Mapping with MAV: Experimental study on the contribution of absolute and relative aerial position control

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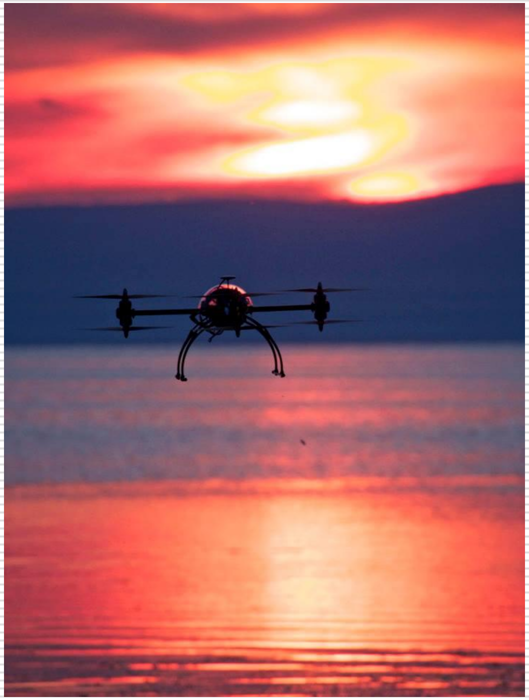

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Outline

1. Motivation

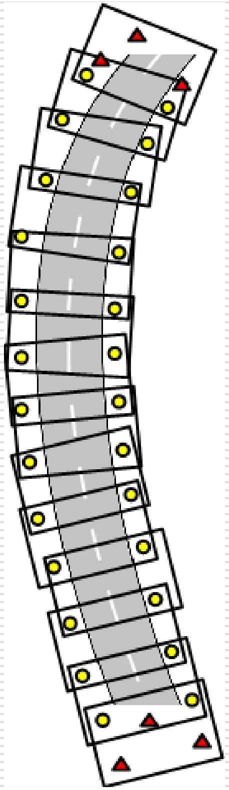
2. Absolute vs. relative aerial position control

3. Case study
   - MAV & calibration field
   - Data acquisition and processing
   - Results

4. Conclusion and future work

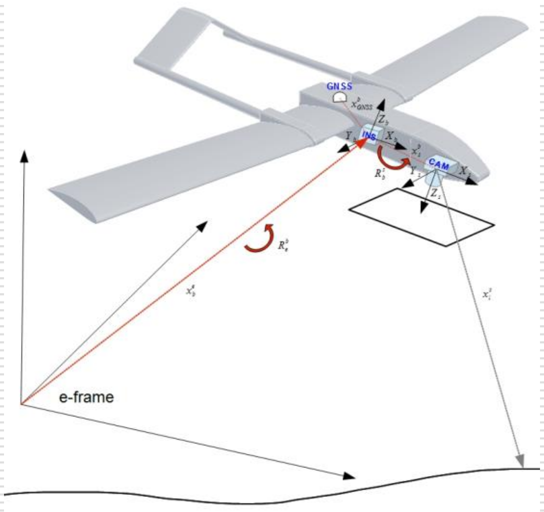
Objectives & agenda

- Overall goal:
  - Maximize mapping accuracy & minimize field survey/setup
- Research:
  - Calibrate the system (find a stable set of parameters)
  - Study the relevance of different positioning models with respect to Micro Aerial Vehicle (MAV)
- Focus:
  - Limits of current MAV mapping approach
  - Camera calibration procedure
  - Absolute and relative models for aerial control
  - Evaluation of robustness under undetected GNSS bias



Limits of conventional models/approaches of ISO

- Integrated Sensor Orientation
  - **absolute** aerial control:
    - Position: residual troposphere, orbits, **wrong ambiguity**
    - Attitude: residual miss-alignment, gyro/accelerometer biases
  - **relative** aerial control:
    - Residual time-correlation is practically eliminated
    - No bore-sight parameters need to be estimated
    - Residual (linear) drift/shifts in Pos./Att. parameters are not affecting the results



Absolute vs. relative position control

Blázquez & Colomina, ISPRS J., 2012

- Absolute:
  (tPA)

nav centre — residual — projection centre — lever-arm — gnss – "shift"

$$\vec{x}^{\,l}_1 + \vec{v}^{\,l}_x = \vec{X}^{\,l} + R^l_c \cdot \left(\vec{A}^{\,c} + \vec{N}^{\,c} \right) + \vec{S}^{\,l}$$

$$R^l_c = R^l_b(rpy + r_{rpy})R^b_c$$

bore-sight

camera-attitude

imu-attitude+residual

- Relative:
  (ΔtPA)

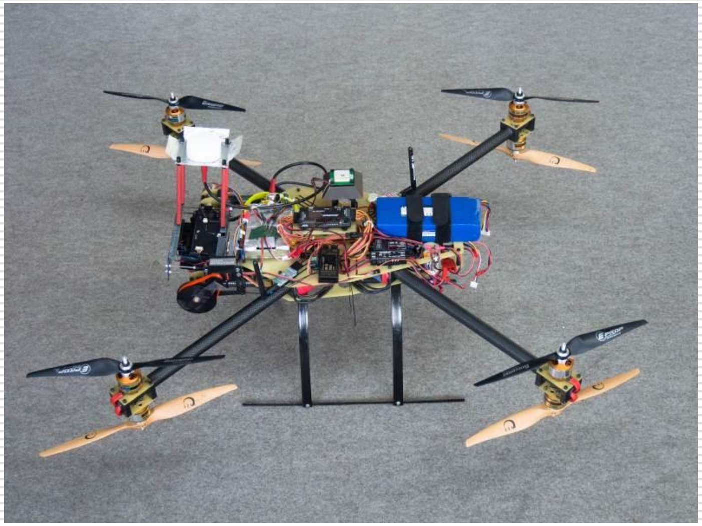
$$\vec{x}^{\,l}_2 - \vec{x}^{\,l}_1 + \vec{v}^{\,l}_{\Delta x} = \vec{X}^{\,l}_2 - \vec{X}^{\,l}_1 + \left[R^l_{c2} - R^l_{c1} \right] \cdot \left(\vec{A}^{\,c} + \vec{N}^{\,c} \right)$$

Challenges of MAV mapping with precise aerial control

- Low **camera/lens quality** – stability of IO parameters
- **Stability** of the camera – antenna – IMU position
- **Inertial sensor quality** - MEMS-IMUs, initial alignment …
- Influence of the **propulsion system** on the GNSS signal – Electromagnetic interference (EMI)
- **Calibration** – Lever-arm and Bore-sight misalignment

MAV and Calibration field

- MAV
  - Custom frame
  - Gimbaled mount for optical & nav. sensors
  - Flying time 10-17 min
  - Payload 1-1.5 kg

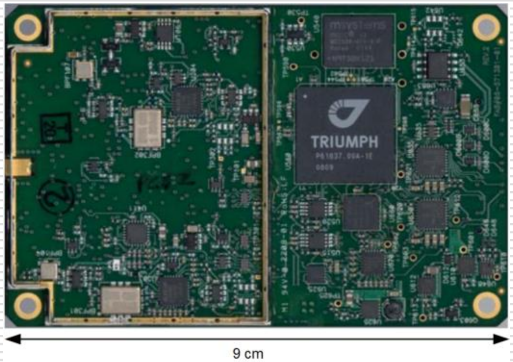


- Calibration field
  - 20x25m
  - 90 digitally coded targets
  - 25 Check/Control points
  - Up to 2 m height differences

Optical sensor and GNSS

- Sony Nex-5N
  - Body
    - Size: 111 x 59 x 38 mm
    - Weight: 280 g
  - CCD
    - Pixels: 12 Mpx
  - Lens
    - 16 mm fixed (24 mm equivalent)

- geodetic-grade GPS/Glonass/Galileo multi-frequency receiver from Javad
  - RTK capability
  - Up to 100 Hz sampling frequency
  - Small & light vs. performance
  - PPS/Event



Testing phase

- Two flight missions (3 months apart)
  - Camera self-calibration
  - Testing of the aerial control models

Camera self – calibration

- Data acquisition
  - Manual flight mission
  - Two convergence angles
  - Two flight levels (5 and 8 m)
  - 92 images taken
  - Resolution ~ 1.5-2 mm/px

- Processing
  - Automatic target recognition
    - Customized open-source software library (ARToolKitPlus)
  - Fembun bundle adjustment
    - Testing of different distortion models

Results of camera self calibration

- Model: Brown with k_1 and k_2 is sufficient to describe the imaging distortions for the given lens

- **Pertinent results:**

Parameter	Value
Maximum convergence angle	78°
Degrees of freedom	1680
RMS v_x (image measurements)	**2.8 µm**
RMS v_y (image measurements)	**3.3 µm**
σ_{xpp} (principal point)	**0.9 µm**
σ_{ypp} (principal point)	**2.0 µm**
Principal distance	16.022 mm
σ_{pd}	**3.5 µm**
k_1	-2.827 E-04
σ_{k1}	**1.4 E-06**
k_2	1.589 E-06
σ_{k2}	**7.9 E-09**

Case study – flight & processing

- 68 images taken over the calibration field
  - Various flying speed, nadir-looking camera, altitude ~10 m

Processing:

- Aerial position control
  - Synchronized (<1ms)
  - Interpolated carrier phase 10Hz positions (GrafNav)
- Image measurement
  - Customized open-source software library (ARToolKitPlus)
- Bundle adjustment (Fembun)
  - Absolute and relative observations
  - Fixed IO parameters except PD
  - Measured lever-arm

Case study – scenarios

- Goals (absolute/relative aerial position):
  - Study the benefit of aerial relative position control for MAV
  - Study the influence of GNSS-position bias

Selected cases:

- Case I: AT + 3 GCPs (placed close together)
  - A) No aerial control
  - B) Relative aerial control (61 obs.) + GNSS bias
- Case II: AT + 1 GCP + GNSS bias
  - A) Absolute aerial control (all 68 obs.)
  - B) Absolute aerial control (6 obs.) + Relative (61 obs.)

All the cases are evaluated with respect to 22 checkpoints.

Case I

Check point (22)   Ground control point (3)

Case I – Results

- **A)** AT + 3 GCPs (placed close together)

Position residuals (22 CHKP)	X [m]	Y [m]	Z [m]
MAX	0.071	0.073	0.221
RMS	**0.038**	**0.030**	**0.103**

- **B)** AT + 3 GCPs + 61 relative observations + artificial GNSS bias (~0.2 m)

Position residuals (22 CHKP)	X [m]	Y [m]	Z [m]
MAX	0.012	0.020	0.087
RMS	**0.005**	**0.007**	**0.036**

Case II – Results

- **A)** AT + 1 GCP + Absolute aerial control (all 68 obs.) + GNSS bias (~0.2 m)

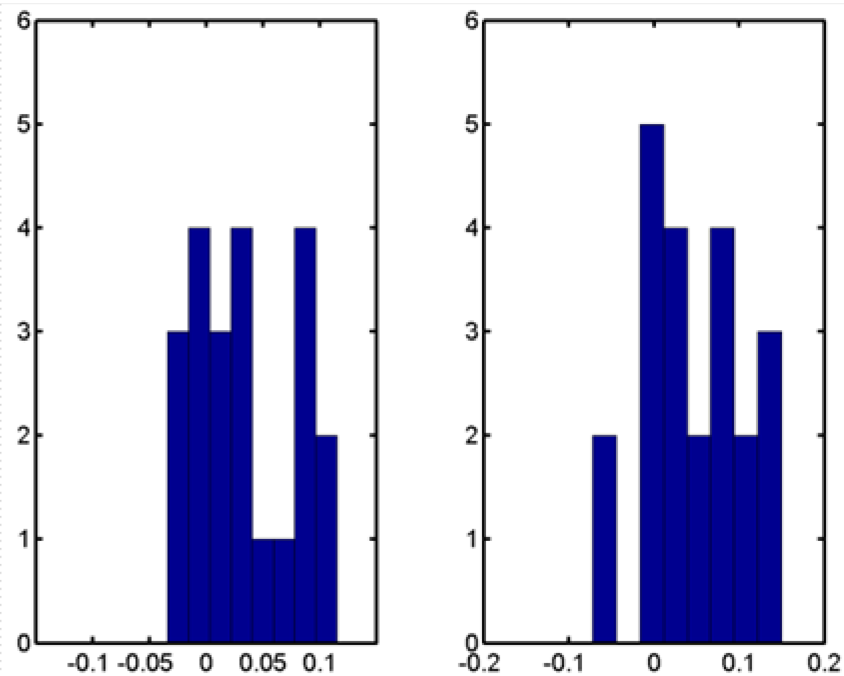
Position residuals (22 CHKP)	X [m]	Y [m]	Z [m]
MAX	0.115	0.079	0.150
RMS	**0.055**	**0.046**	**0.073**

- **B)** AT + 1 GCP + Absolute aerial control (6 obs.) + Relative (61 obs.) + GNSS bias (~0.2 m)

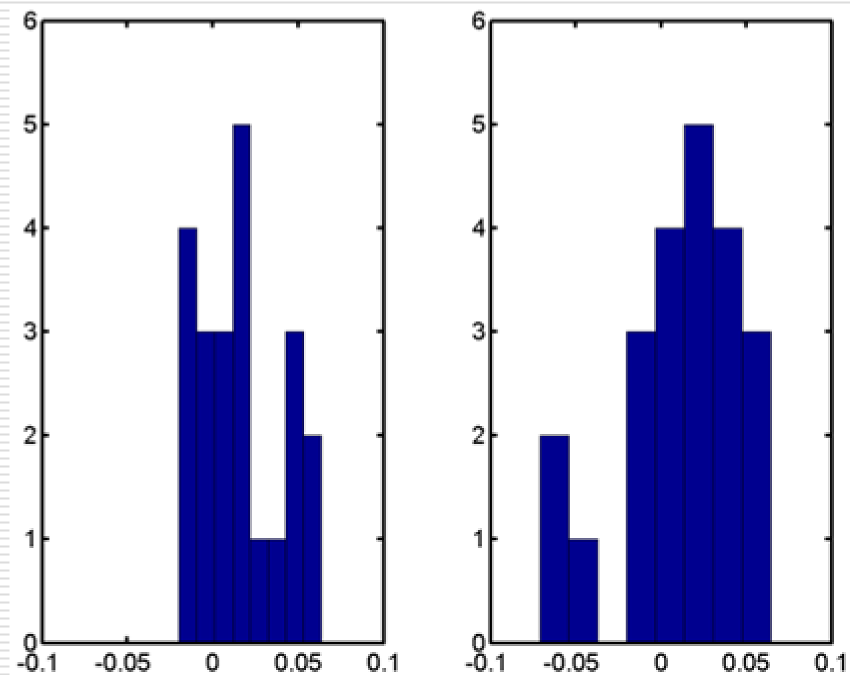
Position residuals (22 CHKP)	X [m]	Y [m]	Z [m]
MAX	0.063	0.041	0.071
RMS	**0.029**	**0.022**	**0.038**

Case II – Histograms of residuals

- **A) Absolute observations**
- **B) Relative + 6 abs. Obs.**



dX [m] dZ [m]



dX [m] dZ [m]

Conclusion and future work

- Calibration
  - synchronization between sensors resolved
  - found a proper lens distortion model
  - proved a sufficient stability of IO parameters between different flight missions

- Contribution of absolute and/or relative aerial position
  - allows **reducing** # of GCPs, while **increasing** accuracy
  - relative obs. are **less sensitive** to GNSS-positions *bias(es)*
  - **1GCP + relative** aerial positions are *sufficient* for datum def.

- Future focus
  - investigate the MAV on-board measured attitude (MEMS)
  - test (low-cost) carrier L1 only GNSS positioning
  - application to real mapping missions

Thank you for your attention!