UAV Sensor Orientation with Pre-calibrated Redundant IMU/GNSS Observations

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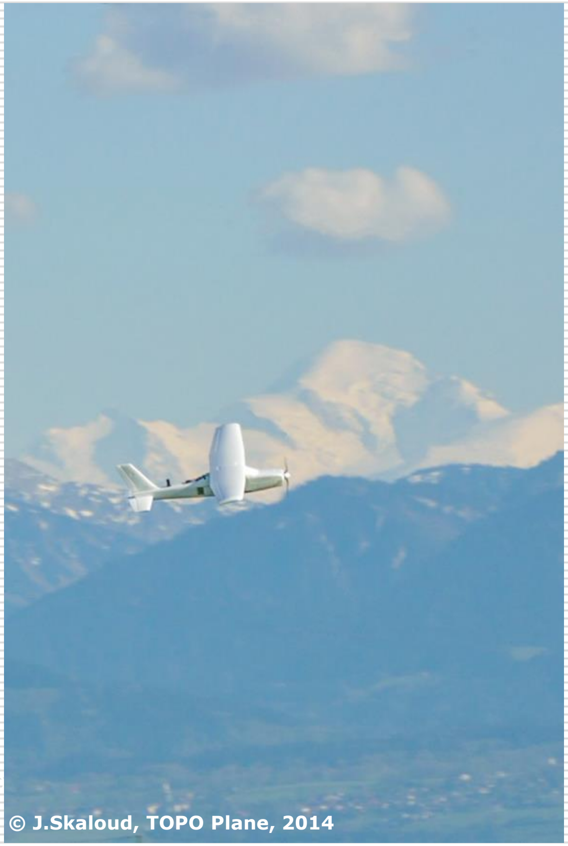

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What's on the menu

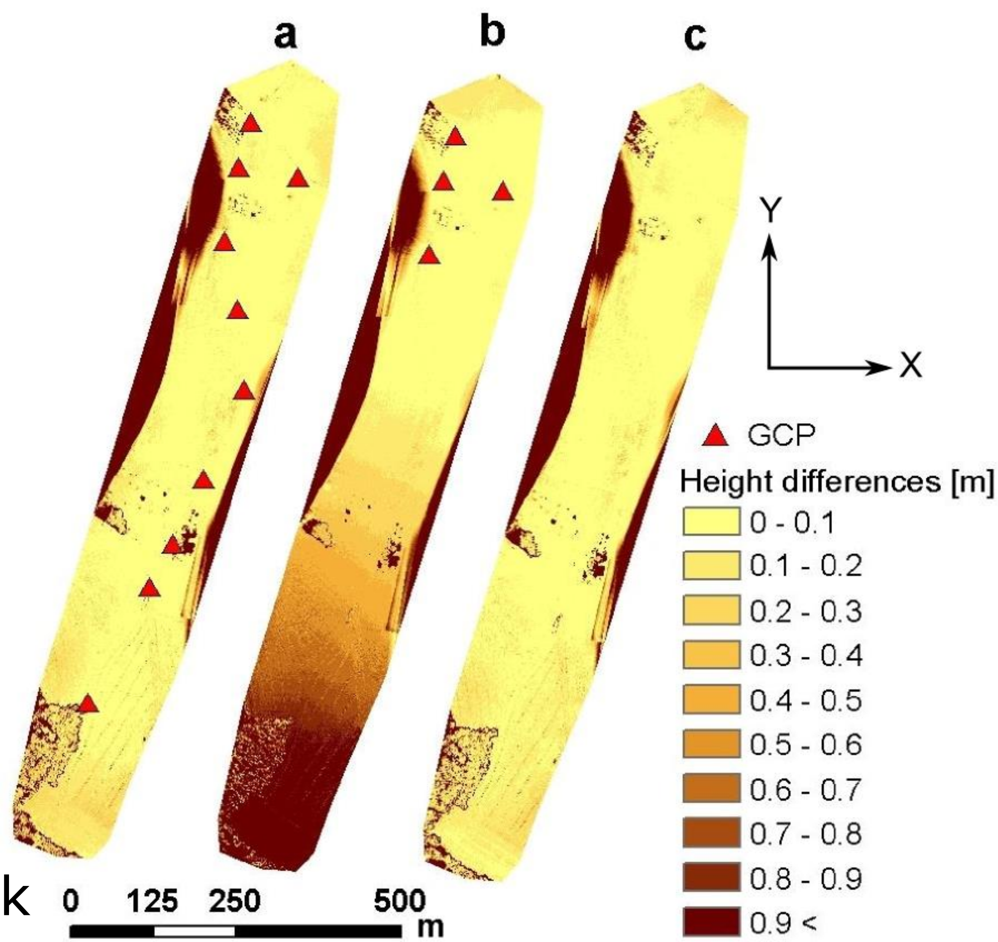
- What
  - Are the needs?
  - Are the challenges?
- Photogrammetric System
  - Airplane
  - Camera
  - Inertial sensors
- Calibration of IMUs
  - Deterministic errors
  - Stochastic errors
- Results
- Conclusion

Motivation

- Rivers
- Highways
- Pipelines
- …

Challenges

- Trajectory usage
  - Input to bundle adjustment
- Good trajectory
- Low-cost MEMS sensors
- Short initialization time
  - Roll/pitch -> accelerometer
  - Yaw from magneto/accel
- Alignment refinement
  - Needs time, flight is short!
- Better initialization
  - Needs sensor calibration
- Position -> less GCPs in block
- Attitude -> needed in corridor



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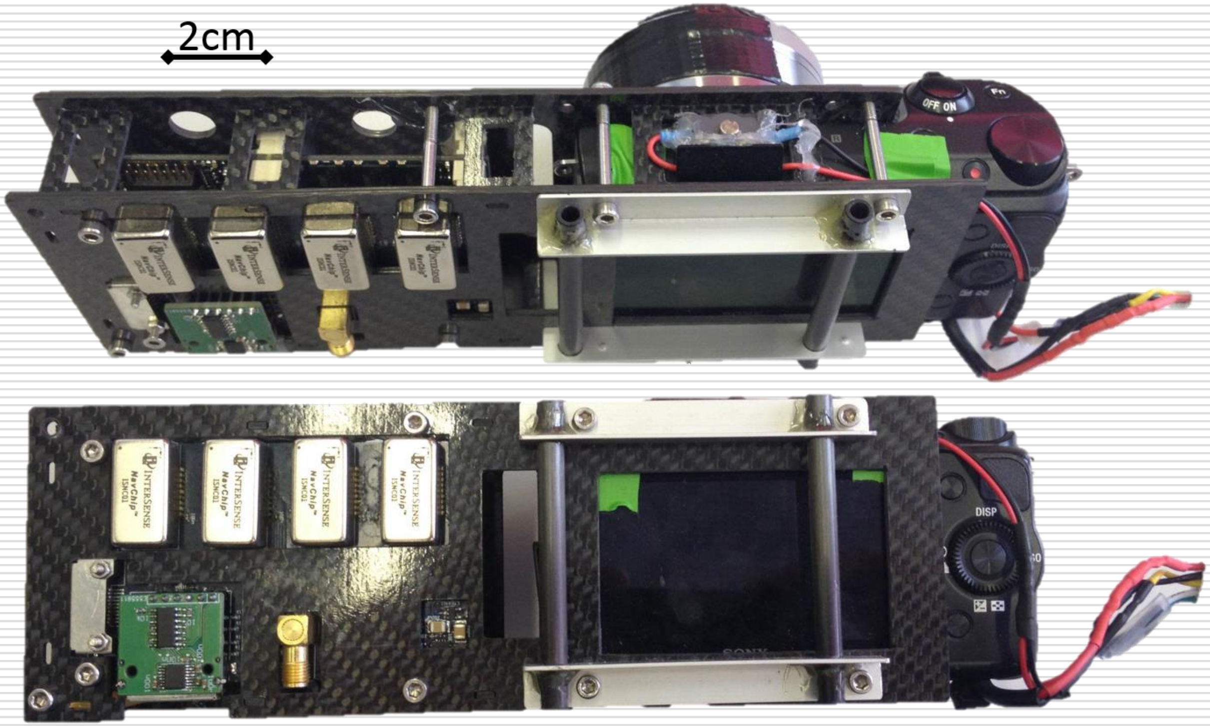
TOPO Plane - structure

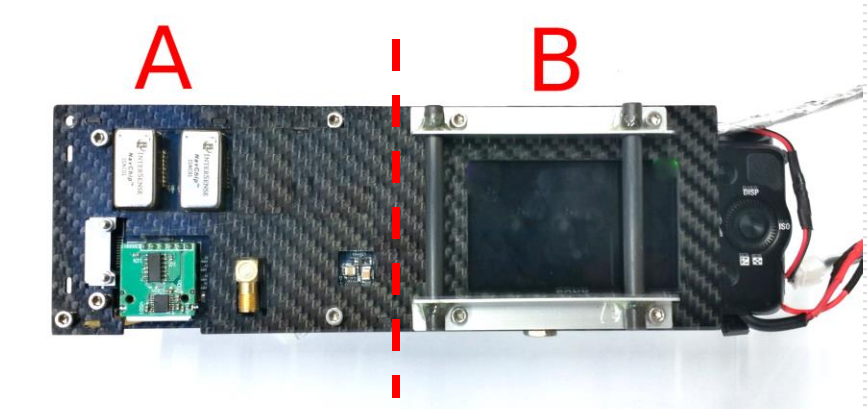
- Custom build
- 150 Euro frame (MAVinci)
- 1630 x 1700 mm
- Operational weight 2.8 kg
- Endurance of 40 min with 600 g payload
- Flying speed 16-20 m/s
- Pixhawk autopilot

TOPO Plane - payload

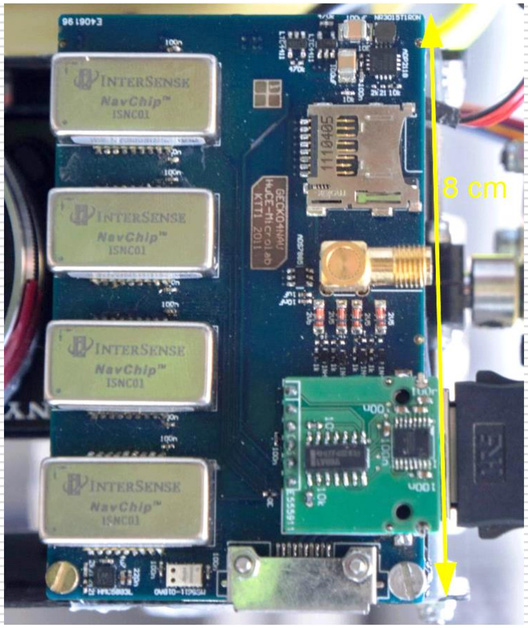


TOPO Plane - payload

- Redundant-IMU (A)
  - FPGA board
  - 1-4 x MEMS IMU
  - 250 – 1000 Hz
  - 0.2 W
  - 24x14x9 mm
  - 6 g



- Camera (B)
  - Sony NEX 5R camera (16 Mpx)
  - 16 mm lens (used in test)
  - synchronization module (flash)



- GNSS
  - multi freq., PPS, Event
  - GPS/Glonass L1/L2 antenna

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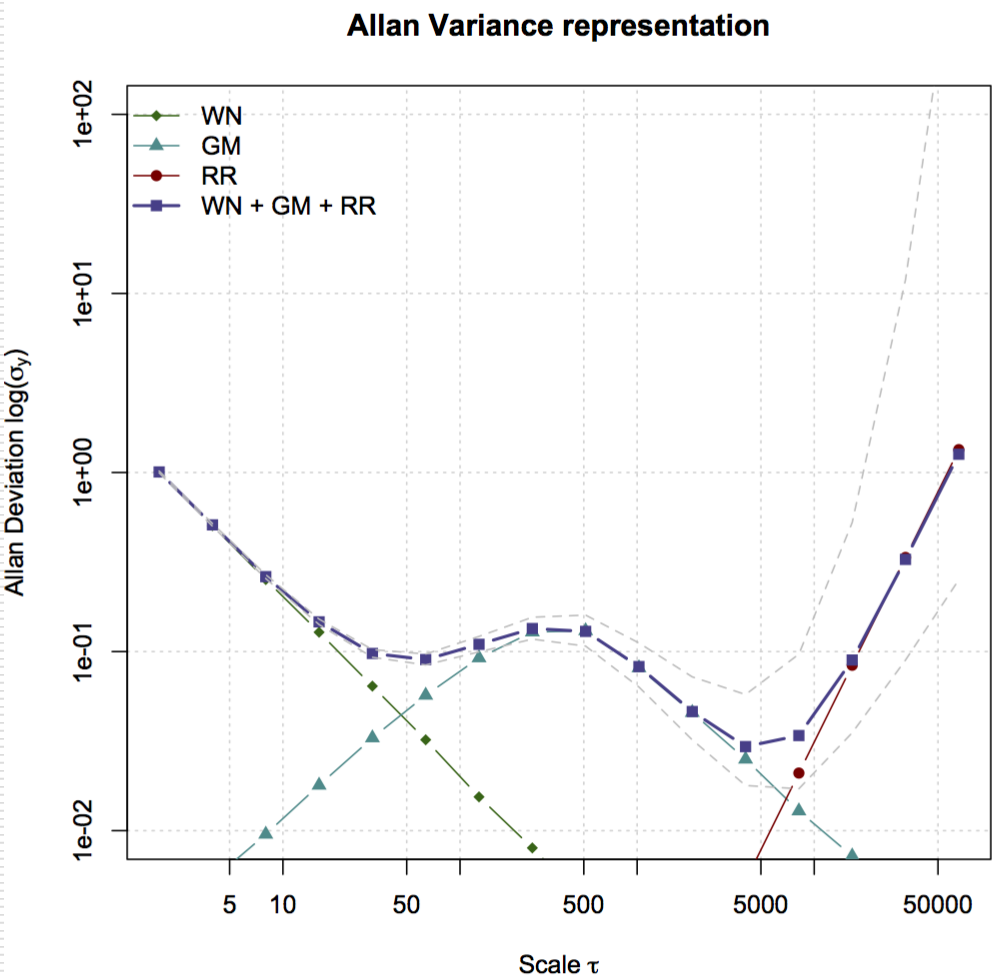
System & sensor calibration

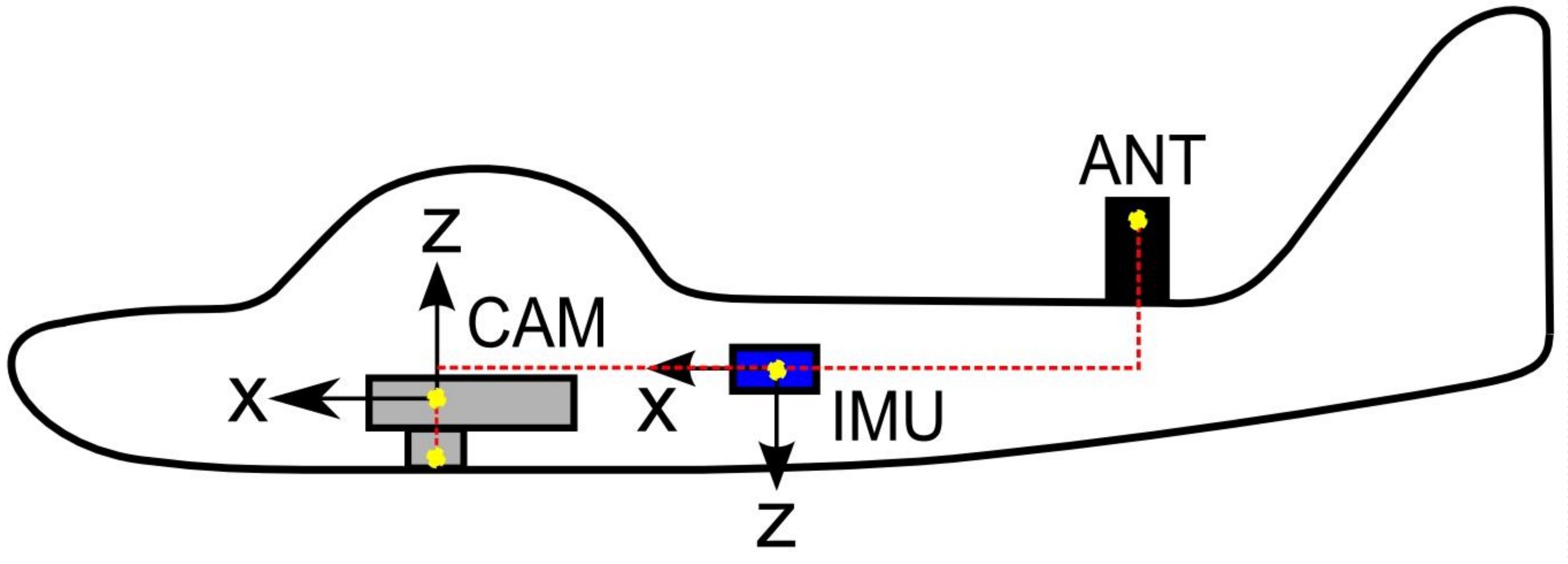
- Camera calibration
  - Self calibration during a separate flight
- IMU calibration
  - LSQ method for estimating "constant" elements (e.g. biases)
  - GMWM for estimating sensor noise characteristics
- Boresight
  - Camera – Body frame (IMU)



Guerrier, S., Skaloud, J., Stebler, Y. Victoria-Feser, M.-P. Wavelet-variance-based estimation for composite stochastic processes, **Journal of the American Statistical Association**, 108(503): 1021-1030.

System & sensor calibration

- Lever-arms
  - GNSS antenna – body frame (IMU)
  - Camera – body frame



Multi-position IMU calibration

- Deterministic errors
- Scale factor, non-orthogonality, and bias
- Measurements l
- True values g

$$\begin{bmatrix} l_x \\ l_y \\ l_z \end{bmatrix} = \begin{bmatrix} 1+S_x & 0 & 0 \\ -\theta_{yz} & 1+S_y & 0 \\ \theta_{zy} & -\theta_{zx} & 1+S_z \end{bmatrix} \bullet \begin{bmatrix} g_x \\ g_y \\ g_z \end{bmatrix} + \begin{bmatrix} b_x \\ b_y \\ b_z \end{bmatrix}$$

- Condition on the compensation process

$$g_x^2 + g_y^2 + g_z^2 - |g|^2 = 0$$

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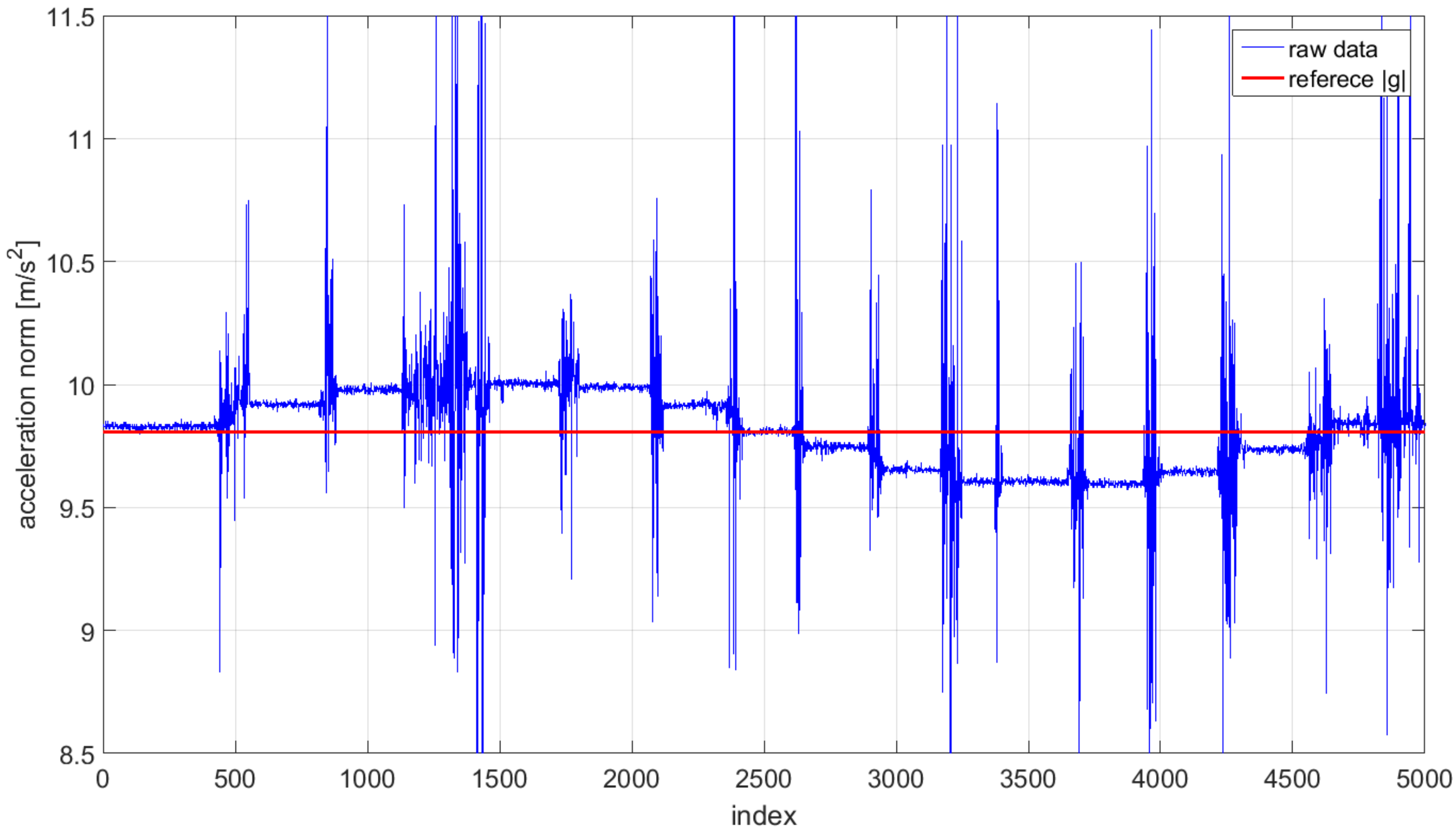
Accelerometer data in multi-orientation

- Norm of static signal at different orientations



Accelerometer data in multi-orientation

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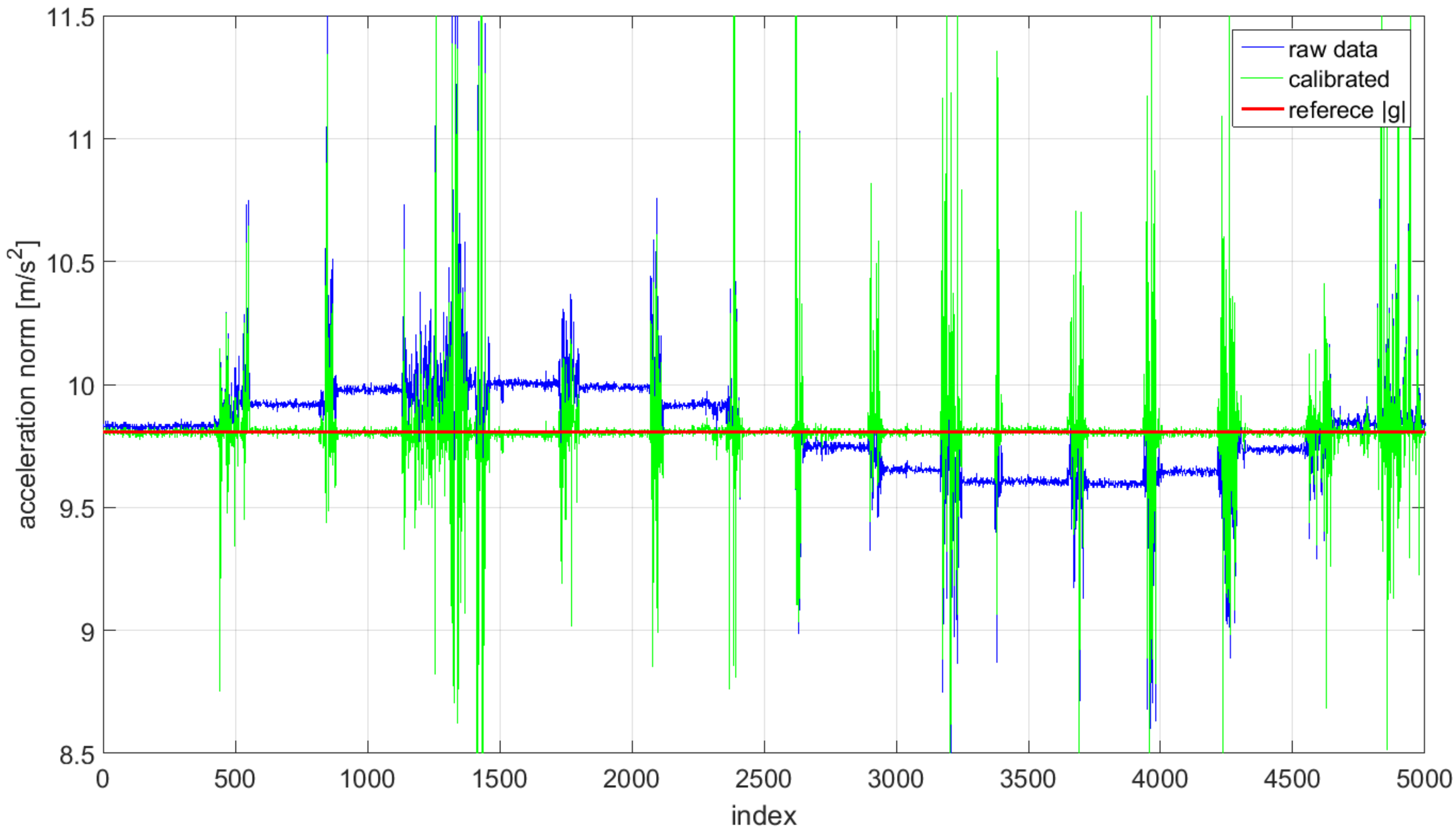

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Calibration results – sensor biases

Property	IMU 0	IMU 1	IMU 2	IMU 3
b_x [mg]	6.764	5.945	**11.397**	-0.997
b_y [mg]	**16.225**	4.198	1.538	**28.220**
b_z [mg]	-0.871	-2.507	-2.058	-5.372

- Each accelerometer has different bias value (switch-on)
- In this example this corresponds to ~2 degree of initial error in roll/pitch

$$\alpha = \arcsin\left(\frac{bias}{g}\right)$$

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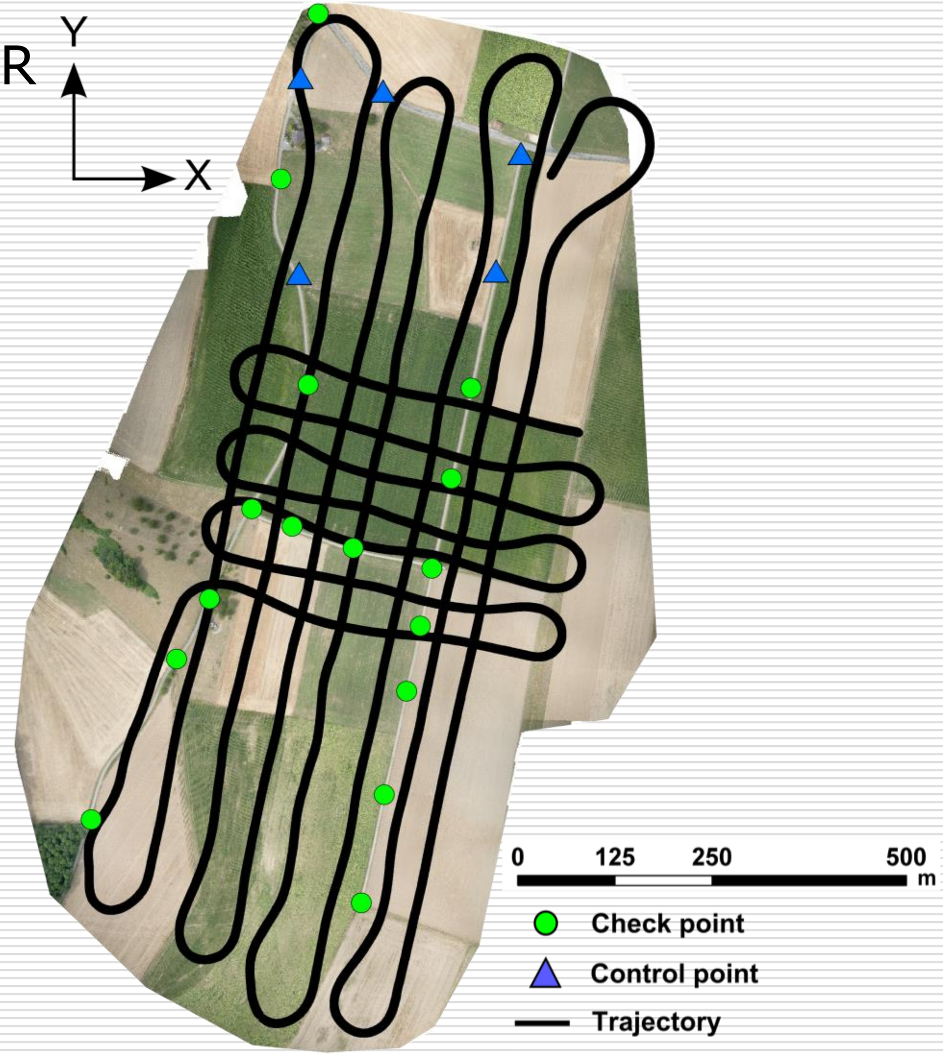
Dataset

- Camera: 16 Mpx Sony Nex 5R
- Lens: Sony 16 mm
- Flying height: 120-150 m
- Mean GSD: 4.5 cm/px
- Overlap fwd/lat: 80/60 %
- Number of photos: 207
- Number of GCPs: 5
- Number of ChPs: 16



Comparison of mapping precision

Indirect Orientation
(via GCPs)

ISO = GCPs +
Absolute **P**osition
Absolute **A**ttitude
uncalibrated

ISO = GCPs +
Absolute **P**osition
Absolute **A**ttitude
precalibrated

ISO = GCPs +
Absolute **P**osition
***R**elative* **A**ttitude
precalibrated

Absolute attitude

Dataset	Accuracy					
	Mean ChP [mm] | [px]			RMS ChP [mm] | [px]		
	X	Y	Z	X	Y	Z
Indirect SO	68 | 1.5	8 | 0.2	-664 | 14.8	16 | 0.4	145 | 3.2	1171 | 26
ISO Ap Aa ***Un**calib*	13 | 0.3	26 | 0.6	74 | 1.6	26 | 0.6	37 | 0.8	87 | 1.9
ISO Ap Aa ***Pre**calib*	14 | 0.3	25 | 0.6	64 | 1.4	28 | 0.6	35 | 0.8	78 | 1.7

- Note on attitude usage
  - Absolute: requires boresight determination/calibration
  - Relative: no pre-calibration necessary

Relative attitude

Dataset		Accuracy					
		Mean ChP [mm] | [px]			RMS ChP [mm] | [px]		
		X	Y	Z	X	Y	Z
IMU 0	ISO Ap **A**a	14 | 0.3	25 | 0.6	64 | 1.4	28 | 0.6	35 | 0.8	78 | 1.7
	ISO Ap **R**a	14 | 0.3	24 | 0.5	45 | 1.0	27 | 0.6	36 | 0.8	65 | 1.4
IMU 1	ISO Ap **A**a	7 | 0.2	26 | 0.6	85 | 1.9	21 | 0.5	37 | 0.8	98 | 2.2
	ISO Ap **R**a	8 | 0.2	26 | 0.6	73 | 1.6	21 | 0.5	37 | 0.8	88 | 2.0
IMU 2	ISO Ap **A**a	8 | 0.2	25 | 0.6	66 | 1.5	26 | 0.6	35 | 0.8	82 | 1.8
	ISO Ap **R**a	7 | 0.2	24 | 0.5	58 | 1.3	25 | 0.6	35 | 0.8	74 | 1.6
IMU 3	ISO Ap **A**a	6 | 0.1	27 | 0.6	56 | 1.2	23 | 0.5	37 | 0.8	73 | 1.6
	ISO Ap **R**a	3 | 0.1	25 | 0.6	37 | 0.8	23 | 0.5	36 | 0.8	59 | 1.3

Conclusion

- MAV
  - An affordable mapping tool => important: image/camera quality
- Usage of navigation sensors / good trajectory
  - Imagery: optional, increases efficiency (less or none GCPs)
  - Laser: necessary
- IMU / attitude
  - Important for corridor mapping
  - Calibration -> improves initialization -> important in abs. attitude
  - R-IMU: lower noise level & -> improved relative attitude

Questions

- REHAK, M. & SKALOUD, J., 2016: Applicability of new Approaches of Sensor Orientation to Micro Aerial Vehicles. ISPRS ICWG III/I Annals of ISPRS Congress, Prague.