Self-Calibration of Fused Camera Images

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Introduction

Large area covering digital cameras currently dominated by **Sony CMOS chips** with **IQ4** 14200 x 10600 pixels (**151 Mpixel**) of 3.76 µm, or coming **IXM811** 19200 x 12800 pixels (**246 Mpixel**) with pixel size of 2.81 µm - larger chips not on market

If larger areas should be covered by one image with same GSD → camera systems + image fusion

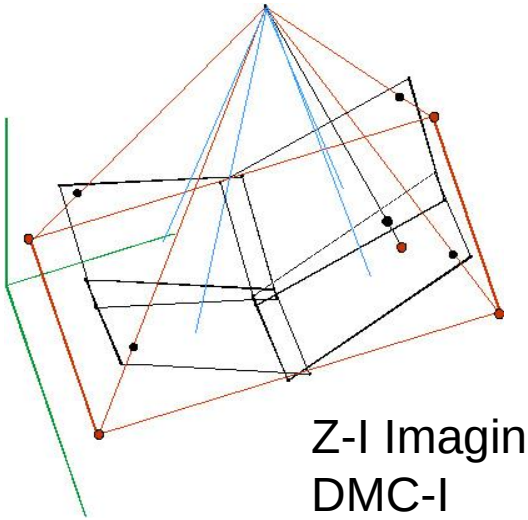
In any case, calibration of the sub-cameras of camera system required to have image coordinates corresponding to mathematical model of perspective geometry for image fusion

For economic reason with camera systems we should **finally generate homogenous fused images free of systematic image errors**

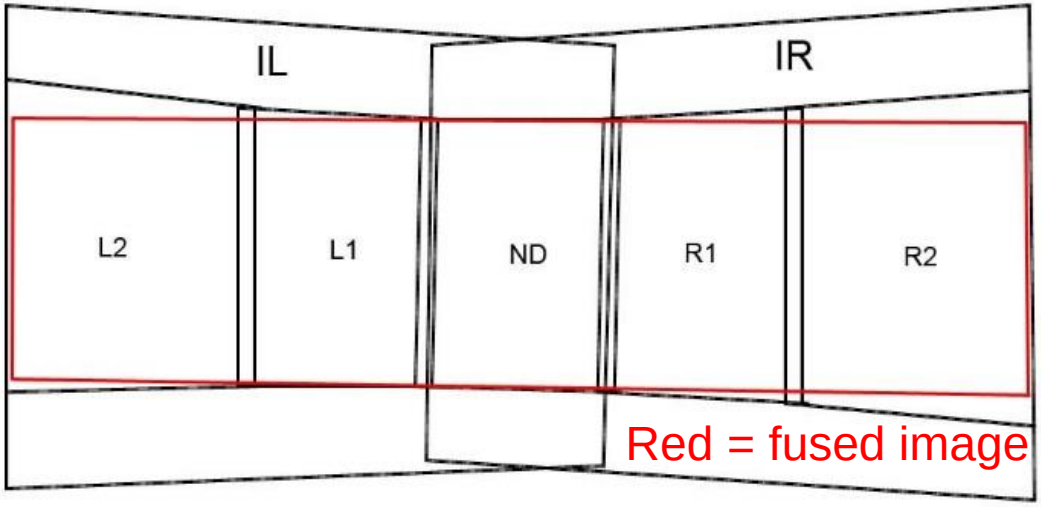
History: “large” camera systems

DMC-1 106 Mpixel, UltraCam-D 86 Mpixel (both camera systems)

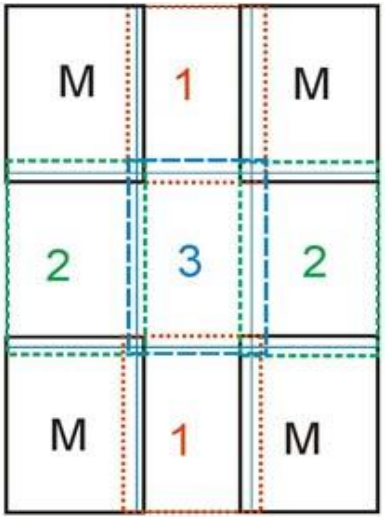
Examples of camera systems



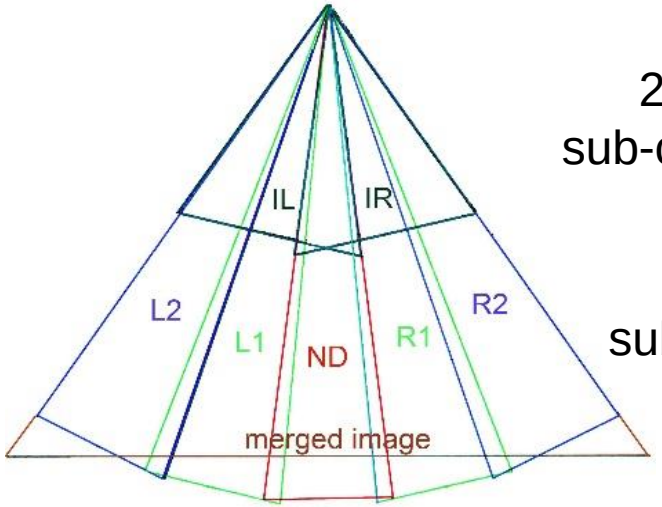
Z-I Imaging
DMC-I



PhaseOne PASPana



Vexcel
UltraCam-D,
UltraCam Eagle



2 NIR
sub-cameras

5 RGB
sub-cameras

Calibration of single cameras

Before fusion of **sub-camera** images geometry of single sub-camera images have to be geometrically corrected by **calibration**, followed by image fusion

→ by simple theory **fused images should be free of systematic image errors**

- sub-cameras may have thermal control, stabilizing camera geometry, but camera systems too large for thermal control – systematic deformations possible

→ **in any case check for systematic errors** – also due to possible errors may occur

(self-) calibration by additional parameters

Brown-Conradi (Australis) additional parameters published > 50 years ago

1) Inner orientation f, xp, yp
2) Radial symmetric dr = K1 * r^3 + K2 * r^5 + K3 * r^7 (strong correlation)
3) P1, P2 decentering distortion parameters
4) B1, B2 affinity and angular affinity

not for all details – especially deformation of image corners
also problems of the image fusion cannot be covered

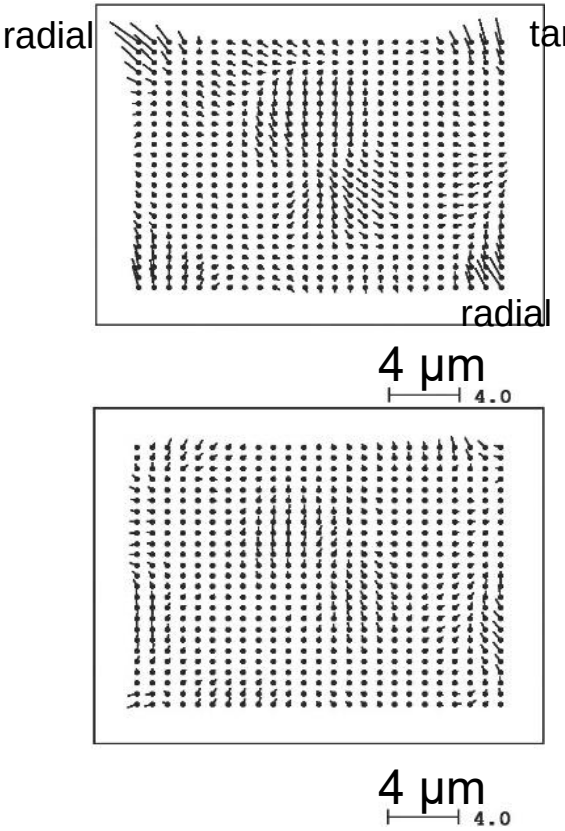
BLUH (**B**undle adjustment **L**eibniz **U**niversity **H**annover)
Basic set of 12 additional parameters
Corner parameters (radial + tangential individually for each corner) - corner deformation typical for digital cameras
Special sets of parameters for camera systems e.g. 27 for PAS Pana (Brown-Conradi included for investigation)
In total 198 additional parameters – not for use of all together – **usually basic set + corner parameters + one special set for used fused camera images**

requirement of additional parameters by Student test, correlation + total correlation – default automatic elimination of not significant parameters

Check for remaining systematic image errors

Bundle adjustments should be checked for remaining systematic image errors
Residuals of block adjustment averaged according to location in image sub-areas (25 x 25 by default)

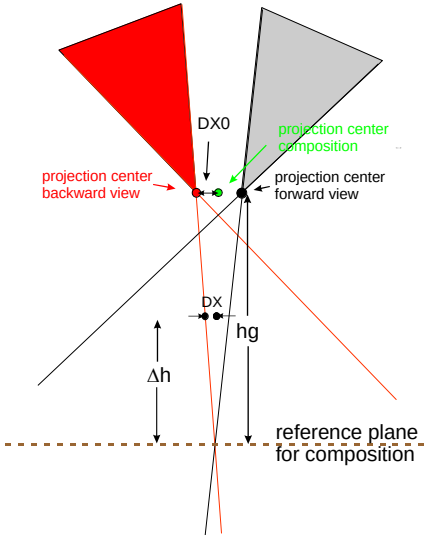
Example: calibration of Leaf P80 (2014)

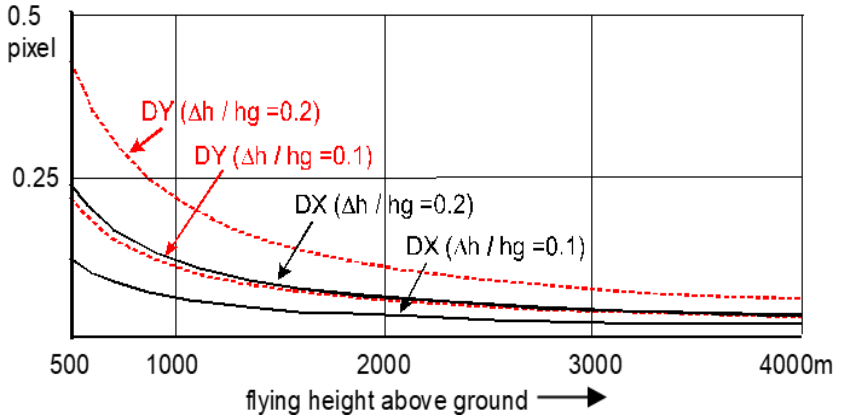


Remaining systematic image errors with Brown-Conradi parameters used before
Sigma0= 2.05 µm remaining:
RMSx=0.30 µm RMSy=0.42 µm max=2.77 µm

Remaining systematic image errors after adjustment with BLUH parameters, including **corner parameters**
Sigma0=2.05µm remaining:
RMSx=0.21 µm RMSy=0.30 µm max=1.34 µm

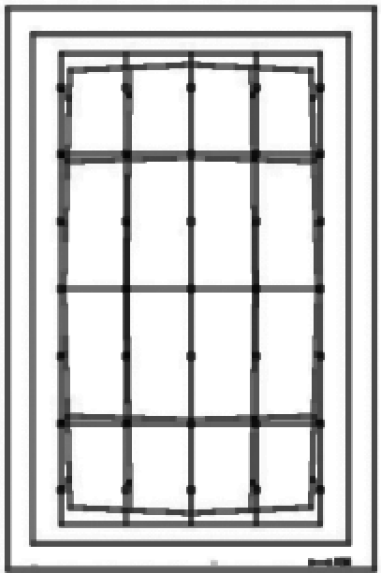
Z-I Imaging DMC-I



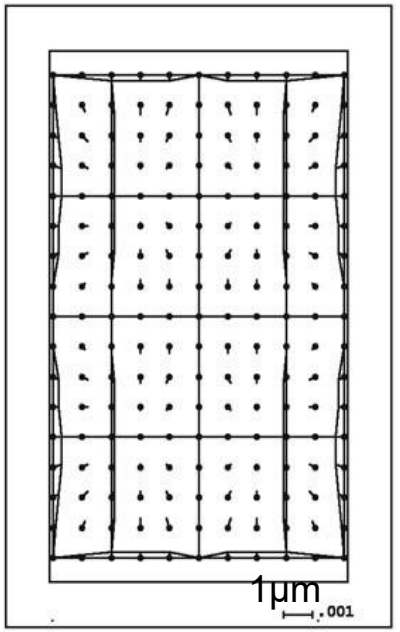


Influence of offset of projection centers should be respected
- if object area is not flat

Influence to image coordinates as F (Δh / hg)



Influence of wrong flying height for image fusion

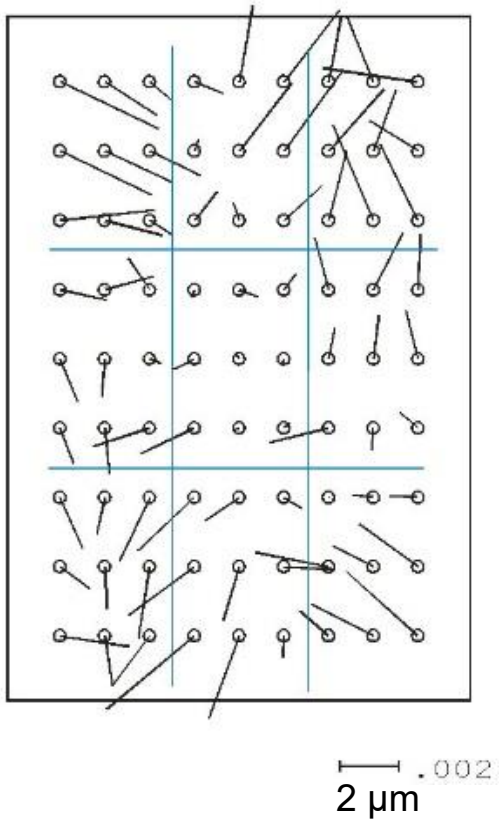


Special additional parameter for same r^3 for all sub-images
- may be caused by thermal effects

Requirement determined by analysis of remaining systematic image errors

10 µm pixel size

Vexcel UltraCam-D

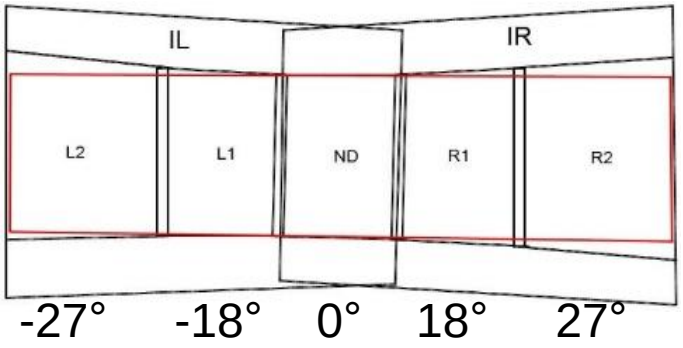


Remaining systematic image errors

Originally not acceptable systematic image errors when panchromatic images have been fused together – improved by fusing the sub-images to the homogenous green image of lower resolution

Now only minor systematic image errors caused by fusion of sub-images

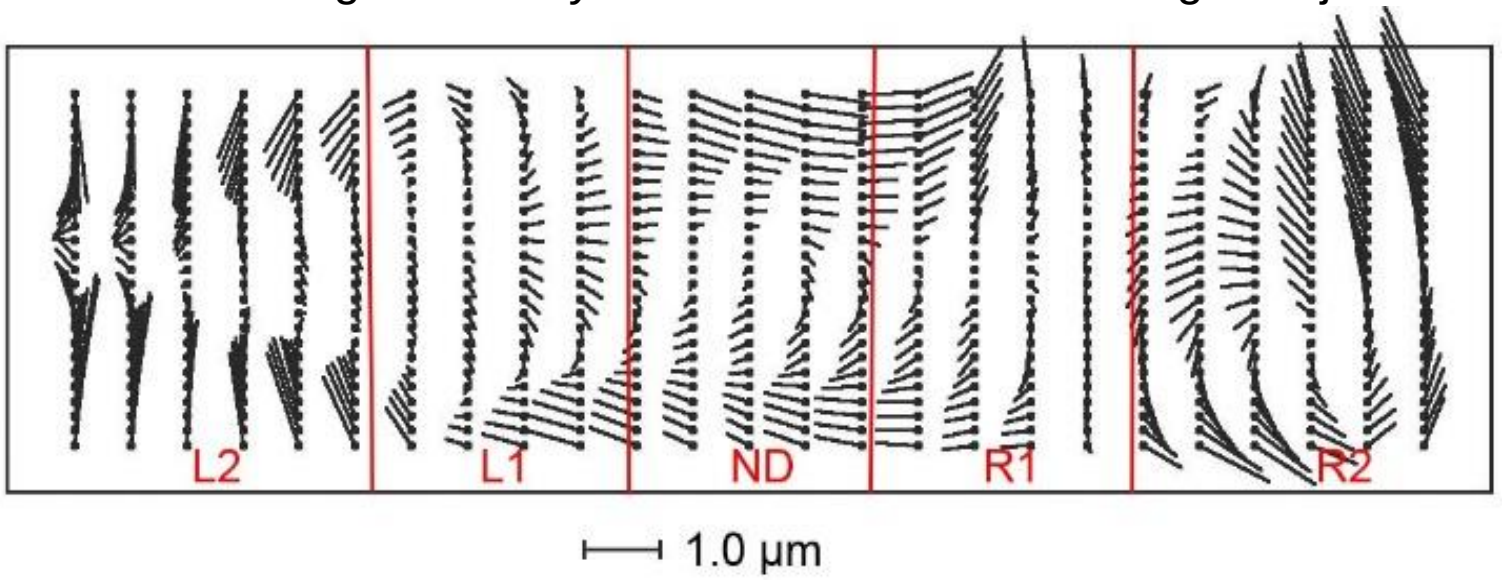
Despite special additional parameters for **any sub-image shift x, y, rotation and scale**



PhaseOne PAS Pana

Test data set Denver
718 images, N-S 75% end-lap, E-W 40% side-lap
+ 44% of area crossing flight lines
1.2 million image points, 25 x 25 image mashes

Image fusion by transformation of RGB-images to joint NIR-images

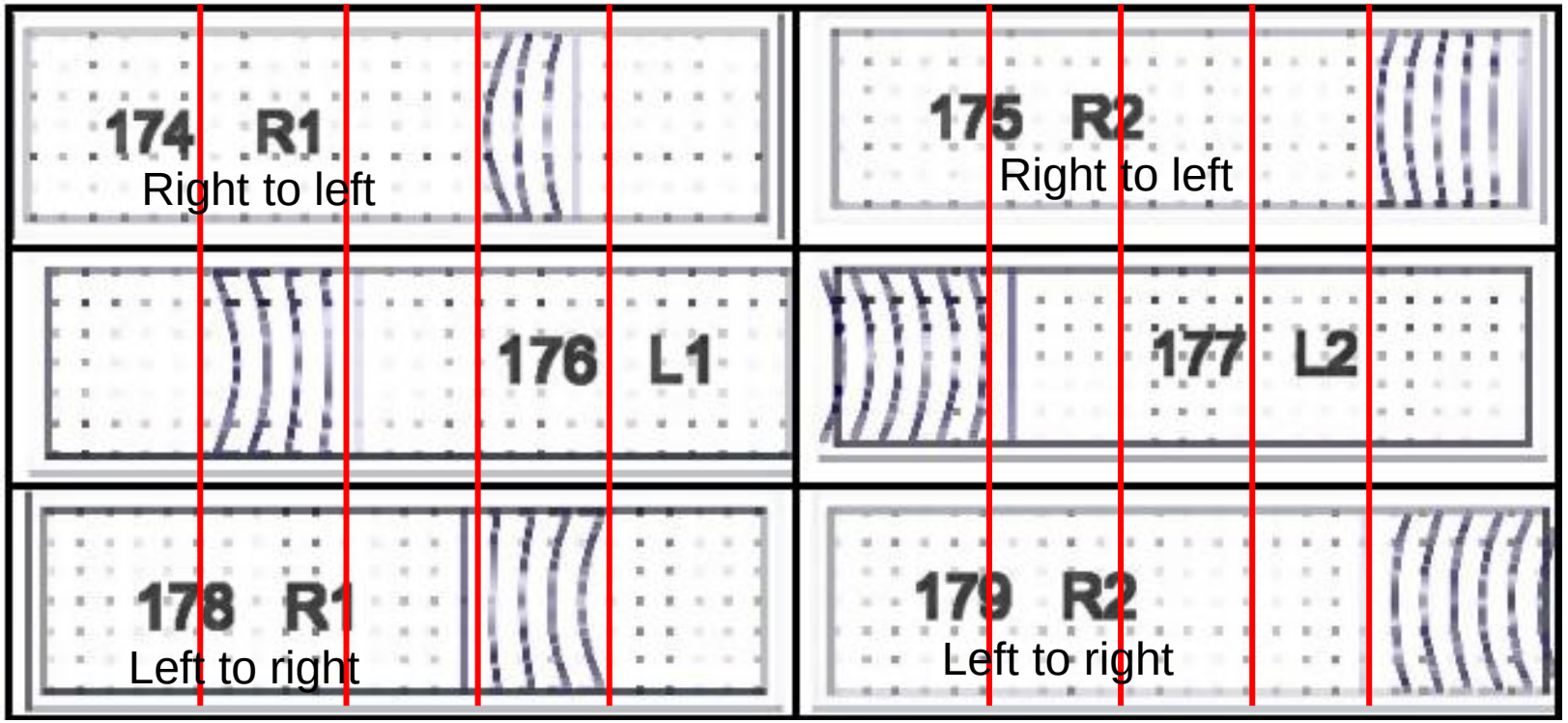


Red lines = limit of sub-images

Pixel size = 3.76 µm
~1900 vectors in image mash

Remaining systematic image errors RMSx =0.27µm RMSy =0.47µm maximal = 1.8µm
Vectors individually for any image mash
Problem: **by failure not the correct calibration of the sub-images used for fusion**

Special additional parameters for PAS Pana with incorrect calibration



Red lines = limits of sub-images

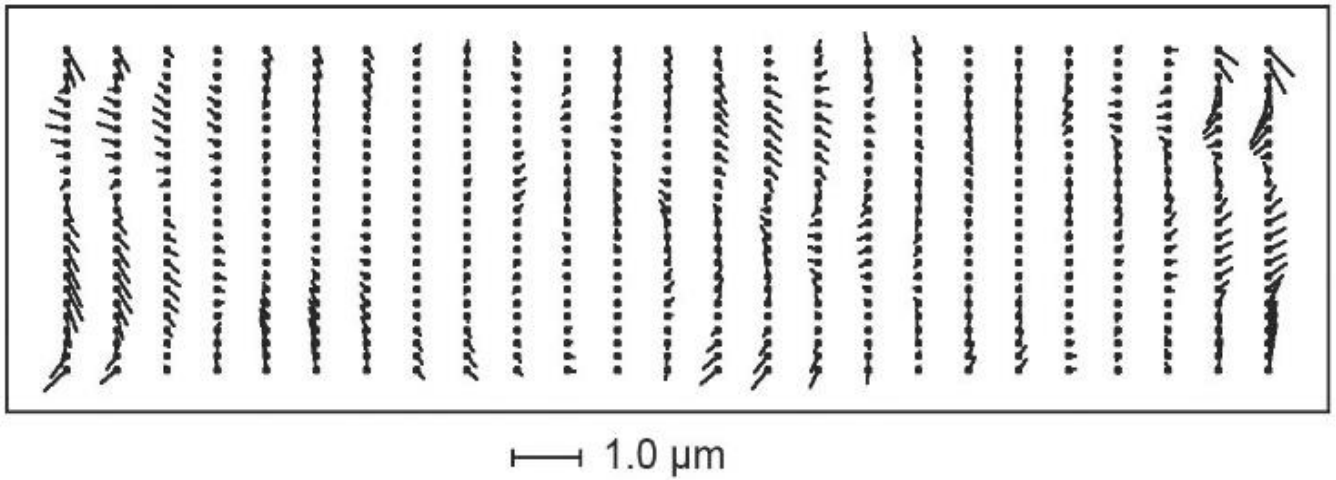
←x_{sub}→

L2 L1 cent. R1 R2 L2 L1 cent. R1 R2 sub-images

additional parameters for PAS Pana - limited to area of one sub-camera

$\Delta x = + / - x_{sub} * y^2 * parameter$

PAS Pana adjustment with special additional parameters



Pixel size = 3.76 µm

Remaining systematic image errors RMSx = 0.12 µm RMSy = 0.18 µm max = 0.95 µm
these remaining systematic image errors can be accepted

before RMSx = 0.27 µm RMSy = 0.47 µm max = 1.8 µm

Bundle block adjustment with 56 additional parameters – only 4 of them not significant
- problems of not correct camera calibration and image fusion can be solved with special additional parameters

Special additional parameters for fused sub-images

In BLUH-program following special additional parameters

For DMC-1 34 – 41 8 parameters

For UltraCam 42 – 73 32 parameters

For PAS Pana 160 – 186 27 parameters

Geometry based on determined remaining systematic image errors, limited to area of sub-cameras

conclusion

Systematic errors in single camera images significantly reduced by using standard sets of additional parameters in block adjustment. Although Brown-Conradi parameters have some limitations, major part of the systematic parameters can be eliminated. Nevertheless important parameters may be corner parameters

Due to limited size of CMOS chips use of camera systems

→ This can cause special systematic image errors of fused images

→ special additional parameters for any type of camera systems required

By analyzing remaining systematic image errors, necessary additional parameters can be constructed to eliminate the geometric problems

With proper image fusion and sets of additional parameters for specific camera geometry, **with fused images same accuracy as with single images**

PAS Pana