GPS and IMU supported Bundle Block Adjustment as Base of Homogenous GIS Data Acquisition

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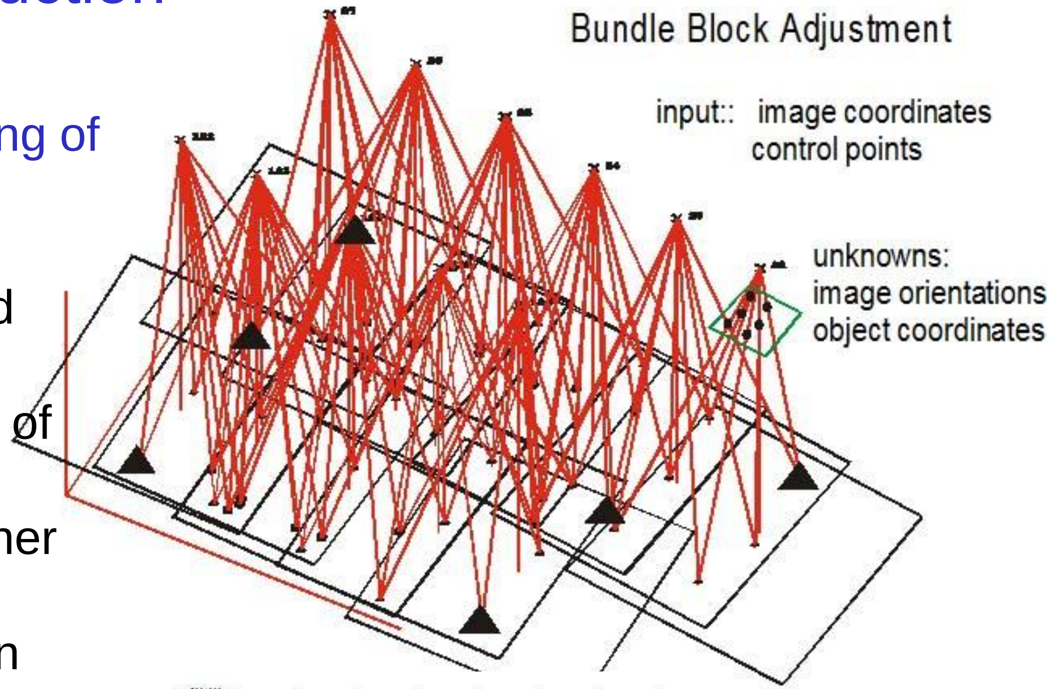
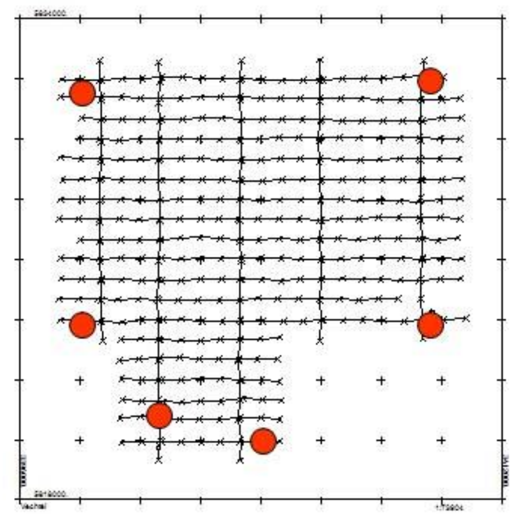
Introduction

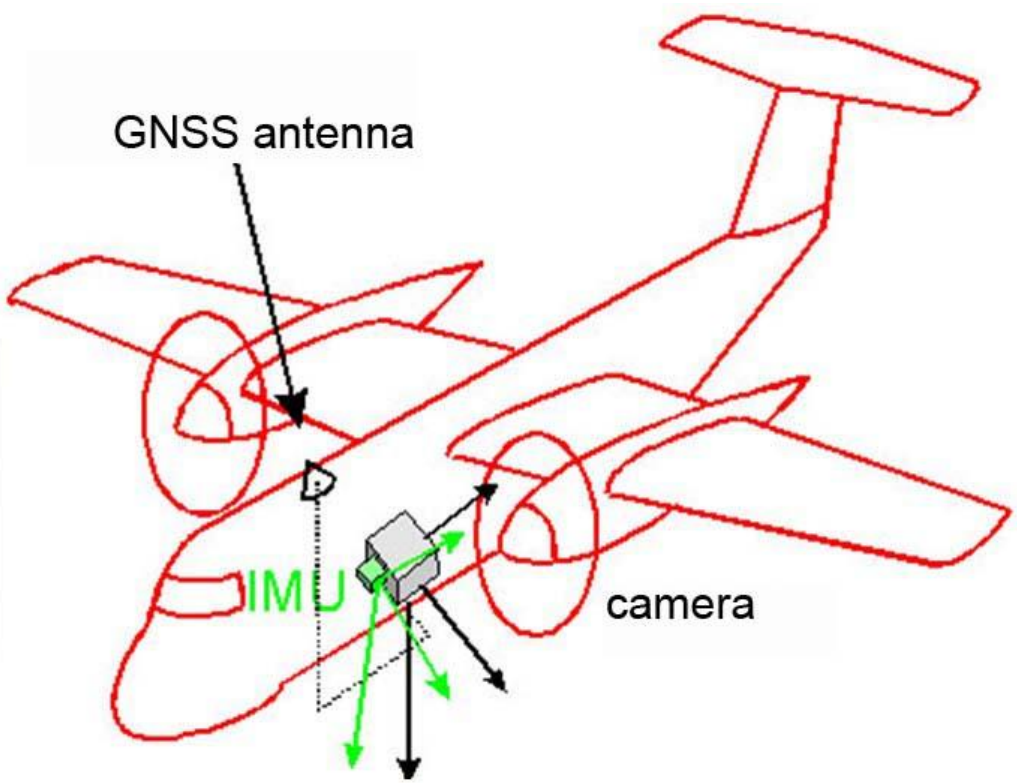


Aerial images
sensor orientation, required for geo-referencing of photogrammetric data acquisition

- Orientation of single model – several ground control points (GCP) required
- Bundle block adjustment – reduced number of GCP
- Bundle block with crossing flight lines – further reduction of GCP
- Projection center coordinates as observation in bundle block adjustment – also without GCP (combined bundle block adjustment)
- Projection center coordinates + attitudes by inertial measuring unit (IMU) → **direct sensor orientation**



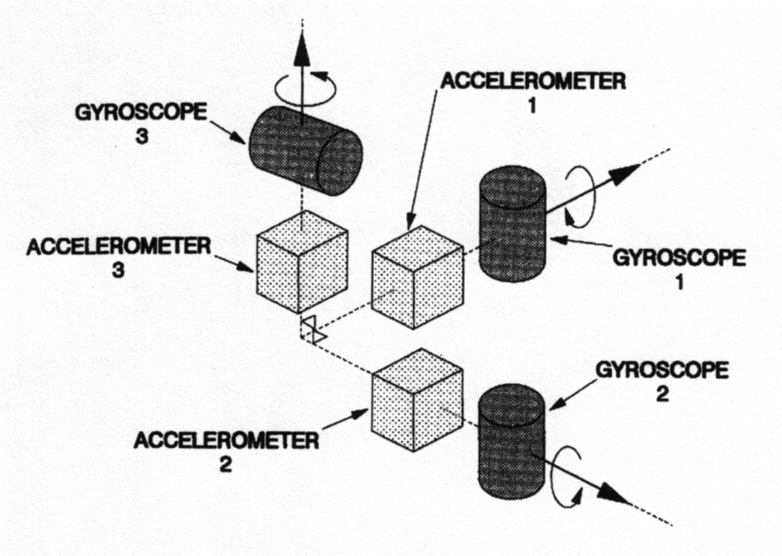
Components of direct sensor orientation



Global Navigation Satellite System (**GNSS**)

GPS, GLONASS, Galileo, GAGAN, BeiDou, QZSS
relative kinematic positioning
position of antenna → projection center

Inertial Measurement Unit (**IMU**) *(INS)*



camera

Large size digital aerial frame cameras

Development dominated by development of CCDs

DMCII-CCD-array

	camera	Pixels (camera) x	Pixels (camera) y	Pixel size [µm]	f [mm]	Mega-pixel
Z/I Imaging	DMC	7680	13824	12.0	120	106
Z/I Imaging	DMCII 140	11200	12096	7.2	92	135
Z/I Imaging	**DMCII 230**	**14144**	**15556**	**5.6**	**92**	**220**
Z/I Imaging	**DMCII 250**	**14656**	**17216**	**5.6**	**112**	**249**
Vexcel Imaging	UC D	7500	11500	9.0	101.4	86
Vexcel Imaging	UC X	9420	14430	7.2	100.5	136
Vexcel Imaging	UC Xp	11310	17310	6.0	100	196
Vexcel Imaging	**UC Eagle**	**13080**	**20010**	**5.2**	**80 / 210**	**261**

Today only digital cameras should be used

-more accurate, higher information content, IMU-system fixed in cameras

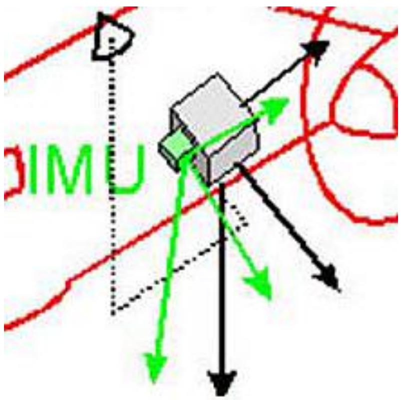
-Large size digital frame cameras or line scan cameras (Leica ADS80) – similar accuracy, only model handling of line scan images more complex

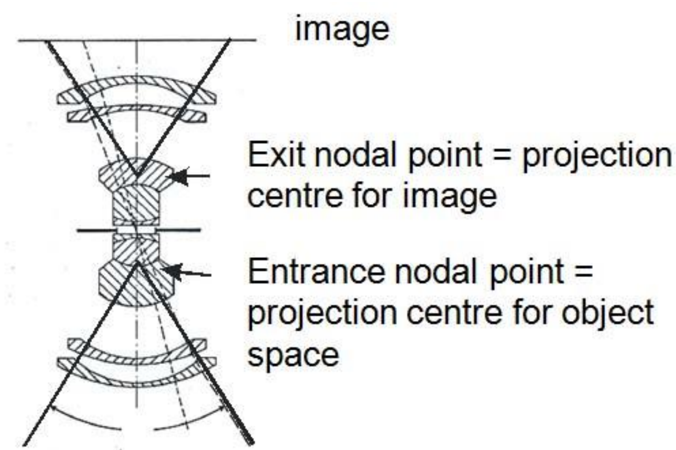
GNSS

Trimble GNSS-Inertial system AP20
0.28 kg

Electronic components of GNSS became small – integration of GNSS with IMU to **GNSS-Inertial system**

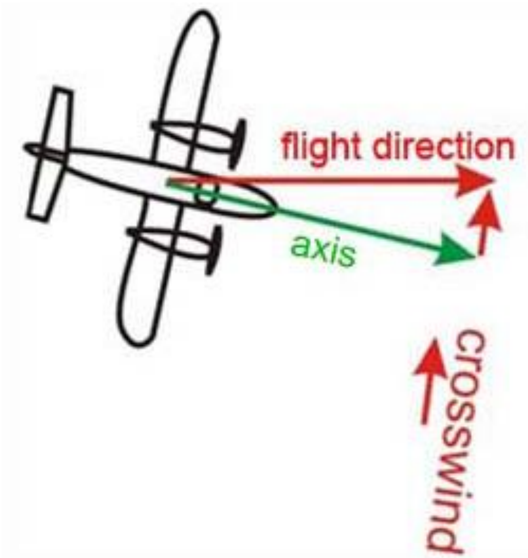
Relative positioning required for precise positioning – CORS-station
-distance ~ 50km or network solution with net of CORS-stations
or worldwide reference system as Omni Star --
→ positioning with standard deviation of ~ 0.1m up to 0.5m

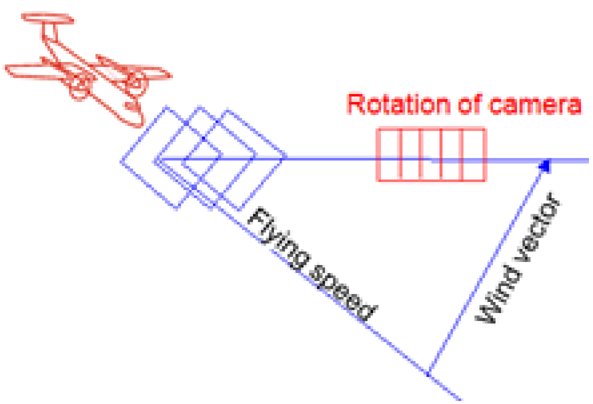




Transformation of position from antenna phase center to projection center (entrance nodal point)
In case of gyro stabilized platform reading of platform attitude

System calibration

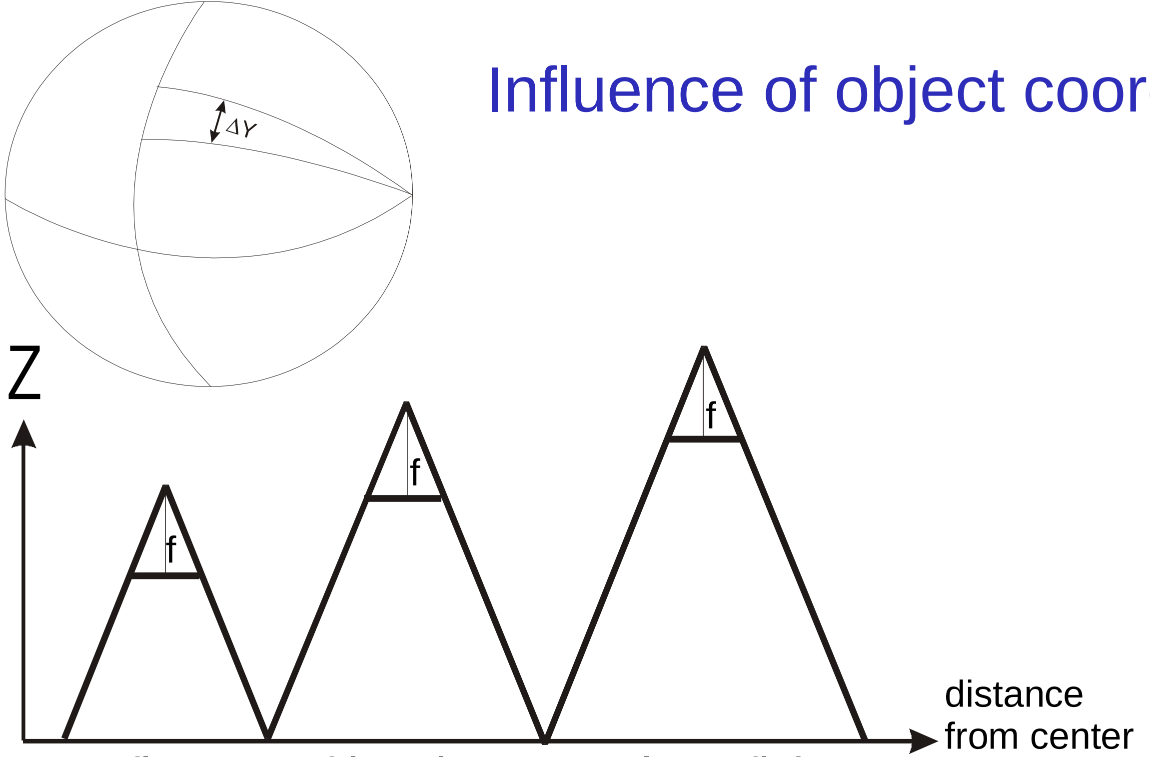




1. Camera calibration: laboratory calibration only for focal length + principal point, details by self calibration in bundle block adjustment
2. Offset antenna phase center – camera entrance nodal point: can be determined at aircraft – problem: camera orientation in aircraft not fixed (crab angle compensation, gyro controlled platform) – crab angle no influence if antenna directly above camera
3. Misalignment of IMU against camera complete calibration by reference adjustment with few GCP including antenna offset, inner orientation of camera based on flight lines flown in opposite direction

   if calibration shall be used in different areas – take care about coordinate system

Influence of object coordinate system



Influence of local map scale to flying height

local scale of transverse Mercator system

S0 = scale factor for meridian (0.9996 for UTM)

R = earth radius

X = distance from meridian

$$scale = S0 \bullet \left(1 + \frac{X^2}{2R^2}\right)$$

For 10 km flying height
at meridian: -4m
333km from meridian: +13.7m

Caused by the flattening of the earth to the mapping coordinate system local scale -scale correction not to Z-coordinates, causing height differences between projection center and ground depending upon location in the national coordinate system

→Handling in tangential coordinate system or height corrections
or calibration within the project area

Inertial Measurement Unit

system	position	roll/pitch	yaw (heading)	
Trimble AP 20 (Applanixs)	0.05 – 0.30m	0.015°	0.035°	Trimble (Applanixs)
Trimble AP40	0.05 – 0.30m	0.008°	0.025°	
Trimble AP50	0.05 – 0.30m	0.005°	0.008°	
Trimble AP60	**0.05 – 0.30m**	**0.0025°**	**0.005°**	
Leica IPAS20 NUS4	0.05 – 0.30m	0.008°	0.015°	Leica
Leica IPAS20 DUSS	0.05 – 0.30m	0.005°	0.008°	
Leica IPAS20 NUS5	0.05 – 0.30m	0.005°	0.008°	
Leica IPAS20 CU56	**0.05 – 0.30m**	**0.002 5°**	**0.005°**	
IGI AEROcontrol (SMU)-m	0.05m	0.010°	0.020°	IGI
IGI AEROcontrol (SMU)-I	0.05m	0.008°	0.015°	
IGI AEROcontrol (SMU)-II	0.05m	0.004°	0.010°	
IGI AEROcontrol (SMU)-III	**0.05m**	**0.003°**	**0.007°**	

Relative accuracy = absolute accuracy if GNSS-data combined with IMU-data

IMU positions and attitudes have drift problems → combination with GNSS-positions by Kalman filtering – GNSS-data support IMU-data and reverse – also GNSS-positions supported by IMU improved – no more problems with cycle slips

Required attitude accuracy

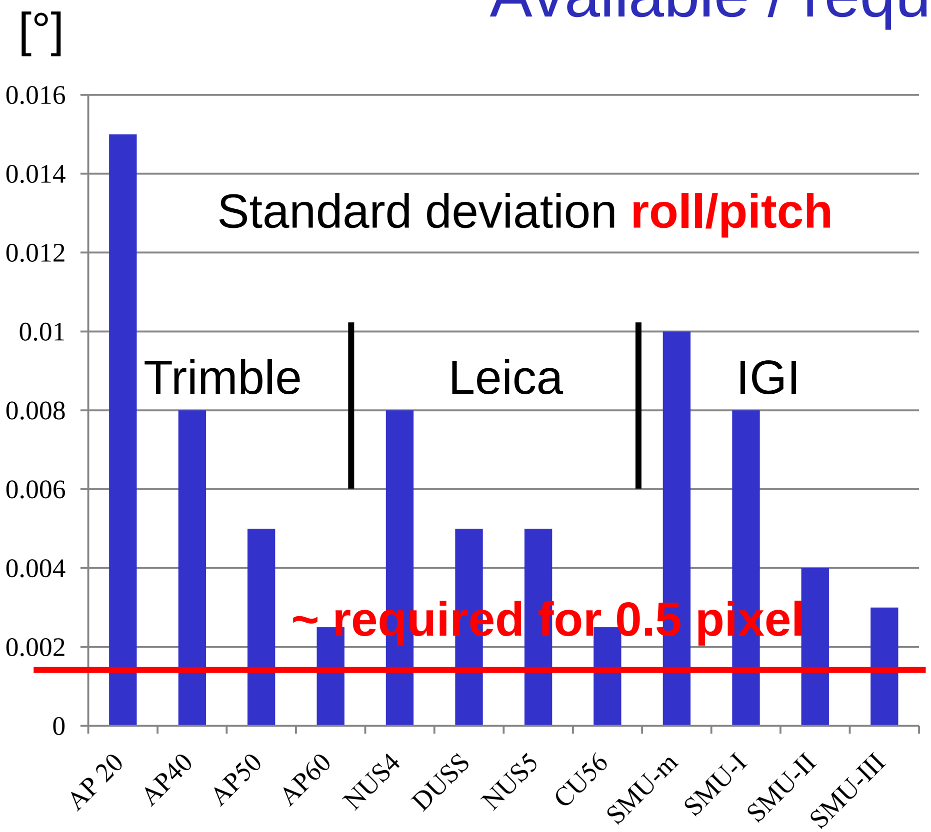
influence of 1µm and 1 pixel in image to roll, pitch and yaw for nadir view

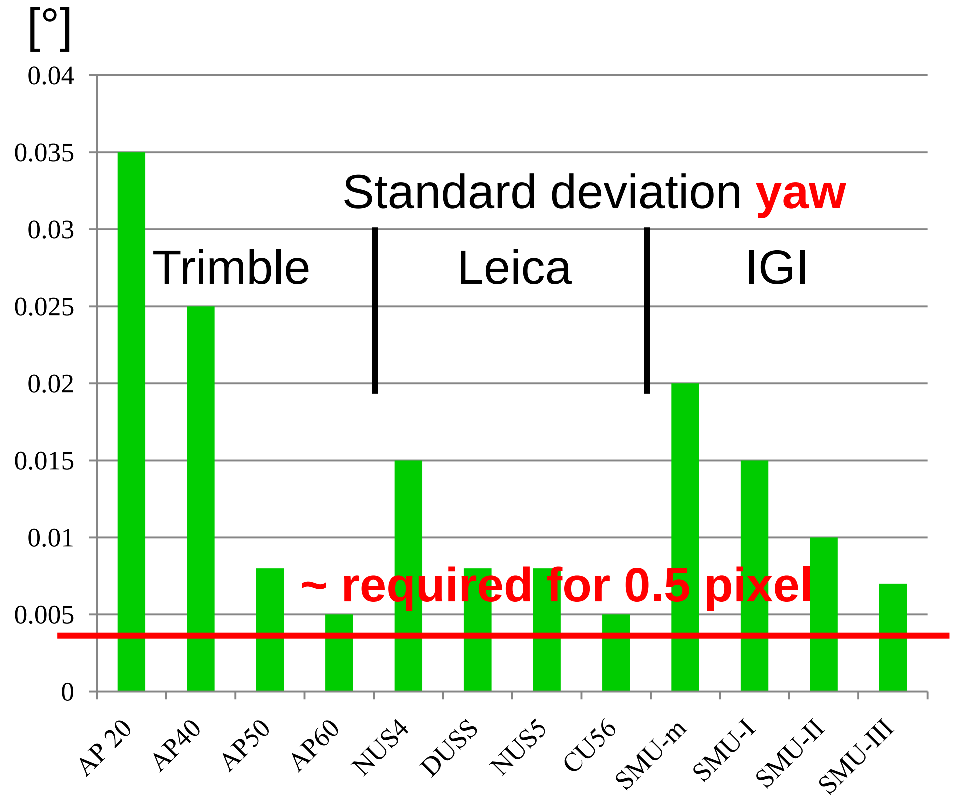
roll / pitch → image yaw → image

	1µm to roll/pitch	0.5 pixel to roll/pitch	1µm to yaw	0.5 pixel to yaw
DMC (1st version)	0.000 5°	0.002 8°	0.001 1°	0.006 9°
DMCII 230	0.000 6°	0.001 8°	0.001 0°	0.002 7°
DMCII 250	0.000 5°	0.001 4°	0.000 9°	0.002 6°
UC XP	0.000 6°	0.001 8°	0.000 9°	0.002 7°
UC Eagle f=80mm	0.000 7°	0.001 8°	0.000 9°	0.002 4°
UC Eagle f=210mm	0.000 3°	0.000 7°	0.000 9°	0.002 4°

By automatic block adjustment σo =1µm operational
Object point accuracy SX, SY = 0.5 GSD and SZ = 0.7 – 1.2 GSD possible
best standard deviation of IMU: roll/pitch 0.0025° yaw 0.007°

Available / required attitude accuracy





→Even with most expensive IMU highest object point accuracy cannot be reached by direct sensor orientation,
operational acceptable results not far away, but problems with disturbing y-parallaxes in model handling cannot be avoided

Direct sensor orientation, integrated and combined block adjustment

Integrated bundle block adjustment: use of orientation from GNSS/IMU + tie points (+ GCP) – by adjustment improvement of direct sensor orientation + improved reliability
-advantage against standard automatic aero triangulation: no problems if gaps of tie points because of poor object contrast or other problems – always orientation values
GCP for reliability check

Combined block adjustment: use of GNSS-projection center coordinates + tie points (+ GCP) – in case of block of images attitude values not required as input, can be computed, also GCP not absolutely required – for reliability at least one GCP
GCP required for single flight line

If no problems with tie points, operationally most often combined bundle block adjustment – nevertheless IMU improves GNSS-positions, direct sensor orientation helpful as approximations for automatic tie point generation

Integrated bundle block adjustment

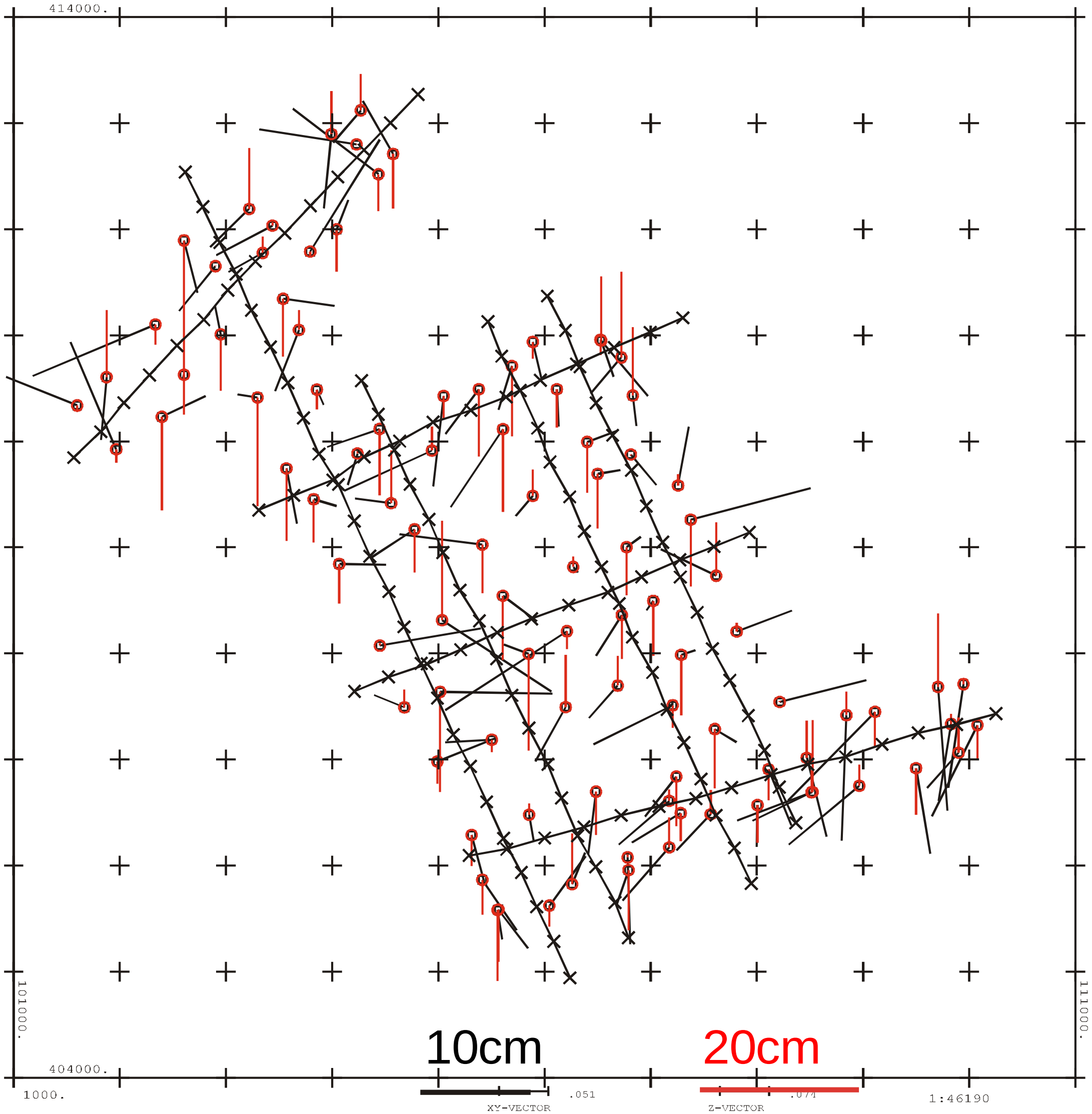


Image scale 1 : 4000

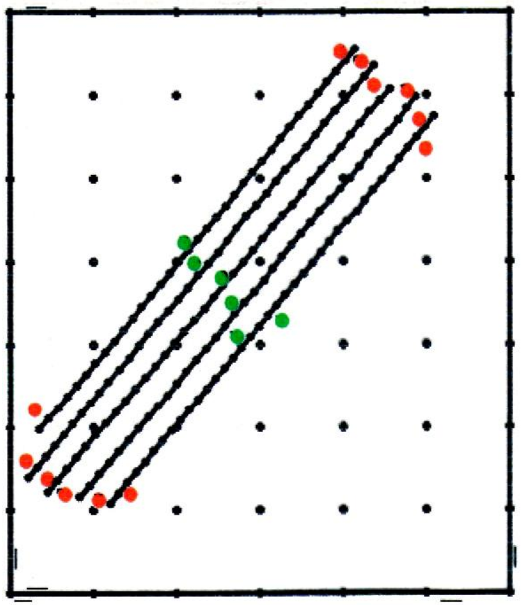
At independent check points:

SX: 5.1cm SY: 5.2cm (13µm)

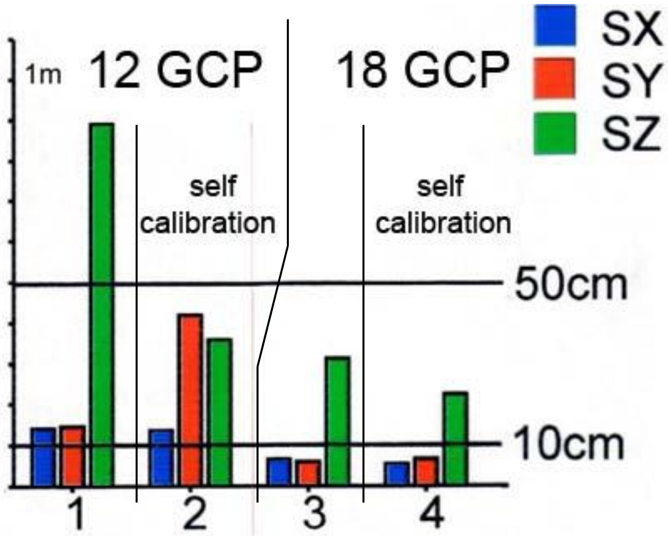
SZ: 7.4cm (11µm for Spx)

Combined bundle block adjustment

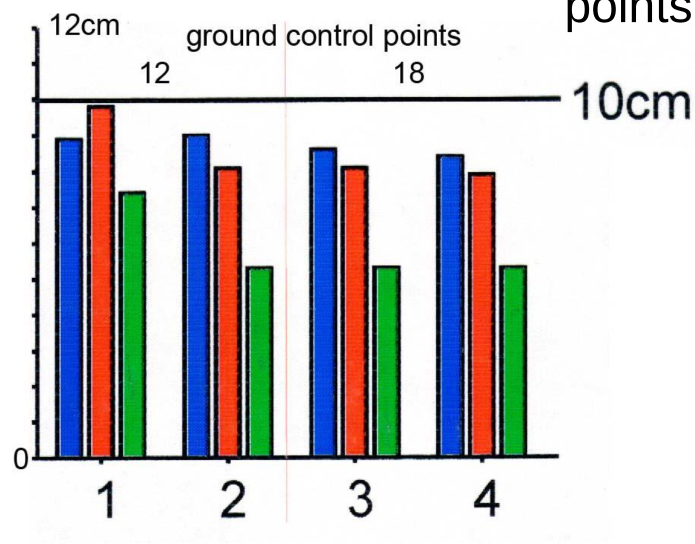
RMS at check points



Block configuration
~ 30 images in flight line
12 (red) or 18 (red+ green GCPs)
Image scale 1:3500

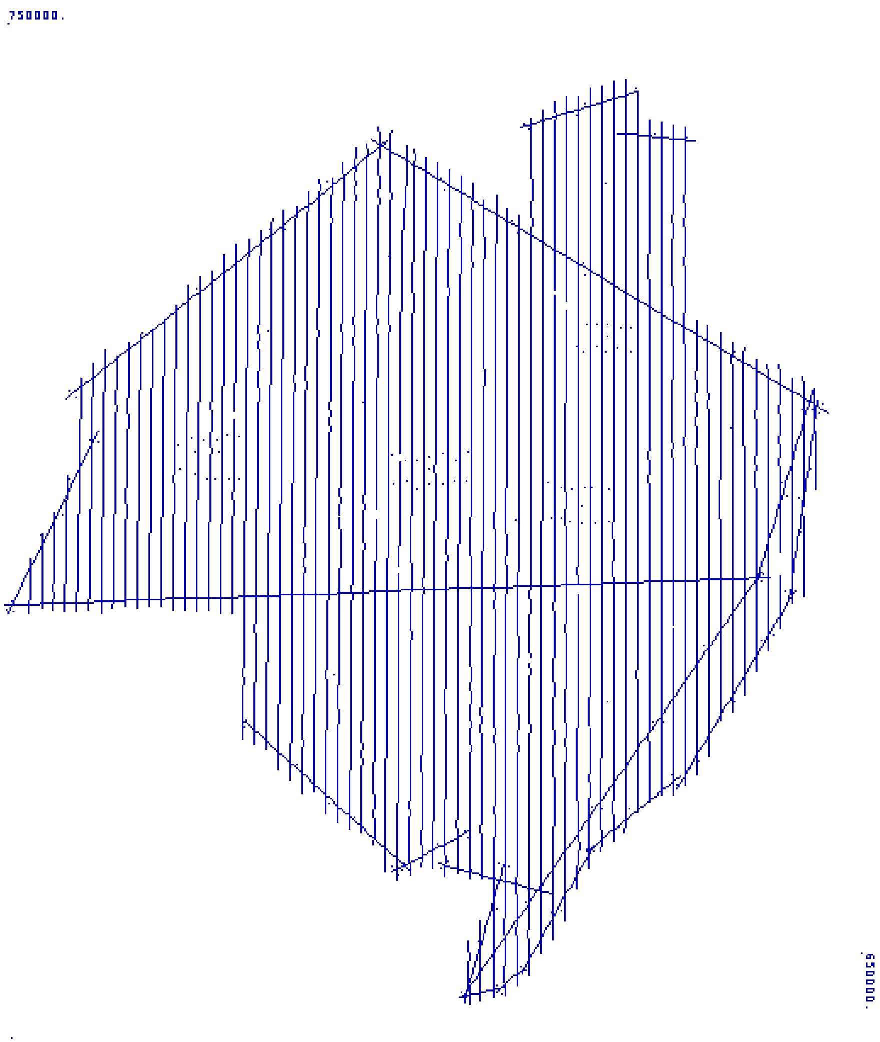


Results of reference adjustment (no GNSS)
Case 1 and 3: no self calibration
Case 2 and 4 self calibration



Results of combined block adjustment
Case 1 and 3: no self calibration
Case 2 and 4 self calibration
SZ = 0.1‰ hg

Combined bundle block adjustment



5501 images, ~ 70 flight lines
Image scale 1:19 200
Scanned with15µm pixel size →30cm GSD
end lap 60%, side lap 30%

With 175 GCP – at check points:

RMSX/Y = 30cm		RMSZ= 23cm
	1.0 GSD	0.77 GSD

With 22 GCP – at check points:

RMSX/Y = 30cm		RMSZ= 24cm
	1.0 GSD	0.80 GSD

Conclusion

GNSS-inertial systems reached high accuracy and reliability level

Hardware components continuously improved (GNSS-inertial + cameras)

use of relative kinematic GNSS-positioning + inertial measurements became standard

GNSS-electronics and IMU today in most cases integrated in a GNSS-inertial system

attitude information from IMU not reaching today high level of digital cameras

→**Integrated bundle block adjustment** with direct sensor orientation also because of reliability, attitude data helpful in areas with no object contrast and as start information of tie point generation

Attitude information not required for block → **combined block adjustment** with GNSS-data nevertheless also for this GNSS-data improved by IMU-information,