Multi GNSS attitude estimation of UAVs during landing

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Abstract

- Extended Kalman Filter (EKF) for estimating the baseline coordinates and single differenced integer ambiguities between two GNSS antennas and receivers [1]
- Single frequency, Multi GNSS (GPS, Glonass, Galileo) single baseline measurements
- Using code, phase and baselength measurements as the EKF's inputs to determine the float solution
- Cycleslip detection based on triple differenced phase and the integrated doppler mesurements
- Integer ambiguity fixing
  - Using modified LAMBDA (Least-squares AMBiguity Decorrelation Adjustment) method based on [2],[3]
  - Inputs are the EKF's states (baseline coordinates and transformed, double differenced integer ambiguities) the covariances, and the baselength between the antennas
  - Searching for the best n integer ambiguity vector in the unconstrained space around the float solution and select the best vector in the baselength constrained space
  - Validation with the norm of the fixed baseline coordinates
  - Update the EKF's baseline coordinate states and the covariances
- Computing bank (ϕ) or elevation (θ) and the heading (ψ) attitude angles from the single baseline coordinates
- Using surveying systems for validation, a small UAV and low-cost sensors for the testing

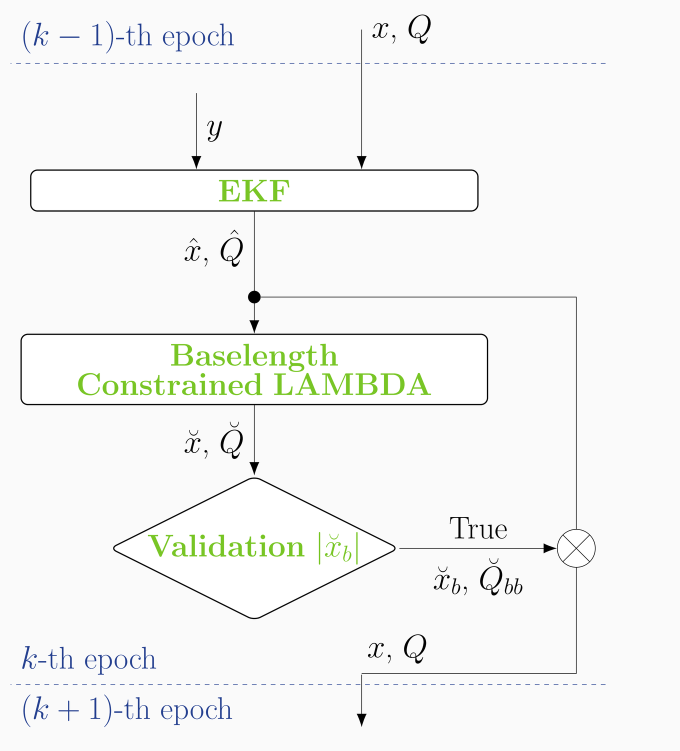

Fig. 1: Algorithm schematic

State Vector and Covariance Matrix:

$$x = \begin{bmatrix} x_b & x_N \end{bmatrix}^T, \quad Q = \begin{bmatrix} Q_{bb} & Q_{bN} \\ Q_{Nb} & Q_{NN} \end{bmatrix}$$

Phase, Code and Baselength Measurement Vector:

$$y = \begin{bmatrix} y_{ph} & y_{pr} & y_{bl} \end{bmatrix}^T$$

b: Baseline components
N: Integer ambiguity components
$\hat{v}$: Float solution variable
$\check{v}$: Fix solution variable

Ground Test and Validation

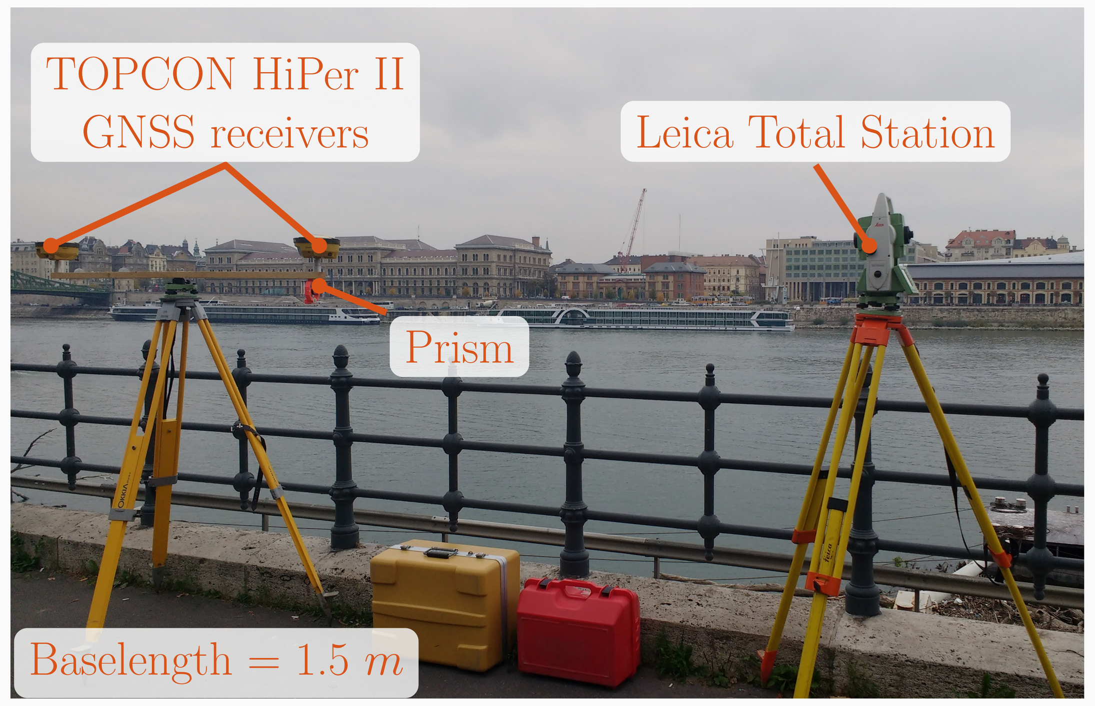

Fig. 2: Ground Test

- Testing the algorithm under real, but ideal circumstances (clear sky, no disturbing terrain features) (Fig. 2)
- Reference angles were computed from the distances between the Prism and the Total Station
- Compare heading (ψ) and elevation (θ) angles from the GNSS (GPS, GLO) solution and the Total station's solution
- Results (Fig. 3)
  - Low mean and standard deviation values at the differences of the two kind of measurements
  - Higher heading differences at the dynamic phases, probably time synchronization problem

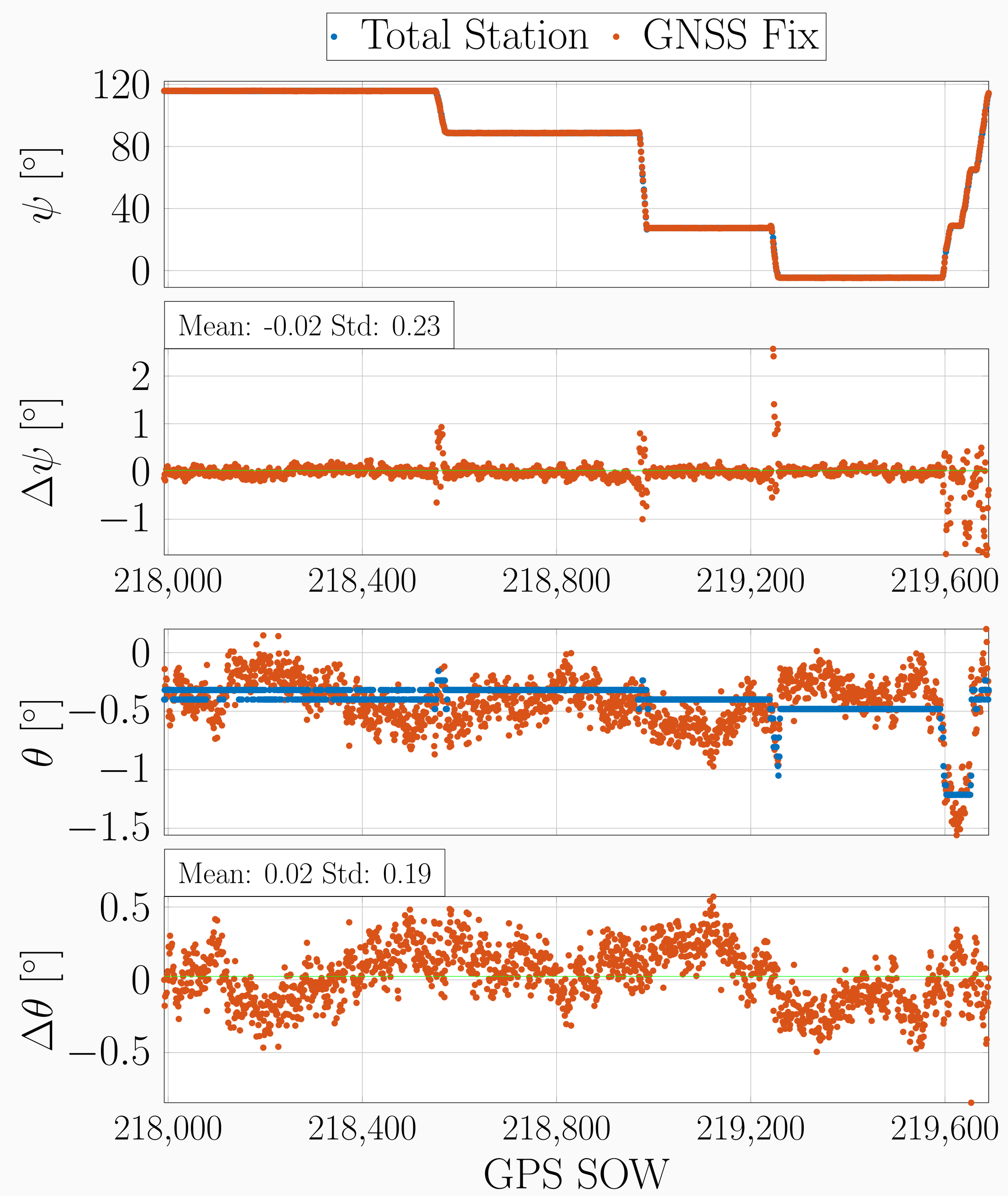

Fig. 3: Heading (ψ) and elevation (θ) angles, and the differences of the two kind of measurements ($\Delta\psi$, $\Delta\theta$)

Flight Test

- Testing the algorithm with UAV flight data using low-cost sensors (Fig. 4)
- Reference angles were computed from the UAV's IMU sensors (LIS331DLH accelerometer, L3G4200D gyroscope, HMC5883 magnetometer). Attitude angle's accuracy ($\phi \pm 5°$, $\theta \pm 5°$, $\psi \pm 10°$) depends on the slideslip angle of the UAV.
- Compare heading (ψ) and bank (ϕ) angles from the GNSS (GPS, GLO, GAL) solution and the IMU solution

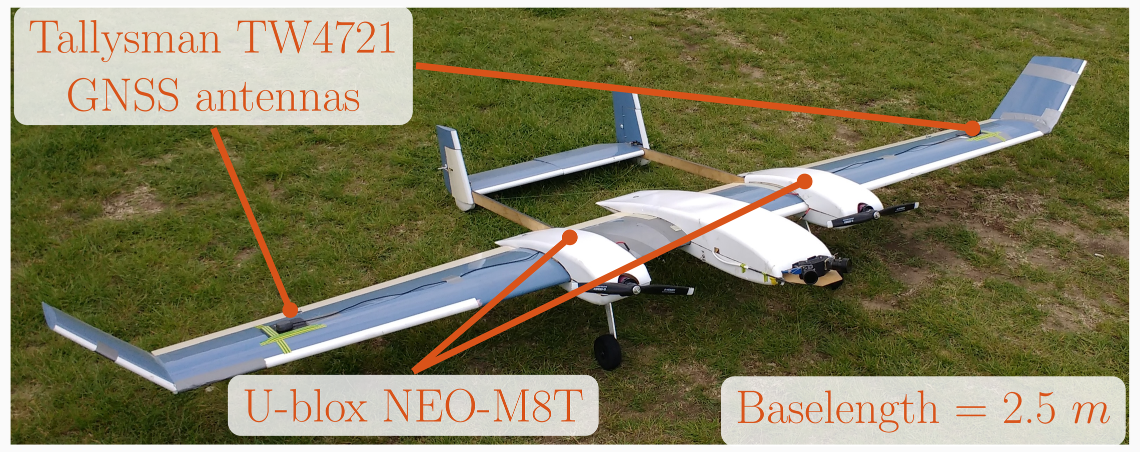

Fig. 4: The UAV with the GNSS receivers and the antennas

Flight phases

- Controlled landing phases, with low glide angle
- Freestyle flight, with a barrel roll

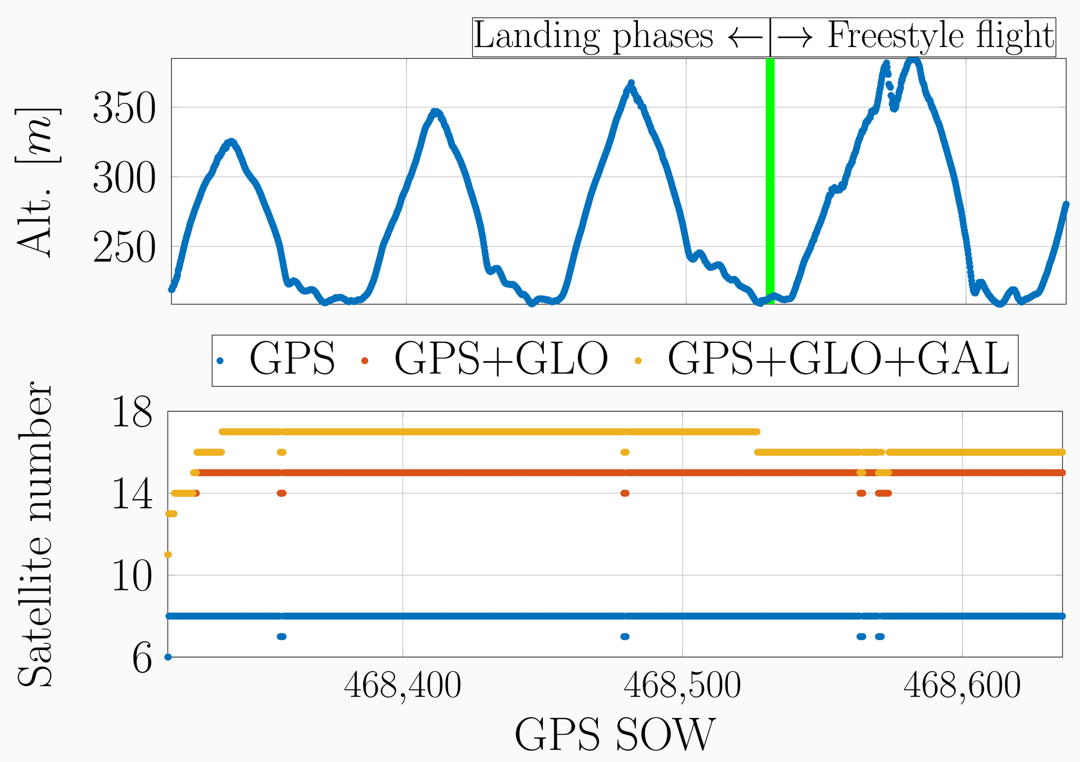

Fig. 5: The flight altitude and satellite numbers

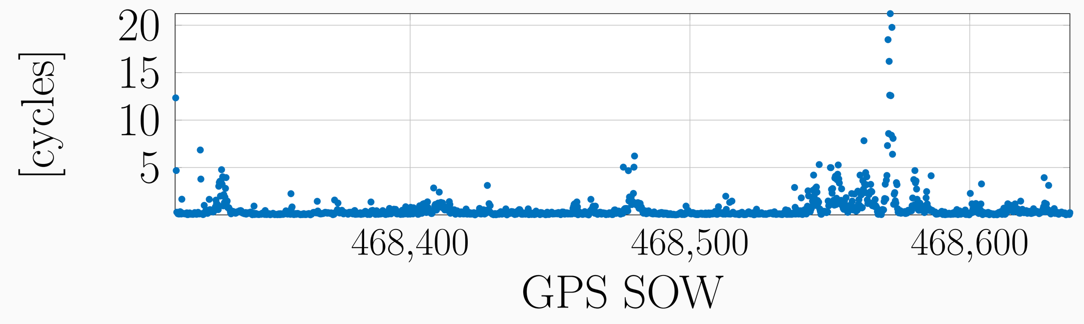

Fig. 6: Mean absolute value of the phase triple differences

Results

- Fix solution rate is 74.5%, lower at the freestyle flight phase. Float solution also has the trend with lower reliability.
- Higher angle differences at the higher dynamic phases, probably caused by slideslip flight, where the IMU solution accuracy is lower.

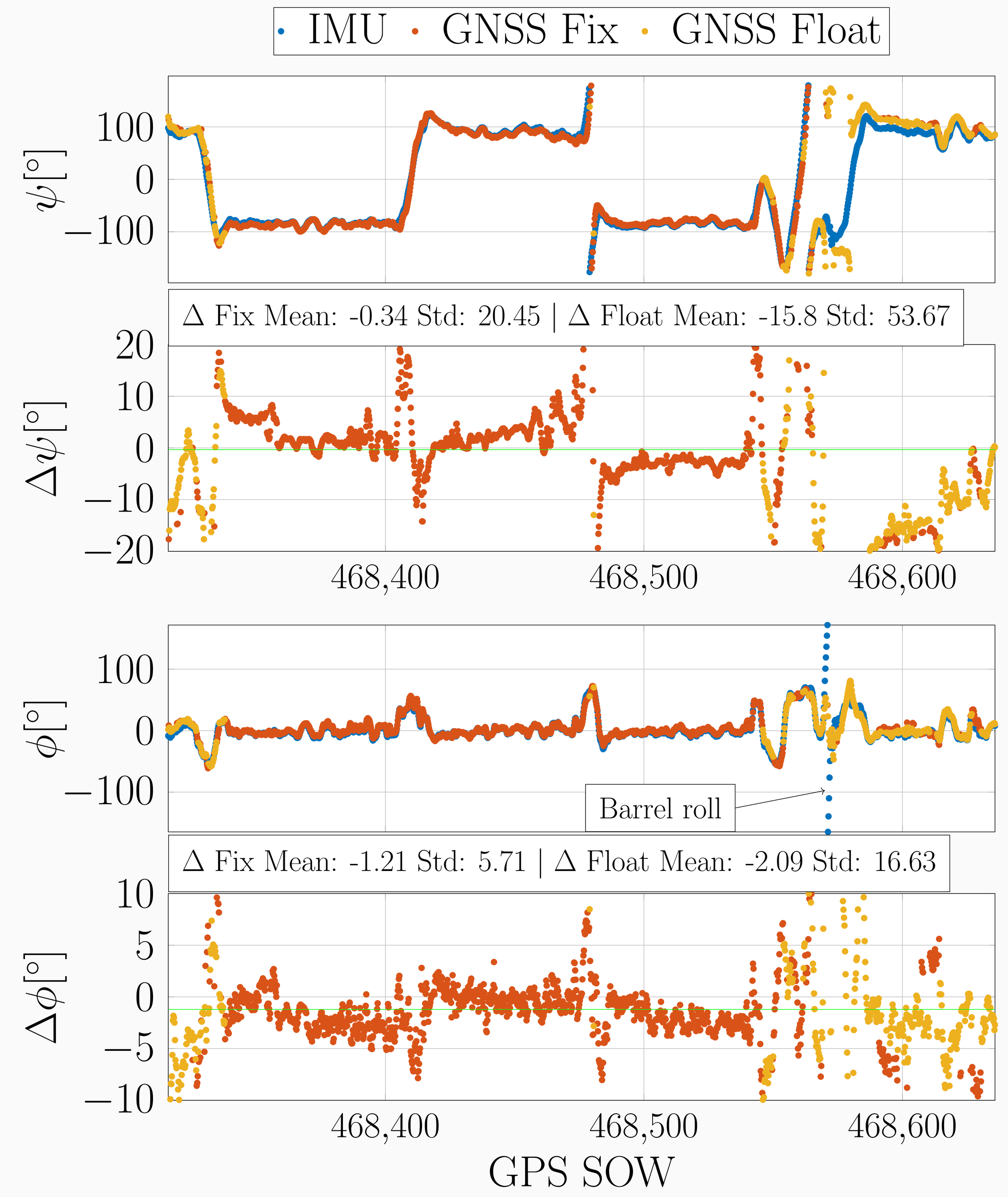

Fig. 7: Heading (ψ) and bank (ϕ) angles, and the differences of the two kind of measurements ($\Delta\psi$, $\Delta\phi$)

Future plans

- Cycleslip determination and reconstruction using accelerometer sensor
- Tight fusion with low-cost IMU sensors for position and orientation estimation
- Validation with tactical grade sensors

The VISION project (Validation of Integrated Safety-enhanced Intelligent flight cONtrol) is an Europe/Japan collaborative research project. To enhance air transport safety, the main objective of VISION is to validate smarter technologies for aircraft Guidance, Navigation and Control (GNC) by including Vision-based systems, Advanced detection and resilient methods.

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