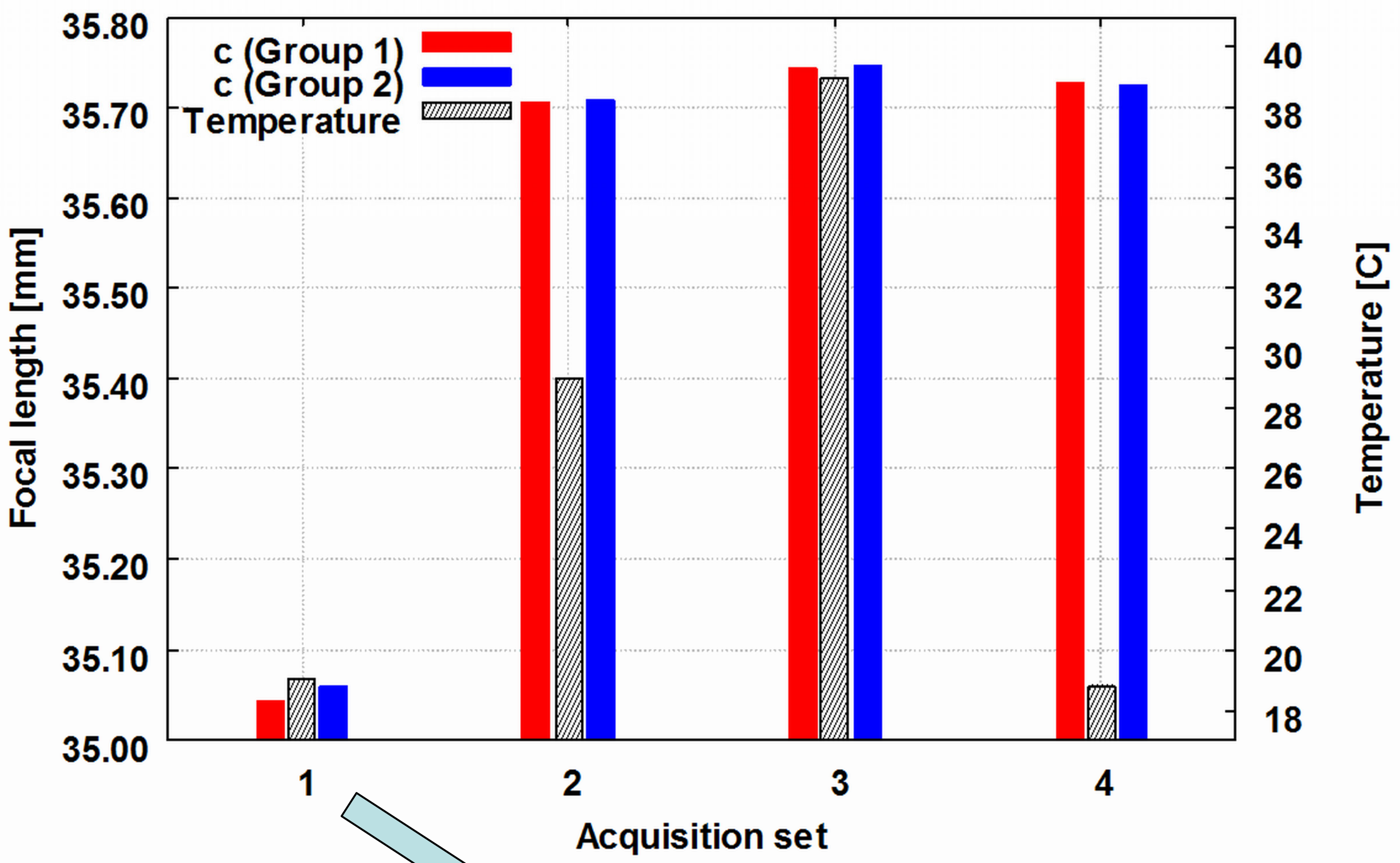

Results for
Hasselblad camera.

Less images were selected (6) due to lenses condensation.

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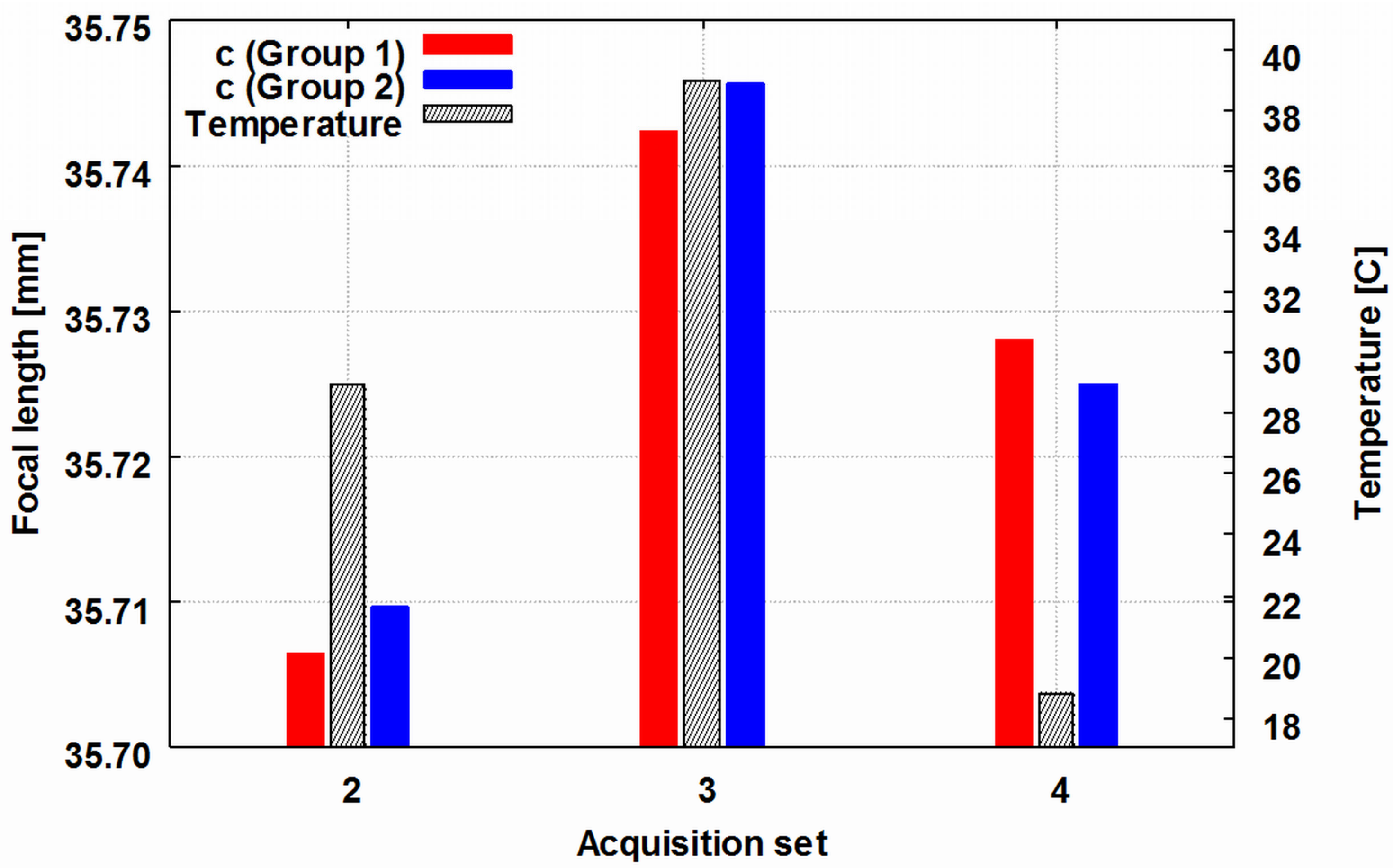

Results for
Hasselblad camera.

Correlation analysis between temperature and IOPs for the Fuji FinePix

H	T [°C]	c [mm]	x_0 [mm]	y_0 [mm]	$k_1\times10^{-4}$ [mm^{-2}]	$k_2\times10^{-7}$ [mm^{-4}]
8:15	19.0	28.457	0.133	-0.110	-1.467	2.005
12:00	29.0	28.462	0.185	-0.100	-1.449	1.668
16:45	39.0	28.491	0.200	-0.094	-1.359	1.377
8:25	18.8	28.462	0.142	-0.133	-1.421	1.795
ρ between T and each IOP		90.2%	96.3%	80.8%	76.6%	-94.0%

ρ – Pearson`s correlation coefficient

|ρ| > 75%

Correlation between temperature and IOPs for the Fuji FinePix – for different groups of IOP and software

IOP group [Software]	Correlation (%)				
	$\rho_{(T,c)}$	$\rho_{(T,x0)}$	$\rho_{(T,y0)}$	$\rho_{(T,k1)}$	$\rho_{(T,k2)}$
Self calibration (c,x_0,y_0,k_1,k_2) [CC]	90.2	96.3	80.8	76.6	-94.0
Self calibration ($c,x_0,y_0,k_1,k_2,P_1,P_2$) [CC]	73.3	72.8	41.7	42.2	-81.8
Field Calibration (c,x_0,y_0,k_1,k_2) [CMC]	73.0	93.3	90.4	78.4	-97.3
Average $\pm\sigma$	*78.8* $\pm$*9.8*	*87.5* $\pm$*12.8*	*71.0* $\pm$*25.8*	*65.7* $\pm$*20.4*	*-91.0* $\pm$*8.2*

Correlation between temperature and IOPs for the Fuji FinePix – for different groups of IOP and software

IOP group [Software]	Correlation (%)				
	$\rho_{(T,c)}$	$\rho_{(T,x0)}$	$\rho_{(T,y0)}$	$\rho_{(T,k1)}$	$\rho_{(T,k2)}$
Self calibration (c,x_0,y_0,k_1,k_2) [CC]	90.2	96.3	80.8	76.6	-94.0
Self calibration ($c,x_0,y_0,k_1,k_2,P_1,P_2$) [CC]	73.3	72.8	41.7	42.2	-81.8
Field Calibration (c,x_0,y_0,k_1,k_2) [CMC]	73.0	93.3	90.4	78.4	-97.3
Average $\pm\sigma$	*78.8 ±9.8*	*87.5 ±12.8*	*71.0 ±25.8*	*65.7 ±20.4*	*-91.0 ±8.2*

Correlations for group 1: $|\rho| > 72\%$

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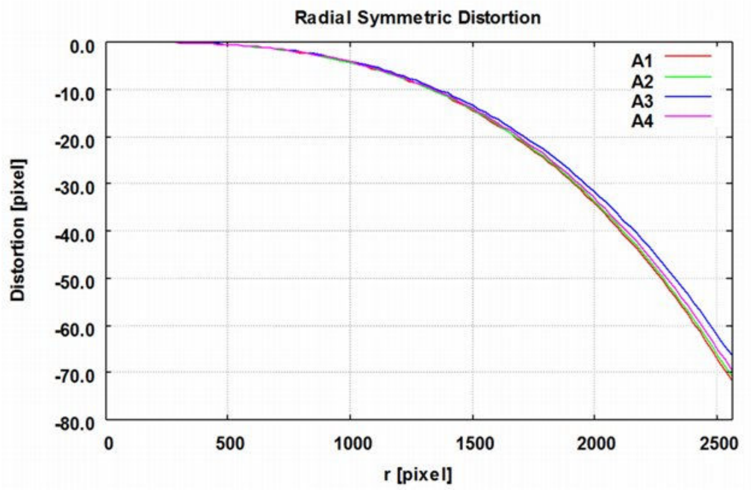
Correlations for group 1: $|\rho| > 72\%$

For the group 2 the correlations $\rho(T,y_0)$ and $\rho(T,k_1)$ were smaller: 41,7% and 42,2% respectively.

Behavior of the radial symmetric distortion for the FinePix camera under different temperatures



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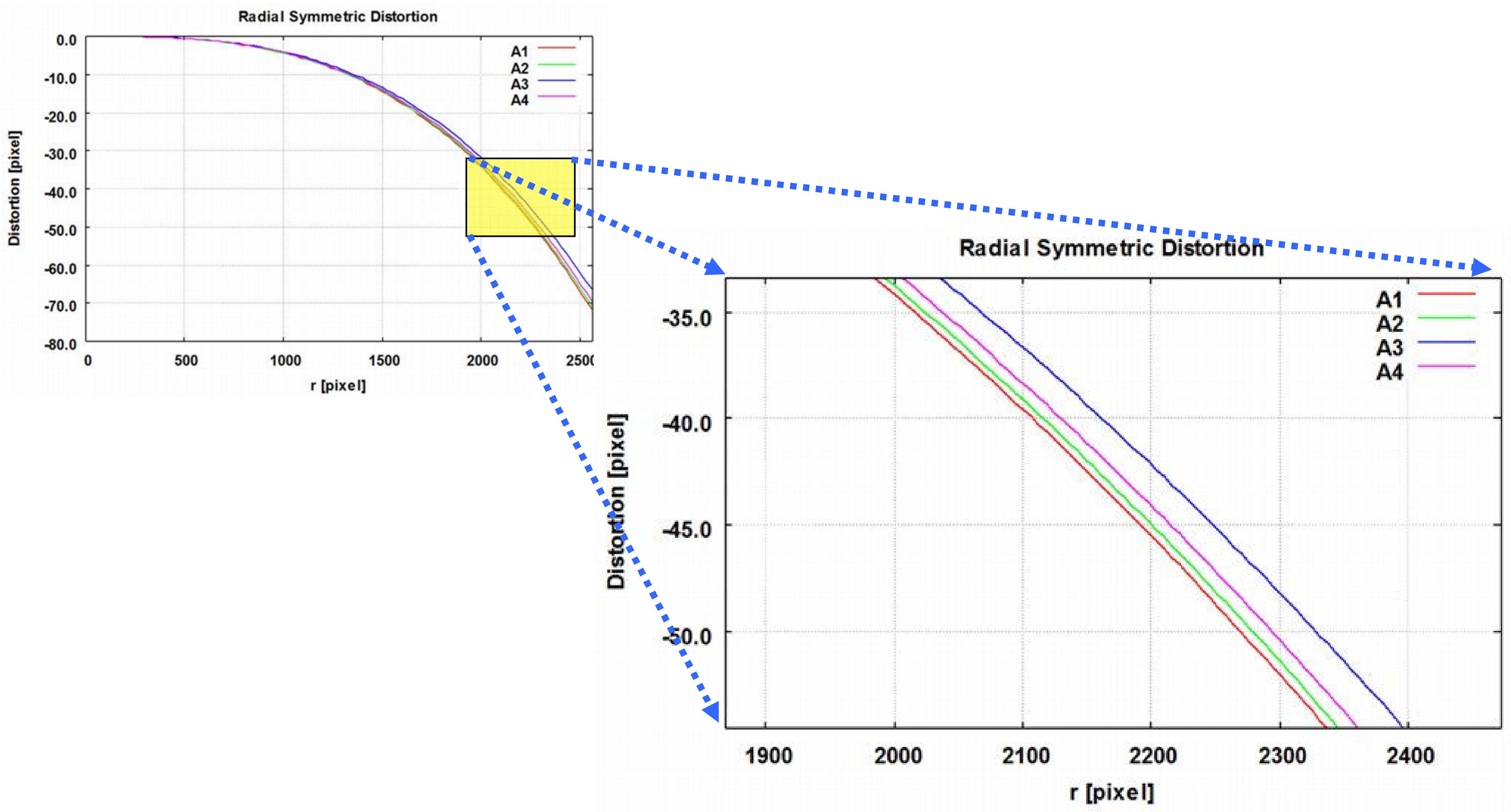

Correlation between temperature and IOPs for the Hasselblad camera

IOP group [Software]	Correlation (%)				
	$\rho_{(T,c)}$	$\rho_{(T,x0)}$	$\rho_{(T,y0)}$	$\rho_{(T,k1)}$	$\rho_{(T,k2)}$
Self calibration (c,x_0,y_0,k_1,k_2) [CC]	53.0	47.0	49.5	-19.1	50.4
Self calibration $(c,x_0,y_0,k_1,k_2,P_1,P_2)$ [CC]	53.7	47.0	50.4	-36.9	48.1
Field Calibration (c,x_0,y_0,k_1,k_2) [CMC]	53.5	46.4	49.2	21.7	9.8
Average $\pm \sigma$	*53.4 ±0.4*	*46.8 ±0.4*	*49.7 ±0.6*	*-11.4 ±30.0*	*36.1 ±22.8*

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Field Calibration (c,x_0,y_0,k_1,k_2) [CMC]	53.5	46.4	49.2	21.7	9.8
Average $\pm \sigma$	*53.4* $\pm$*0.4*	*46.8* $\pm$*0.4*	*49.7* $\pm$*0.6*	*-11.4* $\pm$*30.0*	*36.1* $\pm$*22.8*

The correlations are smaller for this camera.

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The DDC - Double Duration Circuit can explain, at least in part, this behavior.

RMSE for the experiments

- RMSE for the distance discrepancies (in the object space).

FinePix camera: RMSE ≤ 2.1 mm [n_d = distances = 48]

Hasselblad camera: RMSE ≤ 2.7 mm [n_d = 49]

- RMSE for the point coordinate discrepancies (CMC software):

RMSE ≤ 3 mm

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Hasselblad camera: RMSE ≤ 2.7 mm [n_d = 49]

Hasselblad camera: RMSE ≤ 1.35 mm* [n_d = 46]

* When considered the acquisition epochs 2, 3 and 4.

Due to condensation in epoch 1, only 6 images were selected and the geometry was affected.

- RMSE for the point coordinate discrepancies (CMC software):

RMSE ≤ 3 mm

Concluding Remarks

- Focus of this work: Experimental assessments of the correlation between the temperature changes and the estimated IOPs of digital cameras.

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- As independent check, the same data were used by two softwares (one using self-calibration with minimum constraints and another with constraints in the points of the object space), both using convergent images.

- Quality control:

  For self-calibration – RMSE of distance discrepancies computed by the adjustment and directly measured distances.

  For the calibration using points - RMSE for GCP.

Conclusions

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- For the experiments performed with different groups of IOPs, it was observed that the average correlation coefficient between the temperature during the image acquisitions and the estimated focal length was 78.8% ± 9.8% for the Fuji FinePix camera.

- For the Hasselblad camera the average correlation coefficient was 53.4% ± 0.4%.

- In general:

  For different thermal conditions some of the IOPs change.

  The variation magnitude depends on the parameter.

  For some cameras the correlations are high.

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Conclusions

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$$x' = x_0 + \Delta x - f\frac{\vec{m}_1 \times (\vec{X} - \vec{X}_{cp})}{\vec{m}_3 \times (\vec{X} - \vec{X}_{cp})} \qquad x' = x_0(t) + \Delta x(t) - f(t)\frac{\vec{m}_1 \times (\vec{X} - \vec{X}_{cp})}{\vec{m}_3 \times (\vec{X} - \vec{X}_{cp})}$$

$$y' = y_0 + \Delta y - f\frac{\vec{m}_2 \times (\vec{X} - \vec{X}_{cp})}{\vec{m}_3 \times (\vec{X} - \vec{X}_{cp})} \qquad y' = y_0(t) + \Delta y(t) - f(t)\frac{\vec{m}_2 \times (\vec{X} - \vec{X}_{cp})}{\vec{m}_3 \times (\vec{X} - \vec{X}_{cp})}$$

?

Recommendations and Future Works

- The computed values for the IOPs associated with a given temperature could be used to create a look-up table that predicts the IOPs.

- These predicted values and corresponding standard deviations could be used as weighted parameters for *in-situ* calibrations.

Recommendations and Future Works

- The computed values for the IOPs associated with a given temperature could be used to create a look-up table that predicts the IOPs.

- These predicted values and corresponding standard deviations could be used as weighted parameters for *in-situ* calibrations.

- Evaluate the effect of the use of the IOPs predicted by the mentioned look-up table in the 3D reconstruction.

- Compute the correlation between temperature and IOPs for other cameras.

Acknowledgements

Conselho Nacional de Desenvolvimento Científico e Tecnológico for the support on the projects 475932/2003-0, 481047/2004-2, 478782/2009-8 and 312909/2009-8.

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UNESP - Campus of Presidente Prudente

PPGCC – Pos-Graduation Program of Cartographic Sciences
UNESP - Campus of Presidente Prudente

Prof. Dr. Mário L. L. Reiss for providing his MID program for interactive target measurements

Thank for your attention!

Cameras used in the experimets

a) 

b) 

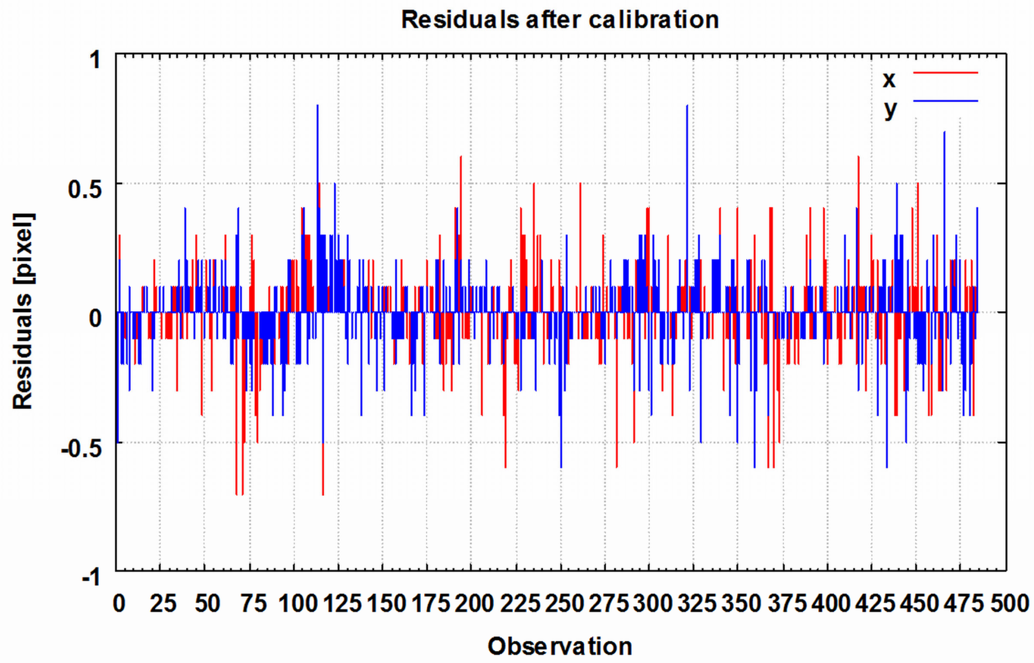
c) 

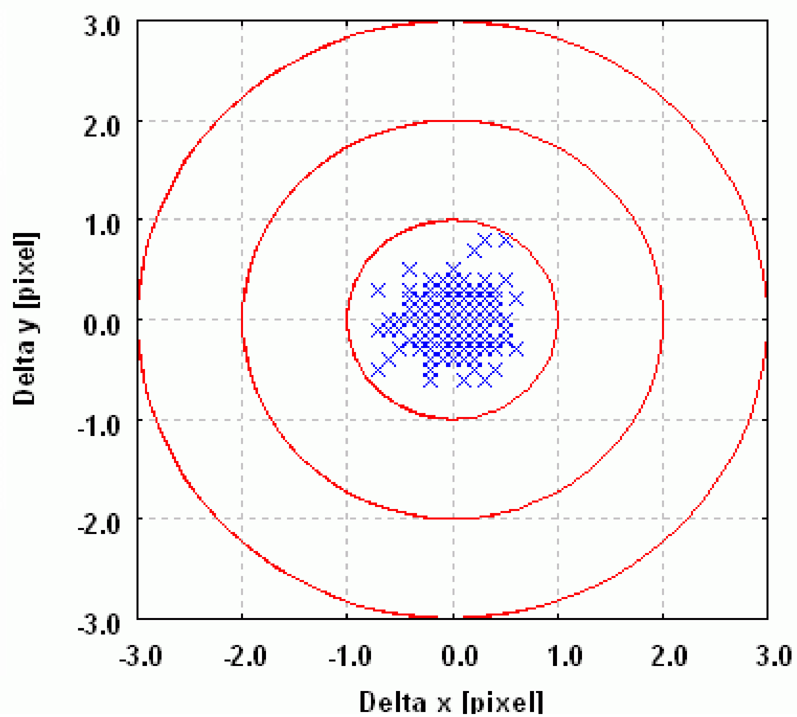
- a) Fuji FinePix S3 Pro [4256 (h) x 2848 (v); 12.1 Mpixel; sensor size 15.5 x 23 mm; pixel size 5.4 µm; f=28mm]
- b) CCD of the Fuji FinePix camera (CCD SR II)
- c) Hasselblad H3D 50 [8176 (h) x 6132 (v); sensor size 36 x 48 mm; pixel size 6.0 µm; f=35 mm]

Change the temperature and image acquisition

- The cameras were first placed in a temperature-controlled room overnight;
- The first set of images was taken at a low temperature, early in the morning. The temperature was measured using three digital thermometers (the average value of three readings was recorded);
- After approximately 4 hours, before the second set of images was taken, the cameras were placed in another temperature-controlled room, where the temperature was greater than in the first room;
- Before the third set of images was taken, the cameras were placed inside a vehicle under the sun for a few hours to raise and stabilize the temperature;
- Finally, the last set of images was taken by repeating the same procedure the next morning.

Residuals in the image coordinates after the self-calibration for acquisition 1 and IOP group (c, x_0, y_0, k_1, k_2, P_1, P_2)





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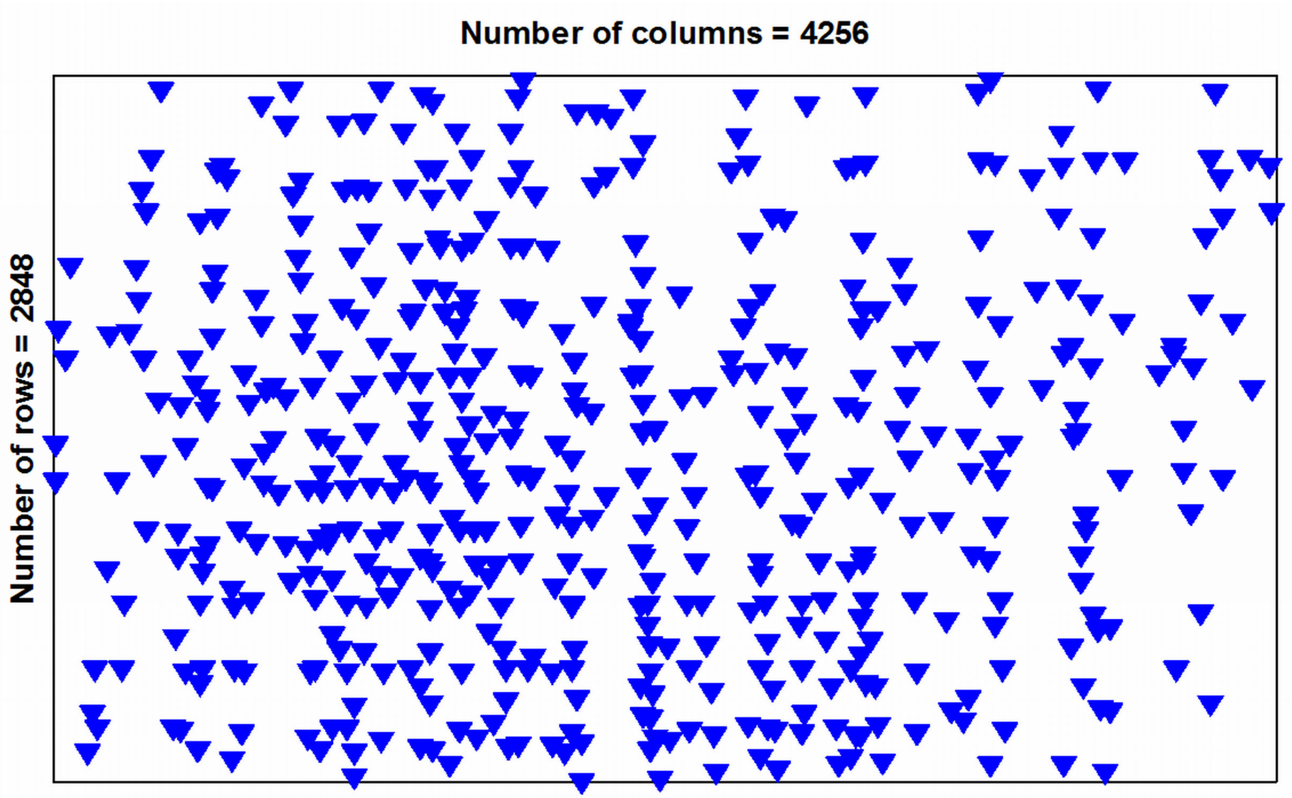
Distribution of points over the image plane for one experiment (with Fuji FinePix camera and 9 images)



In this example the number of measured points is 482. It is important to have points distributed over the entire image plane.

Precision calliper: PANTEC 2000mm / 80", Reading ± 0,020mm