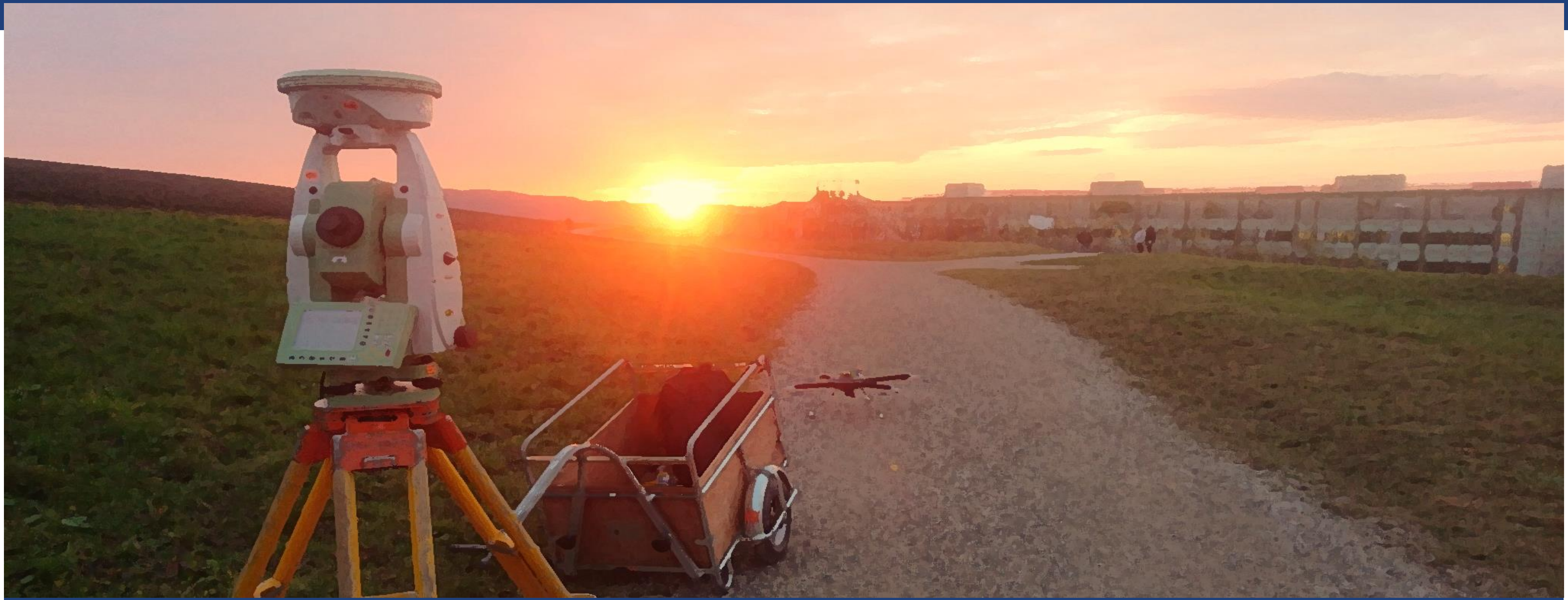


IPA presentation

Measuring Drone Trajectory using Total Stations with Visual Tracking

Yue Pan

Supervisor: Dr. Cenek Albl, Dr. Jemil Butt, Andreas Baumann-Ouyang

Technical support: Alexander Wolf, Thomas Posur

Project codes: https://github.com/YuePanEdward/IPA-GTDroneTraj

Outlines

- Motivation
- Methods
  - Positioning
  - Synchronization
- Results
- Conclusion and outlook

Motivation

https://dronebelow.com/2019/01/07/the-growing-problem-of-rogue-drones/

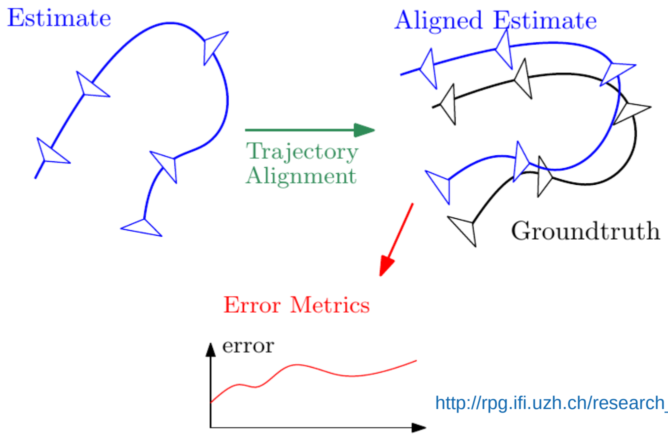
https://mercatornet.com/can-killer-robots-and-drones-act-ethically-in-future-wars/23528/

https://www.nasa.gov/feature/ames/big-city-life-awaits-drones-in-final-year-of-nasa-research/

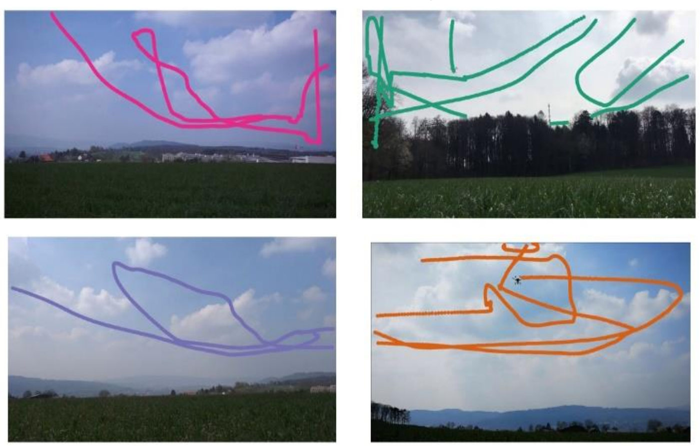
- The era of drones is coming.
- Why do we need to track the drone?
  - Safety: rogue drone near airport, anti-spy
  - Air traffic monitoring and control
  - Localization in GNSS-denied area
- How?
  - Onboard localization sensors (GPS, IMU, etc.): communication needed
  - Total station: high accuracy, expensive, non-robust tracking
  - Visual tracking and trajectory reconstruction: camera network needed

Introduction

Previous work



http://rpg.ifi.uzh.ch/research_vo.html



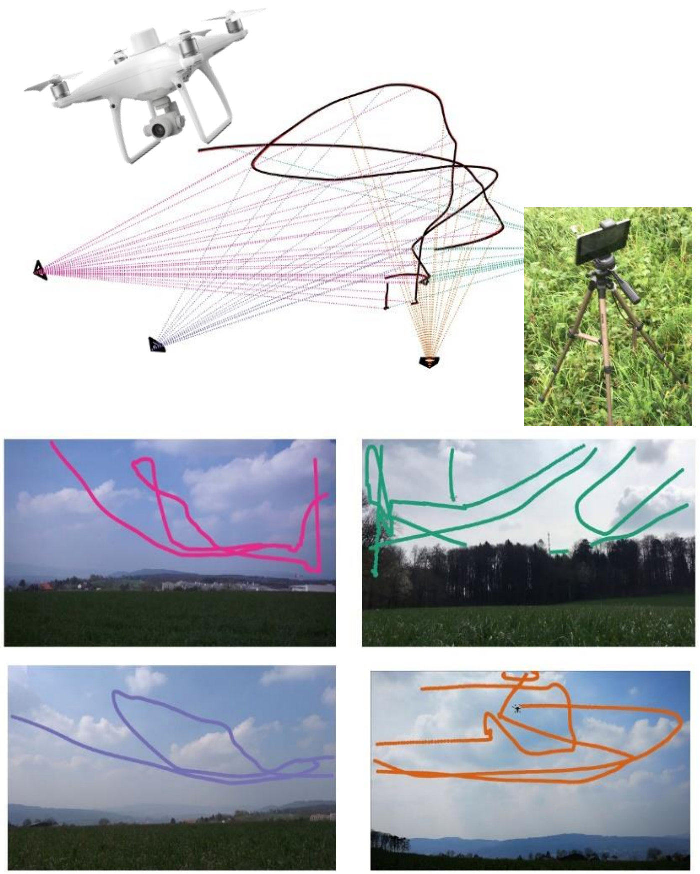
(Li J., et al., IROS 2020)

- Visual tracking and trajectory reconstruction
  - Outdoor with low-cost cameras
  - Input: videos
  - Output: 3D trajectory of the drone
  - By-product: pose of the cameras, synchronized video

- A dataset is needed
  - For the algorithm's input: videos
  - For evaluation:
    - Ground truth trajectory (pose) of the drone
    - Ground truth pose of the cameras
  - For synchronization:
    - Timestamps under unified system

Introduction

Dataset: ground truth trajectory



(Li J., et al., IROS 2020)

https://www.fixposition.com/#products

https://github.com/CenekAlbl/drone-tracking-datasets

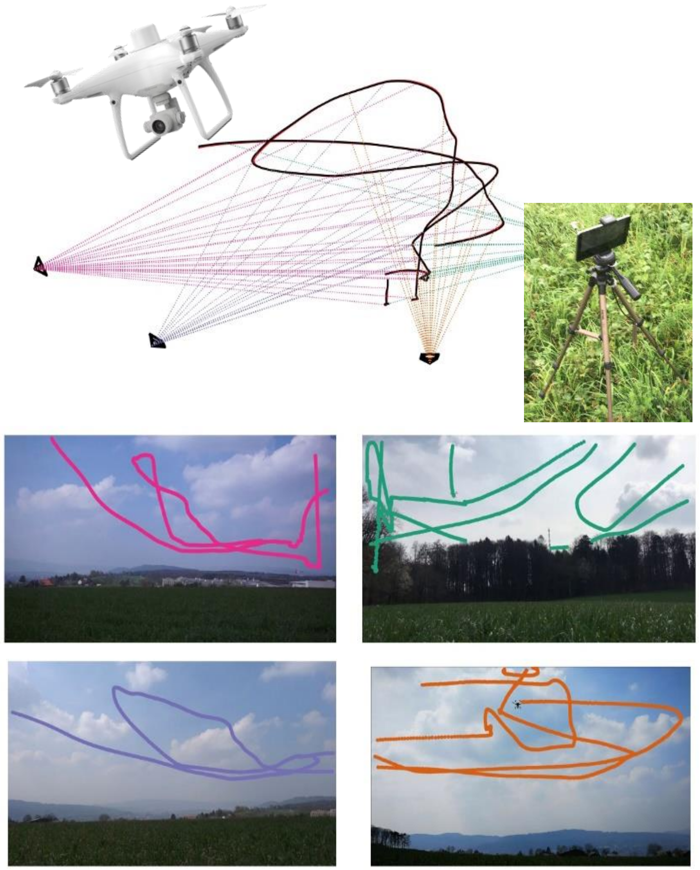
- **Previous (Fixposition RTK)**
  - Out-of-the-box
  - Claimed to have 2cm accuracy
  - No orientation output
  - No raw data & covariance output
  - No synchronization between video and RTK box
  - Closed source

https://github.com/YuePanEdward/IPA-GTDroneTraj

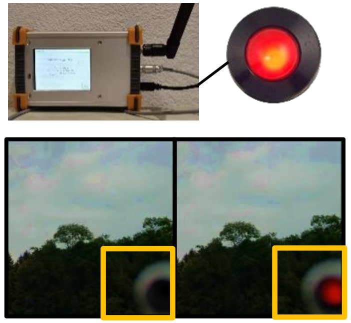
- **Goal (total station + IMU)**
  - Sub-mm ranging accuracy
  - 6DOF pose available
  - Raw data & covariance available
  - Overall synchronization
  - Under control

Introduction

Dataset: camera radio-synchronized system

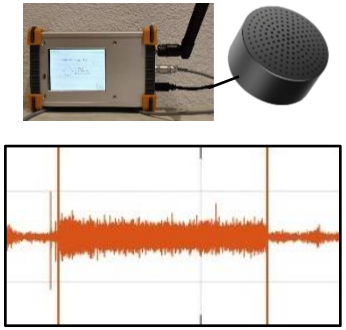


(Li J., et al., IROS 2020)



https://github.com/CenekAlbl/drone-tracking-datasets

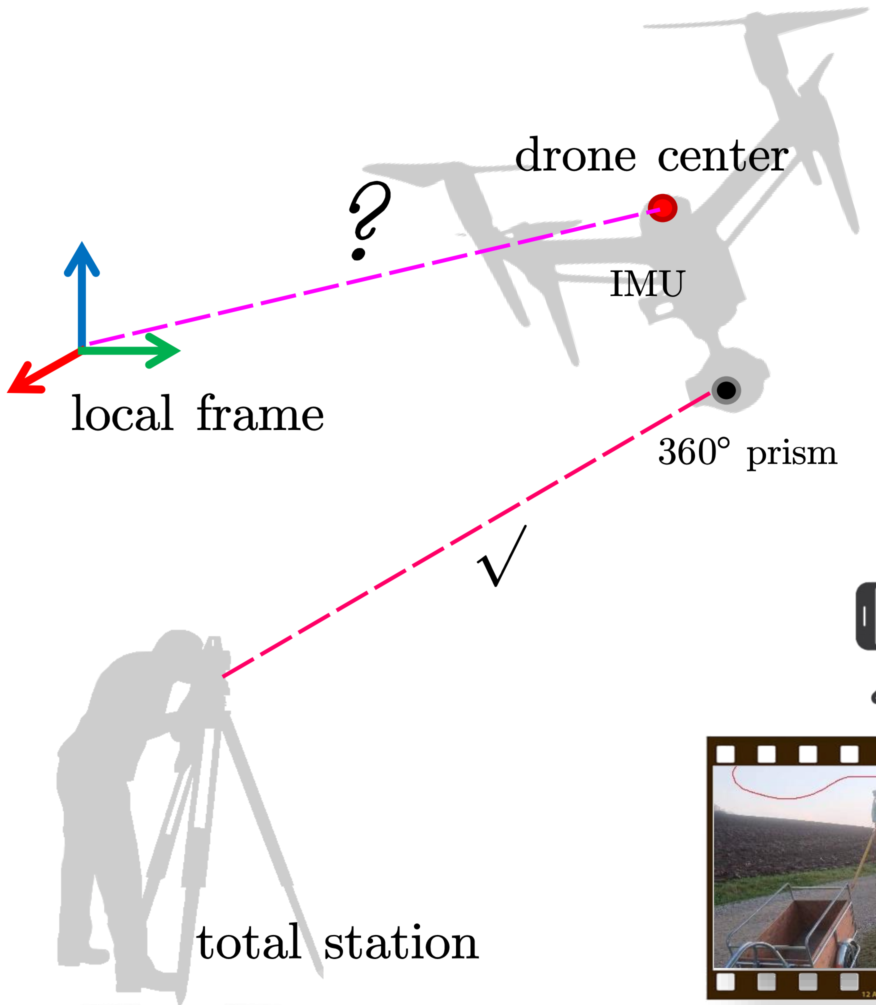
- Previous (LED flash)
  - Sub-frame synchronization unavailable
  - LED involved in the video

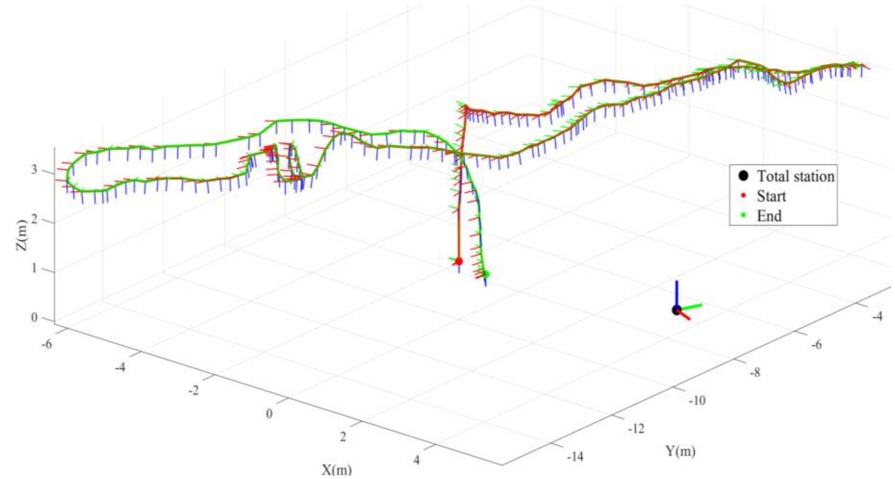


https://github.com/YuePanEdward/IPA-GTDroneTraj

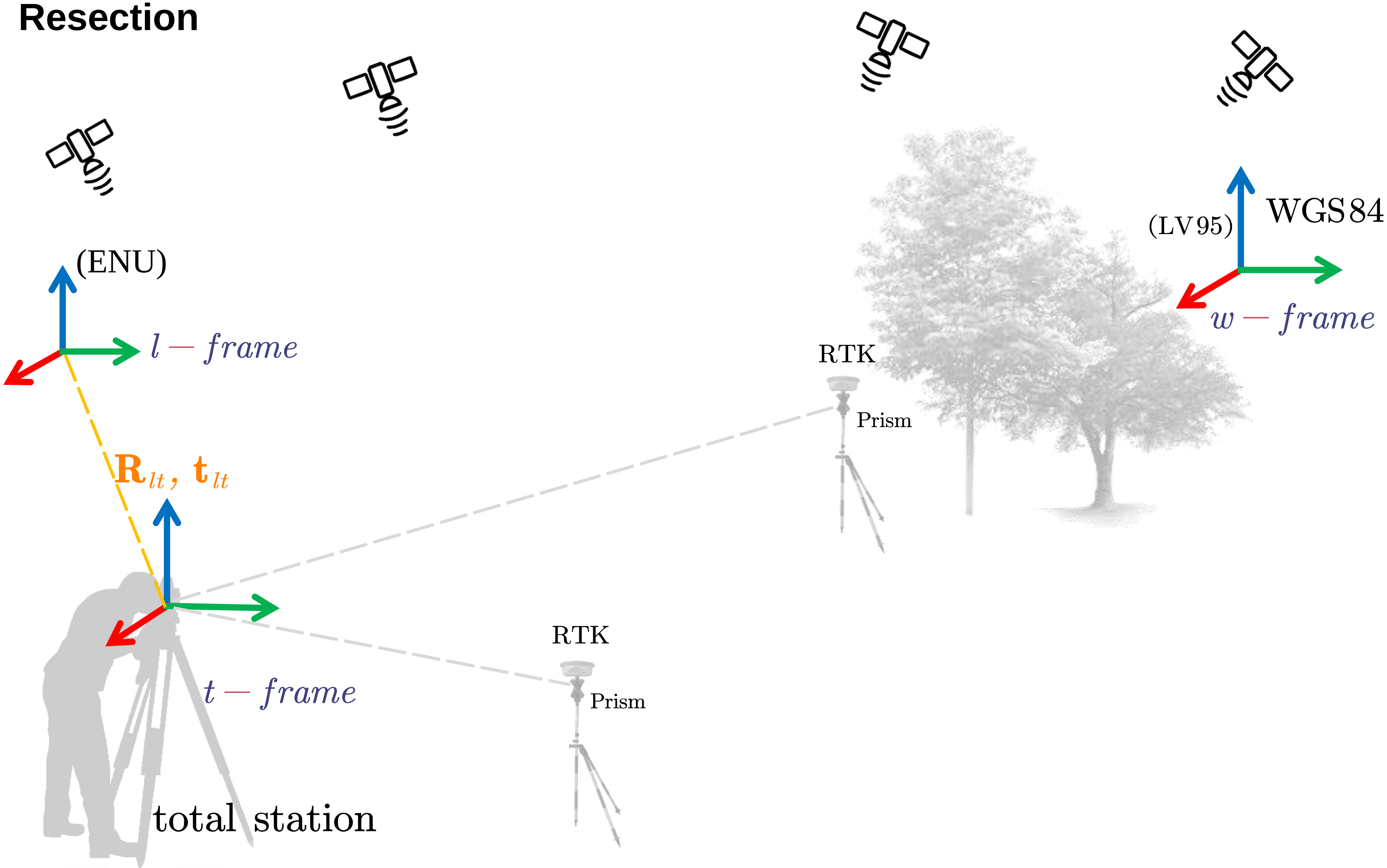
- Goal (audio)
  - Sub-frame synchronization available (higher sampling rate)
  - No disturbance to the video

Problem formulation



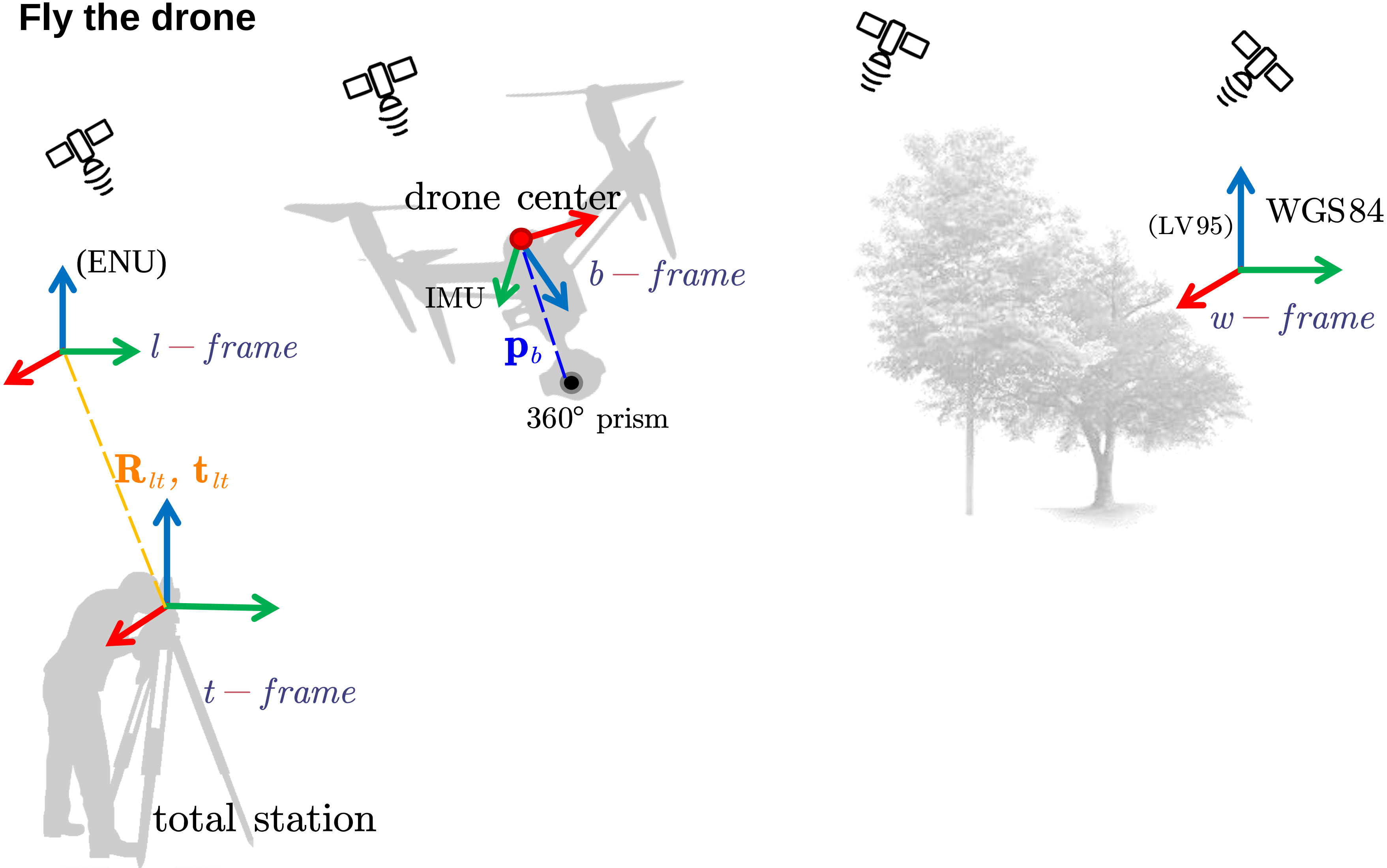


Our approach
Resection



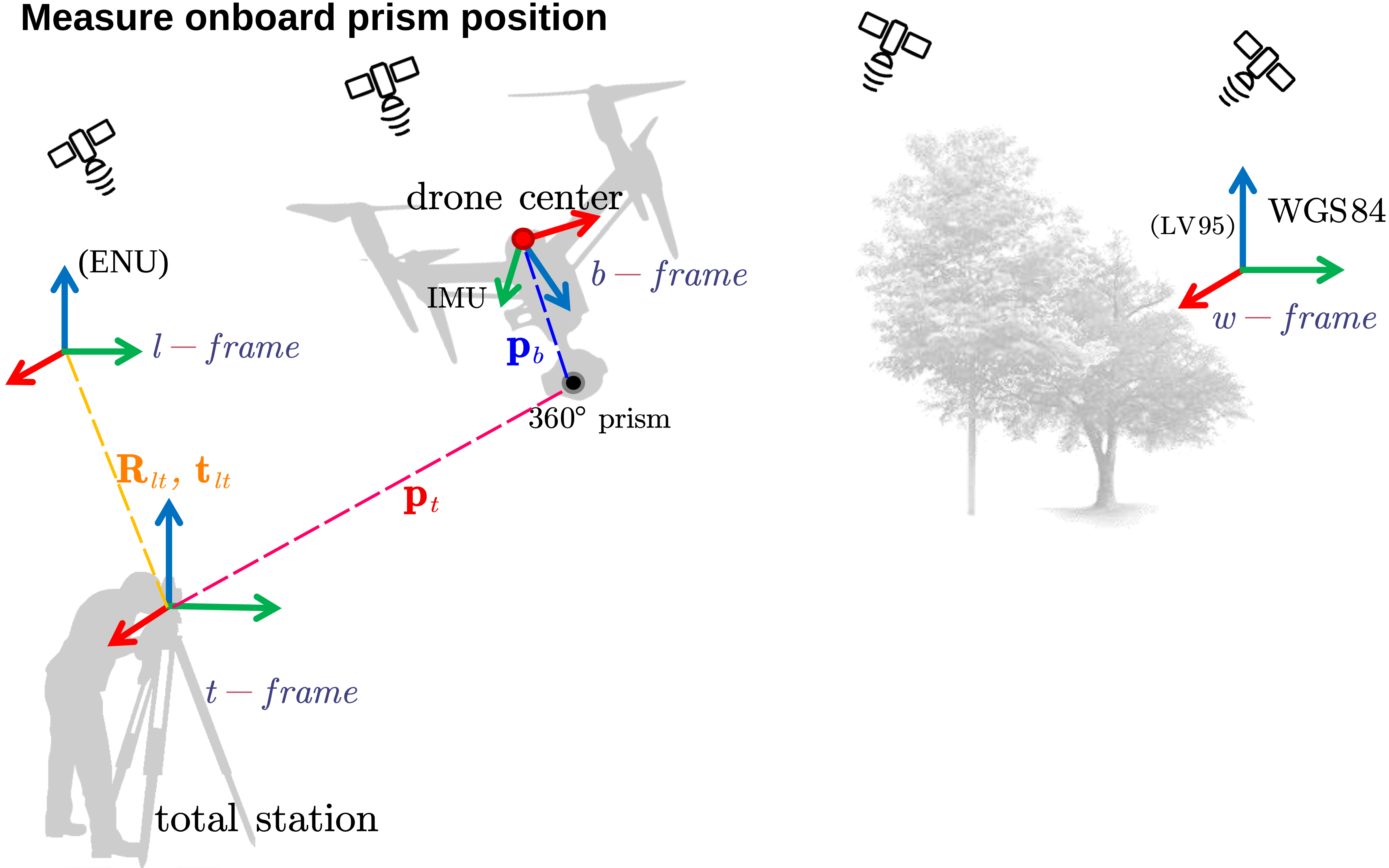
Our approach

Fly the drone



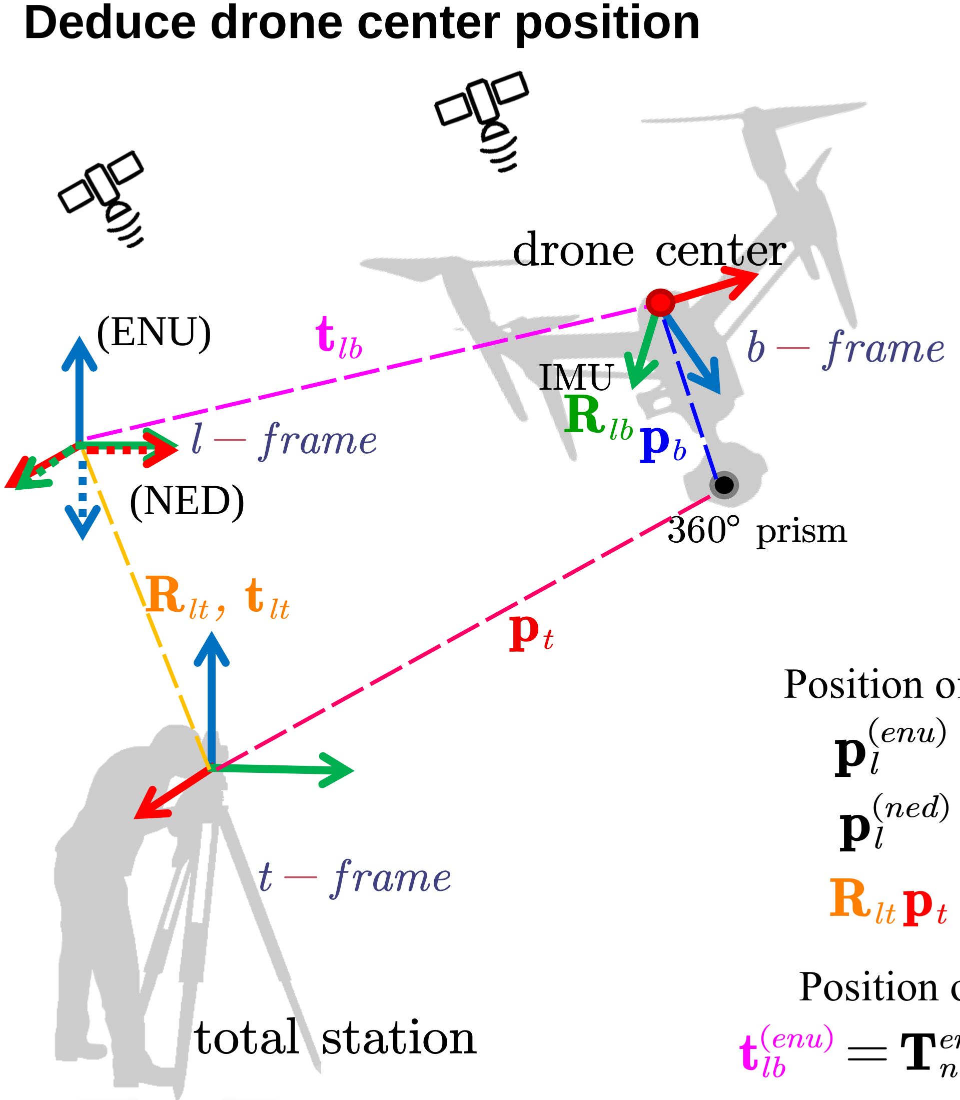
Our approach

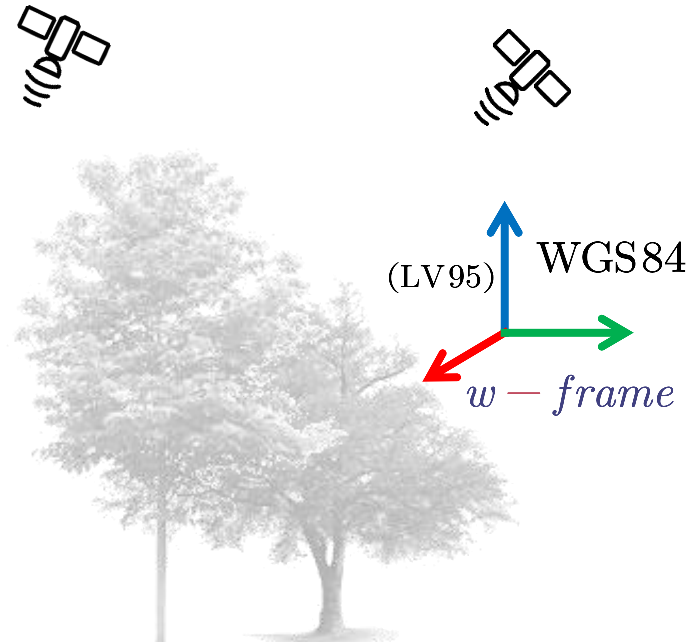
Measure onboard prism position



Our approach

Deduce drone center position





Position of the drone's prism in local frame:

$$\mathbf{p}_l^{(enu)} = \mathbf{R}_{lt}\mathbf{p}_t + \mathbf{t}_{lt} \quad (1)$$

$$\mathbf{p}_l^{(ned)} = \mathbf{R}_{lb}\mathbf{p}_b + \mathbf{t}_{lb} \quad (2)$$

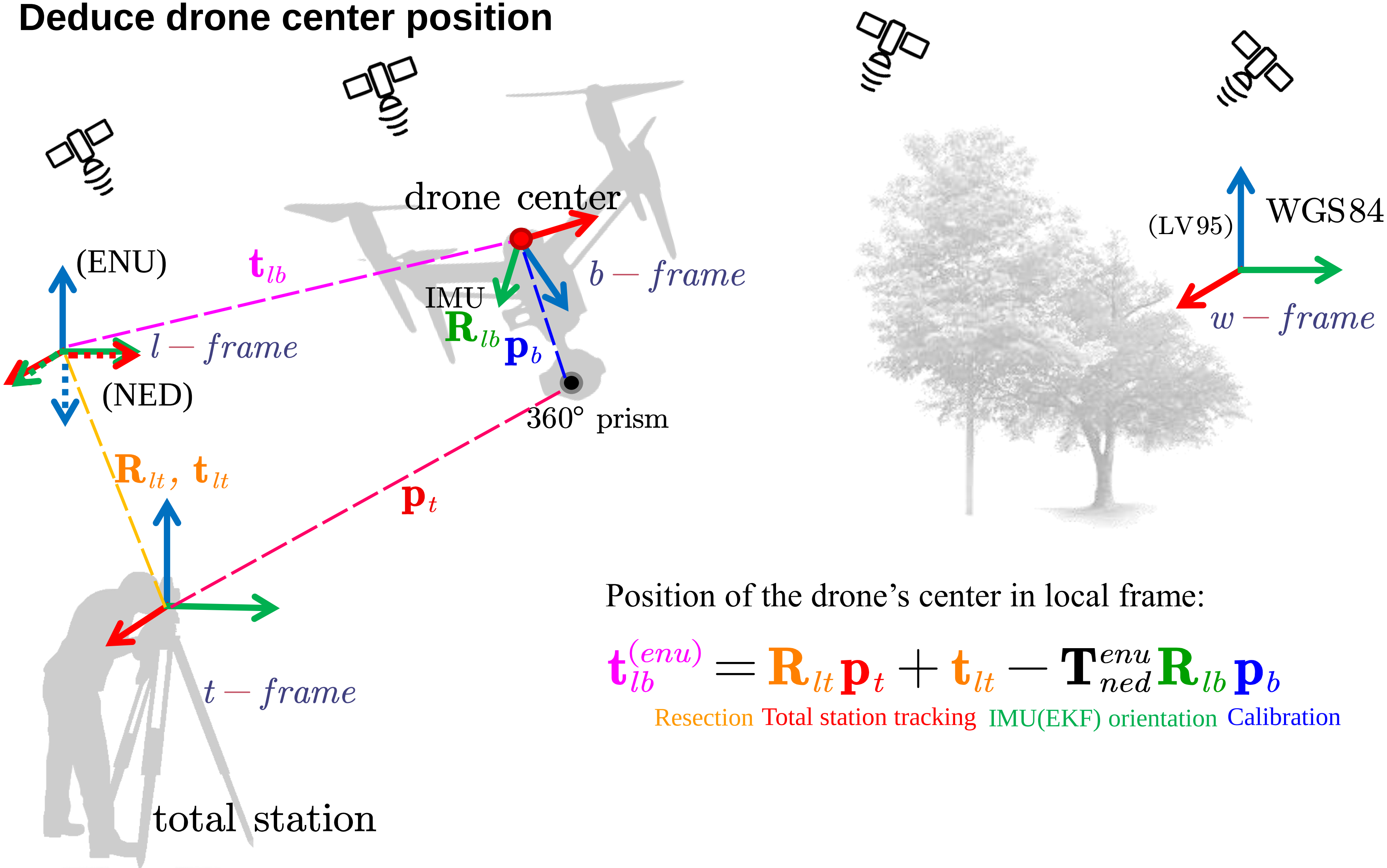
$$\mathbf{R}_{lt}\mathbf{p}_t + \mathbf{t}_{lt} = \mathbf{T}_{ned}^{enu}\left(\mathbf{R}_{lb}\mathbf{p}_b + \mathbf{t}_{lb}^{(ned)}\right) \quad (3)$$

Position of the drone's center in local frame:

$$\mathbf{t}_{lb}^{(enu)} = \mathbf{T}_{ned}^{enu}\mathbf{t}_{lb}^{(ned)} = \mathbf{R}_{lt}\mathbf{p}_t + \mathbf{t}_{lt} - \mathbf{T}_{ned}^{enu}\mathbf{R}_{lb}\mathbf{p}_b \quad (4)$$

Our approach

Deduce drone center position



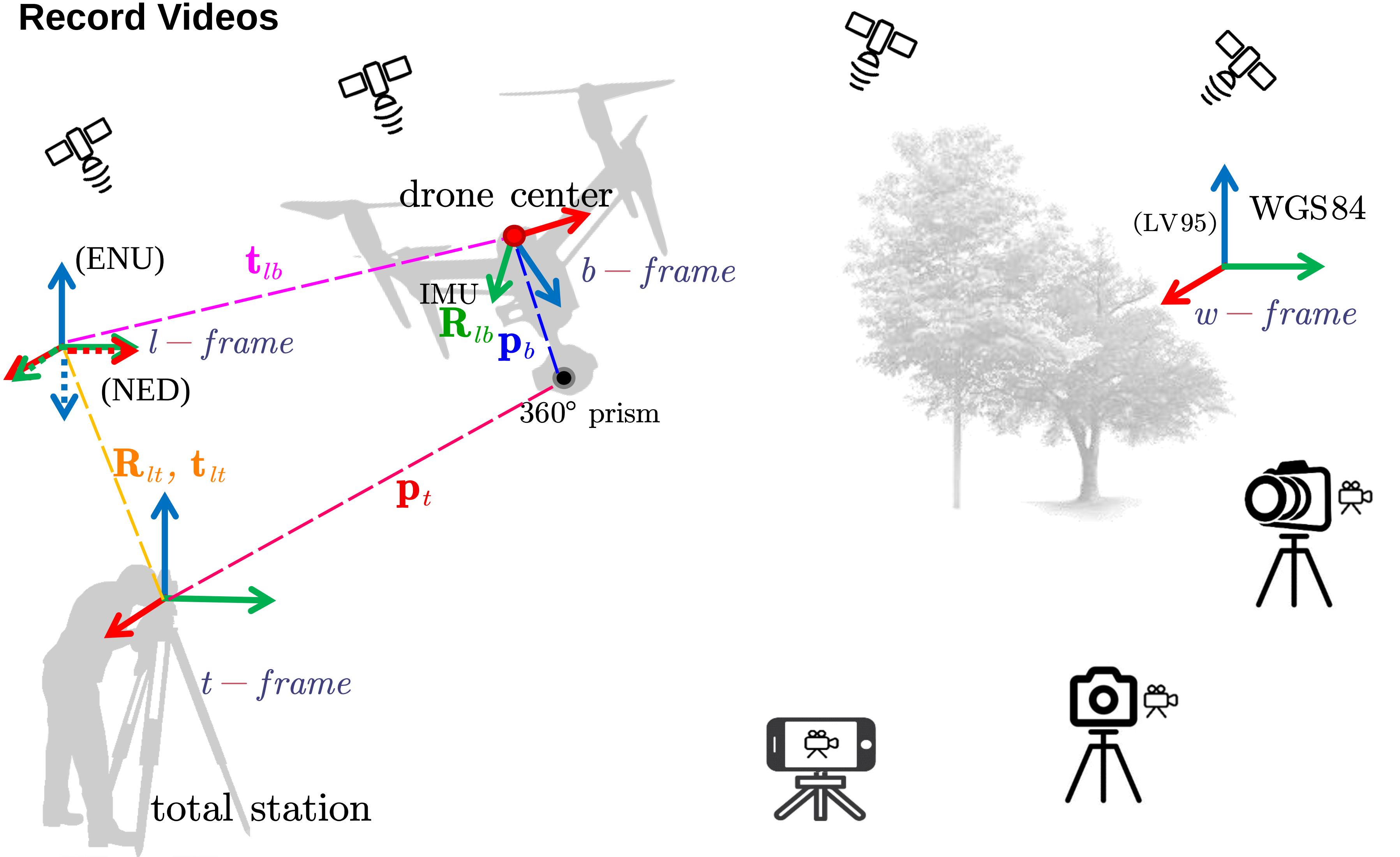
Position of the drone's center in local frame:

$$\mathbf{t}_{lb}^{(enu)} = \mathbf{R}_{lt}\mathbf{p}_t + \mathbf{t}_{lt} - \mathbf{T}_{ned}^{enu}\mathbf{R}_{lb}\mathbf{p}_b$$

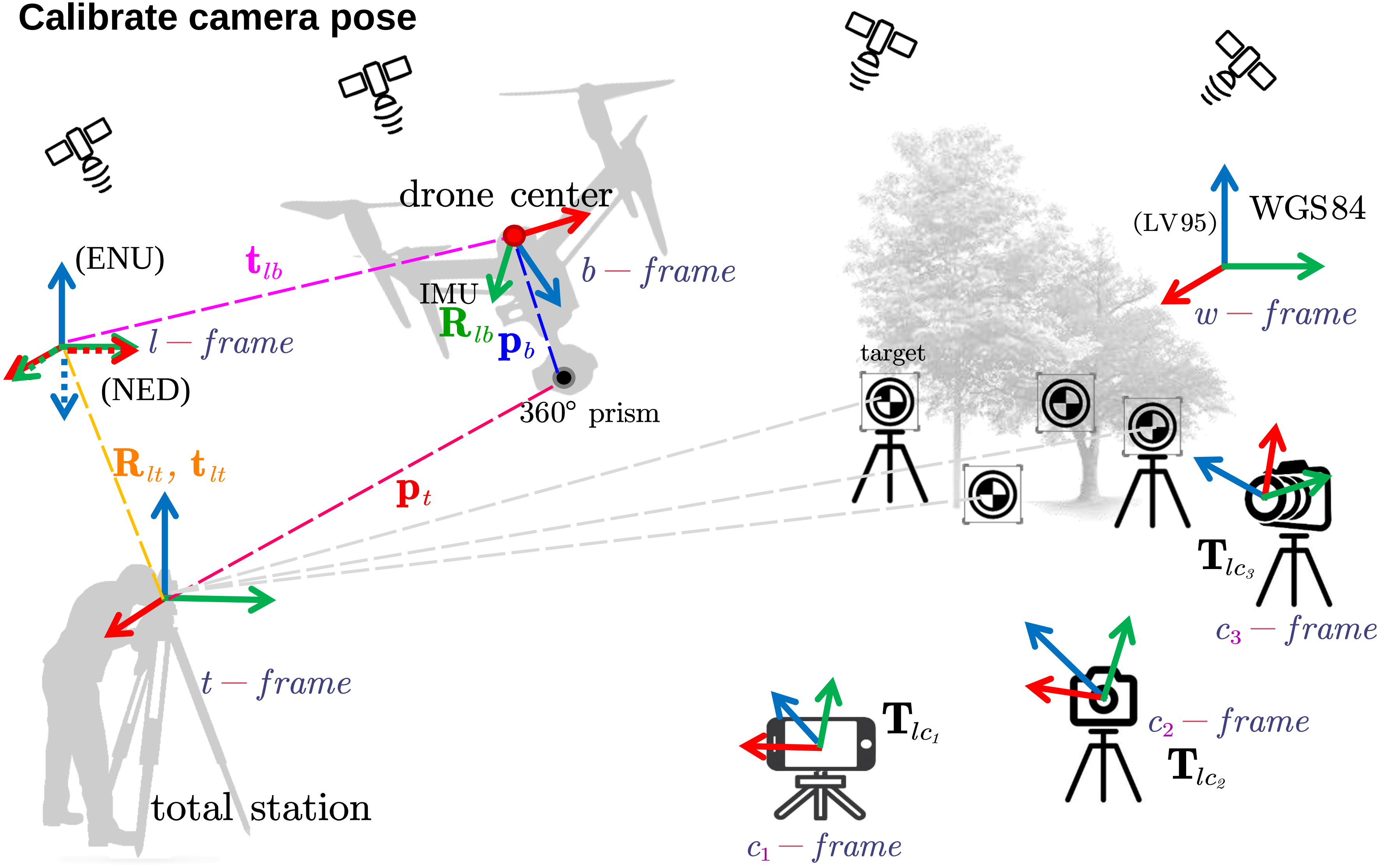
Resection Total station tracking IMU(EKF) orientation Calibration

Our approach

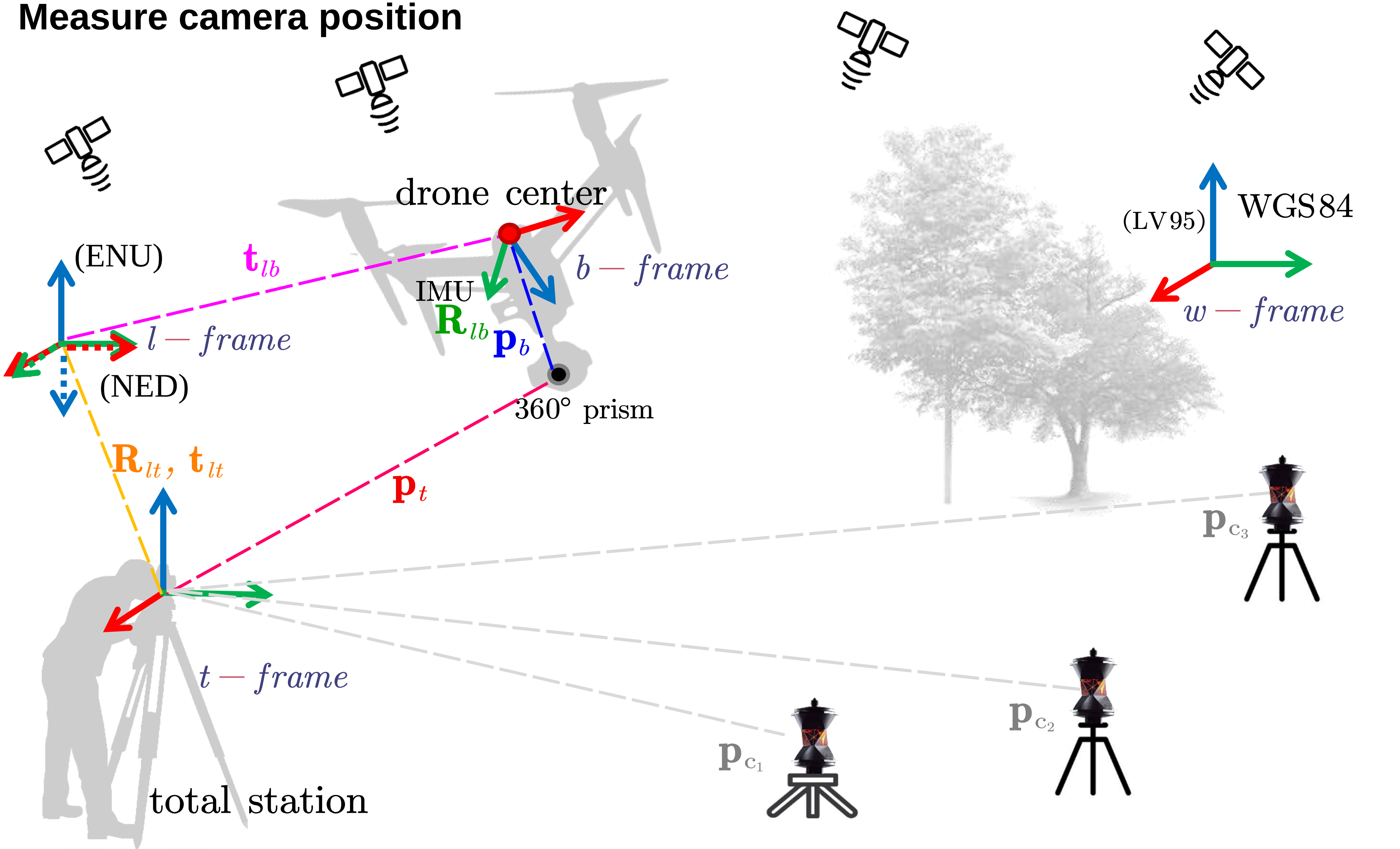
Record Videos



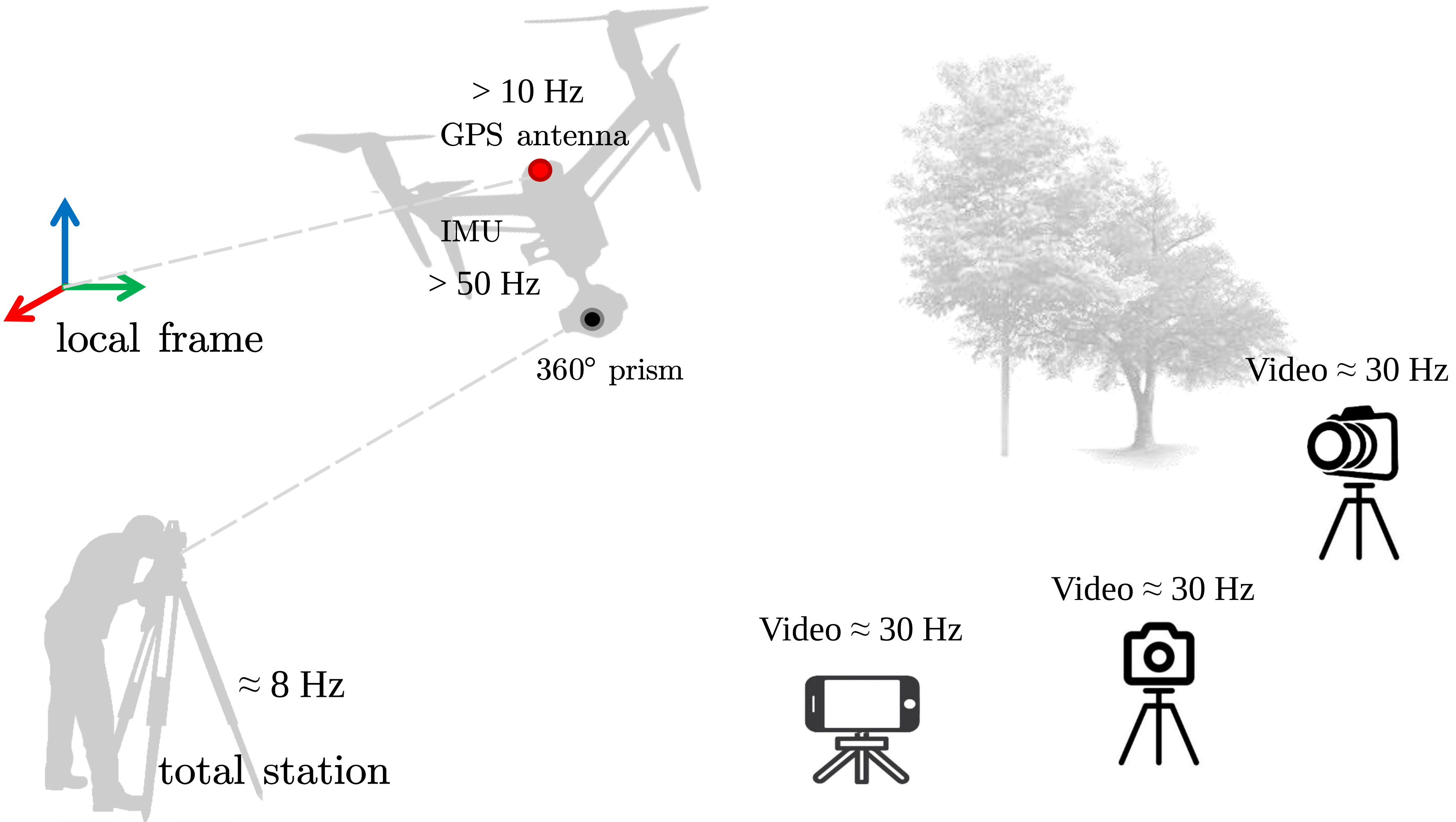
Our approach
Calibrate camera pose



Our approach
Measure camera position

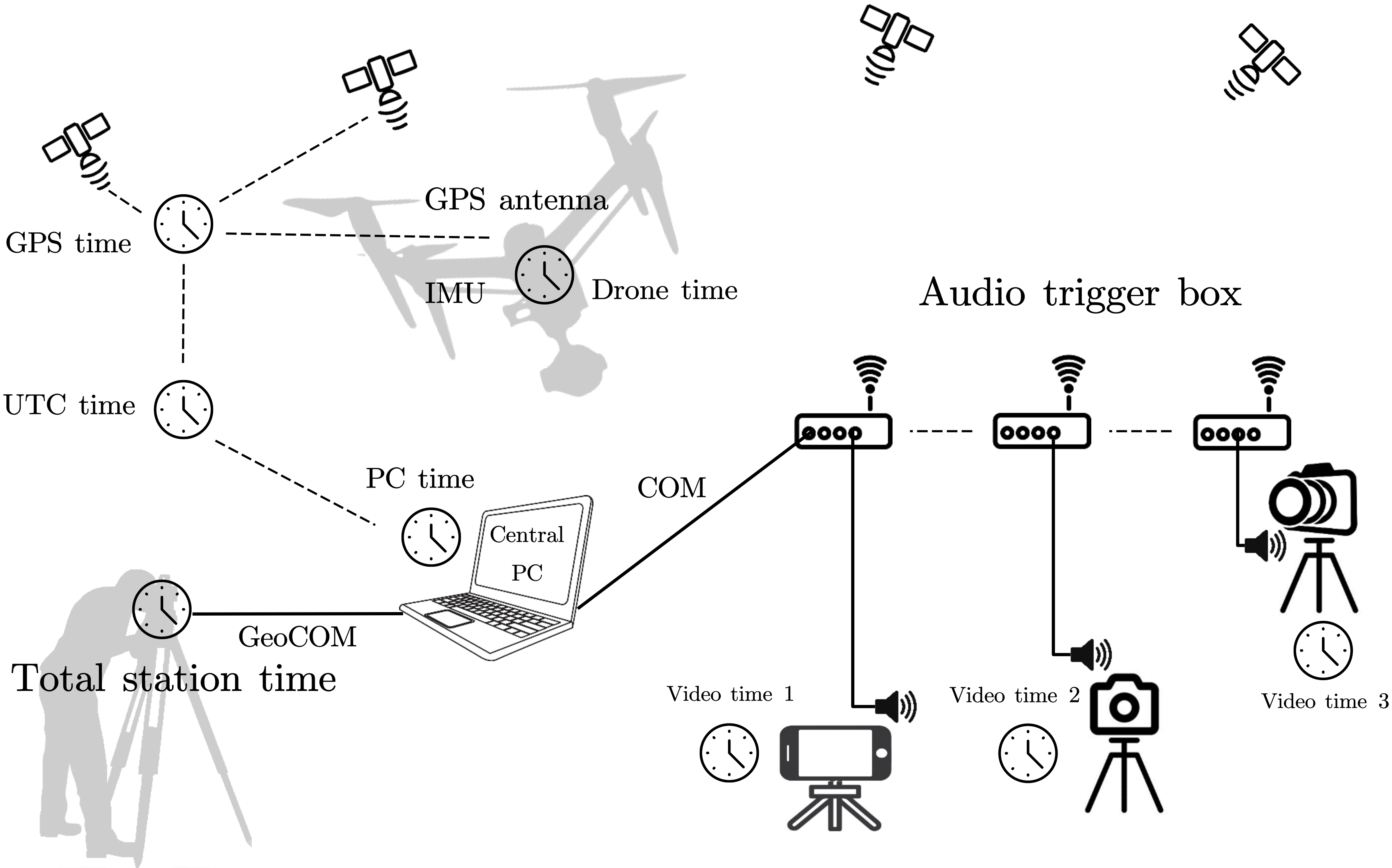


Measurement frequency



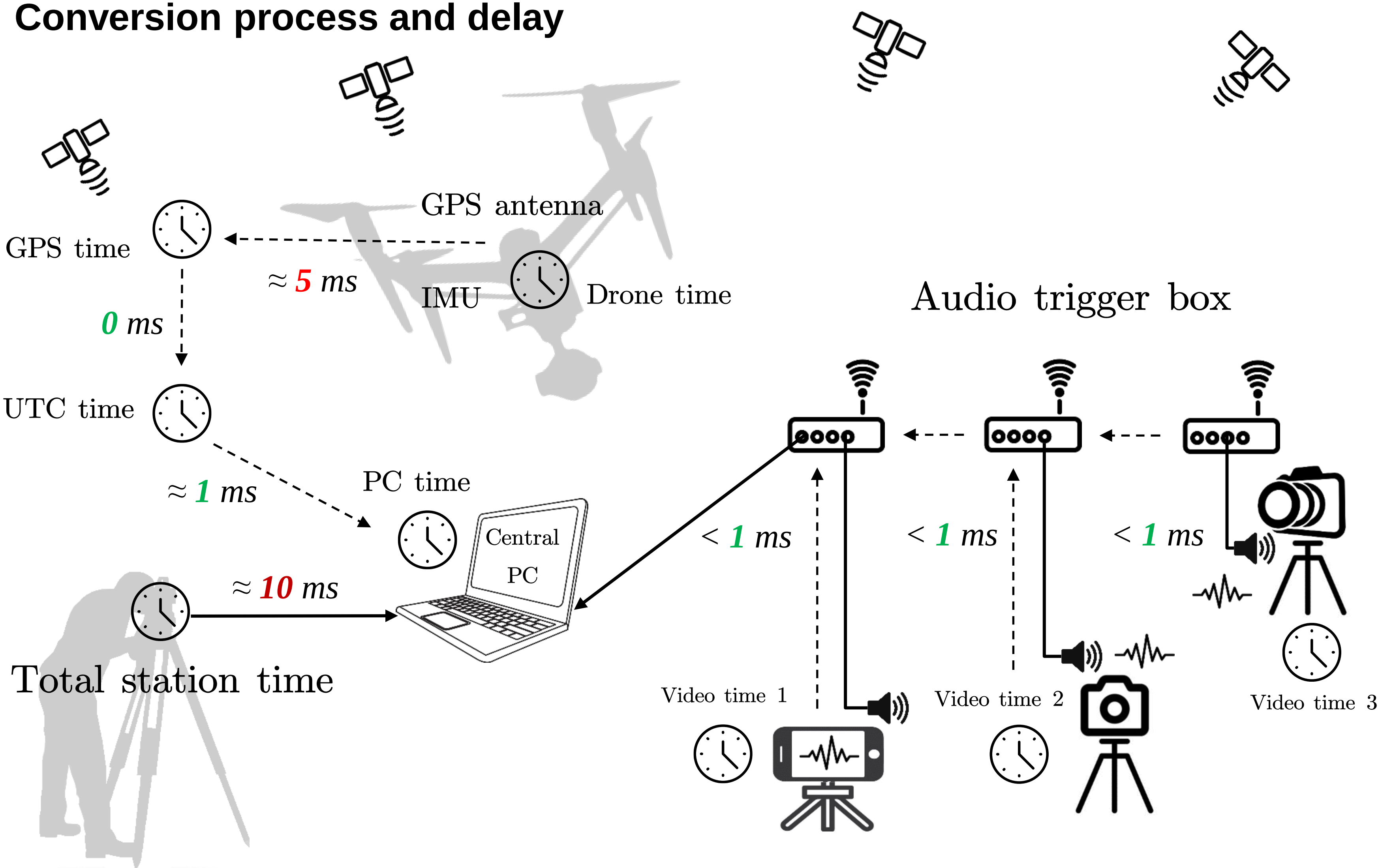
ETH zürich

Time systems



Overall synchronization

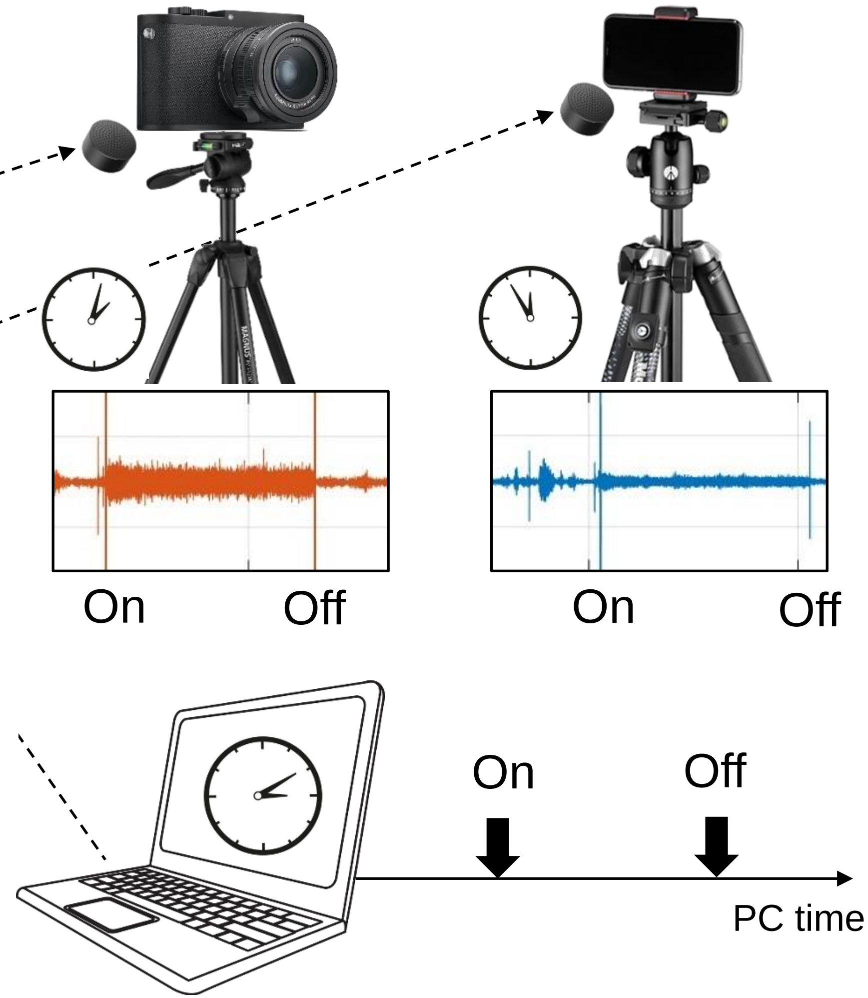
Conversion process and delay



Synchronization detail

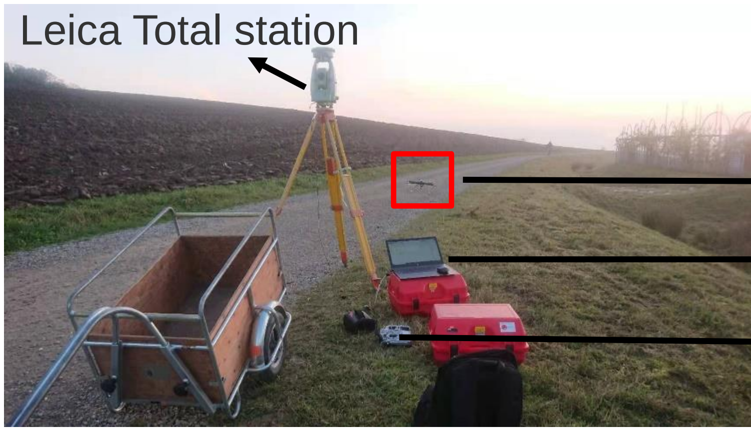
Cameras and central PC

- Radio-synchronized audio trigger
- Sub-frame (44100 Hz audio signal)
- Speakers close to microphones
- Triggered several times during the experiment



Experiment set-up

Equipments and site



Drone

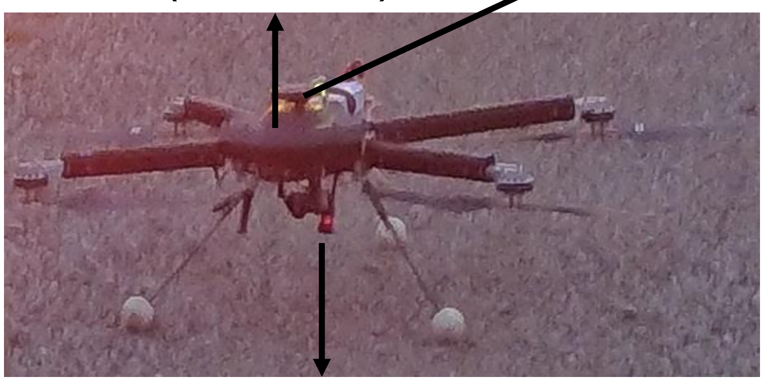
PC

Joystick

Test site: Honggerberg

Pixhawk box
(IMU inside)

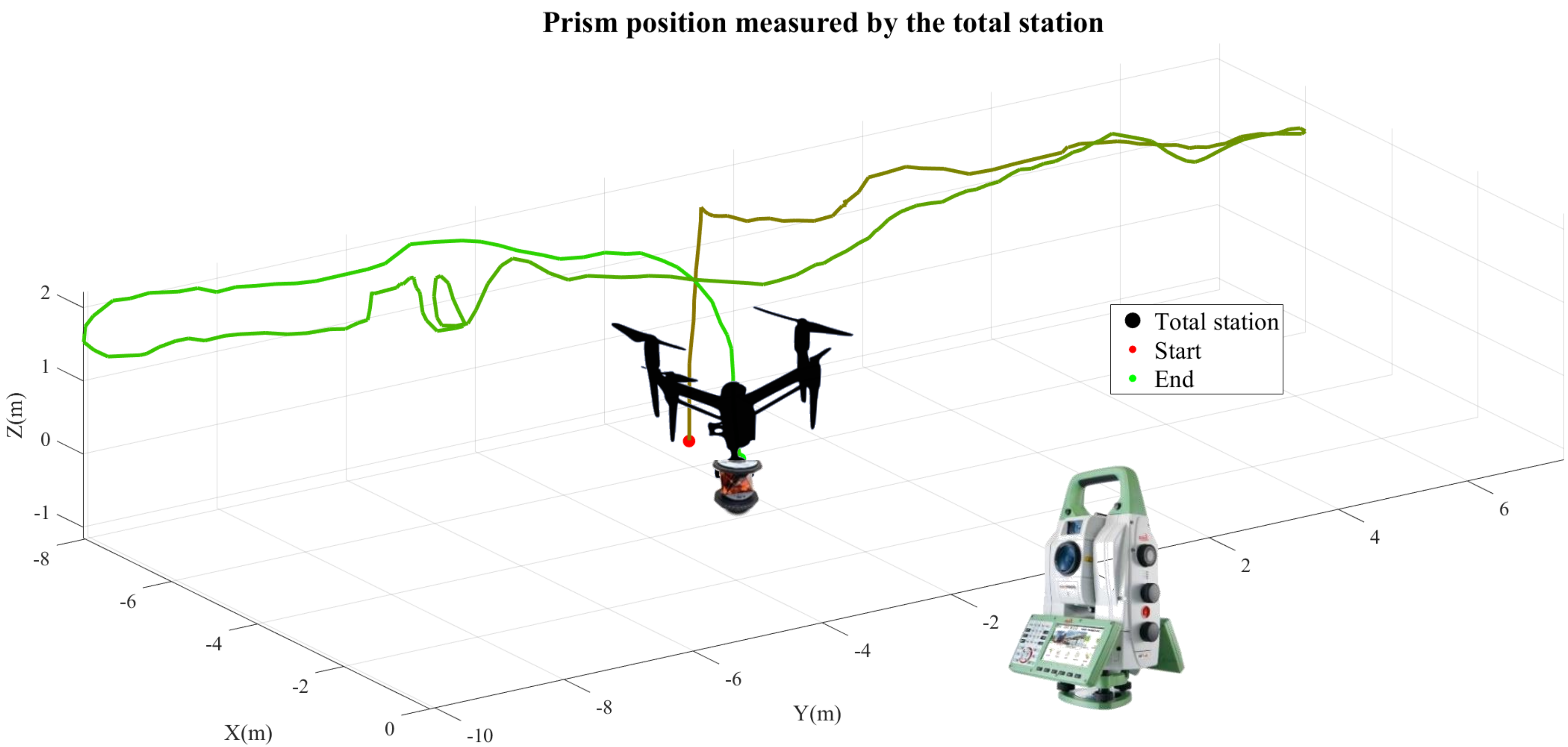
Here GPS Antenna



Leica mini-360° prisim

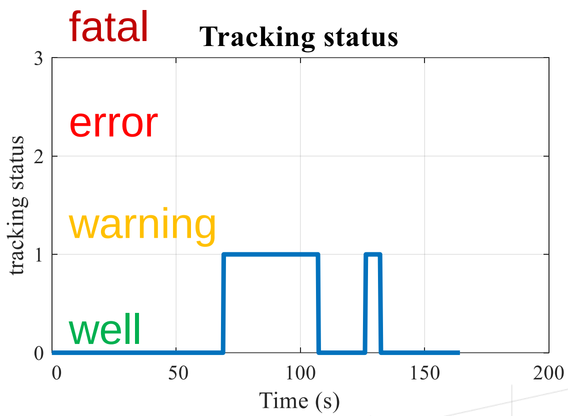
Experiment results

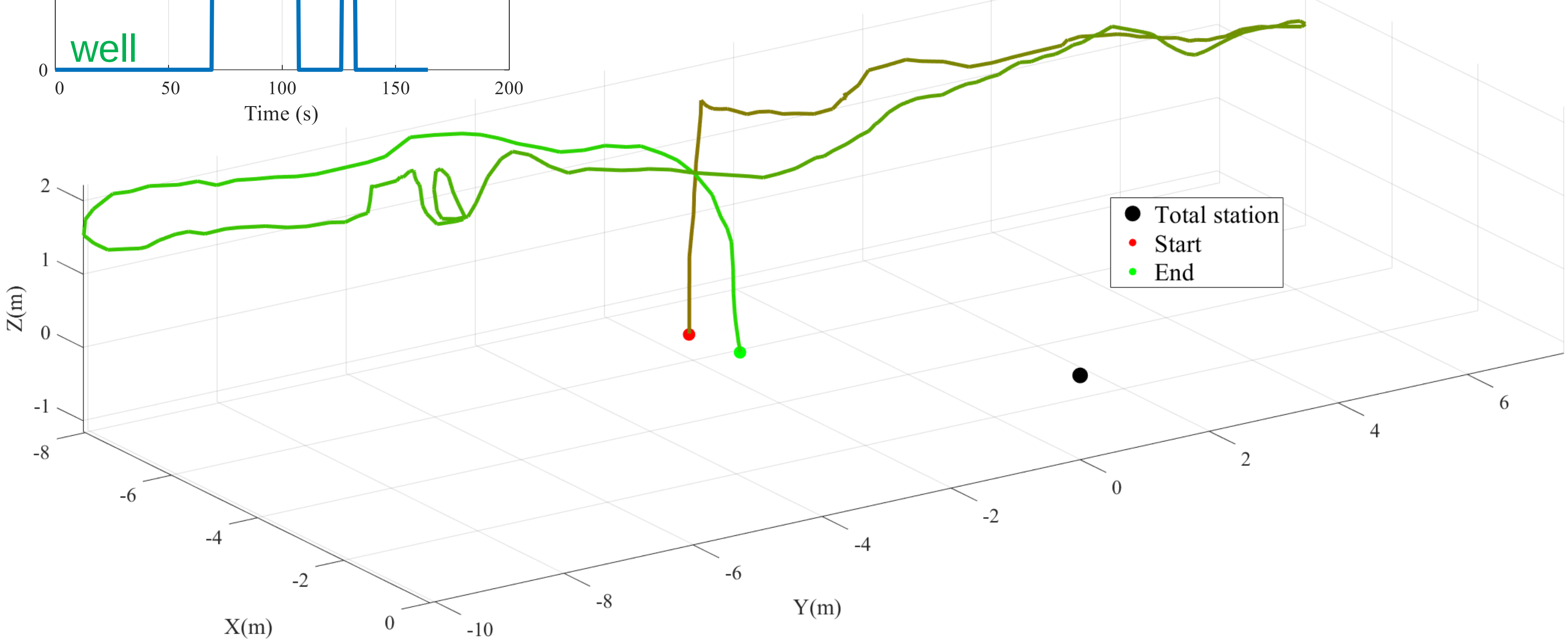
Prism position tracked by total station



Experiment results

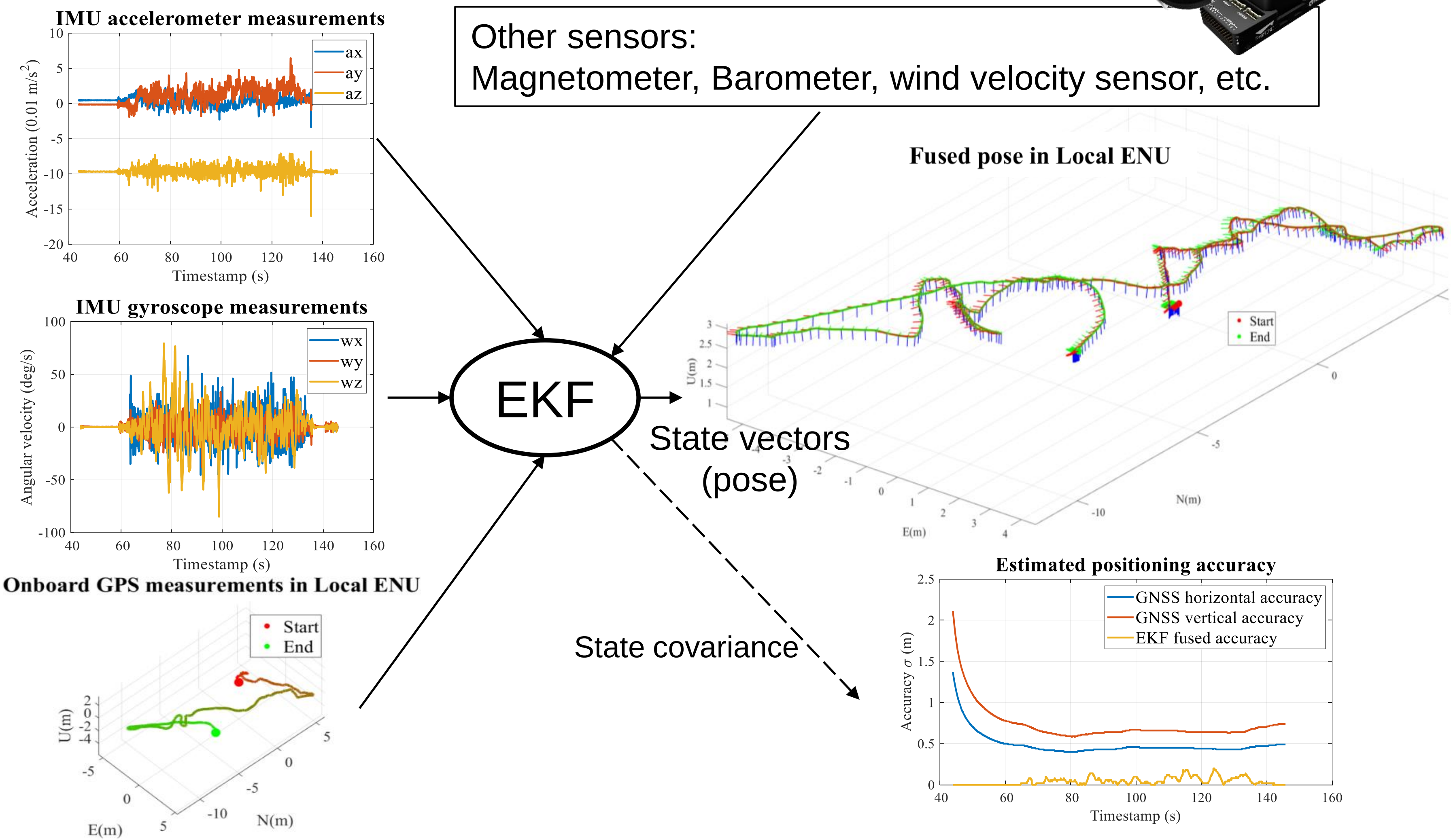
Prism position tracked by total station





Experiment results

Pose of drone center by fusing onboard sensors



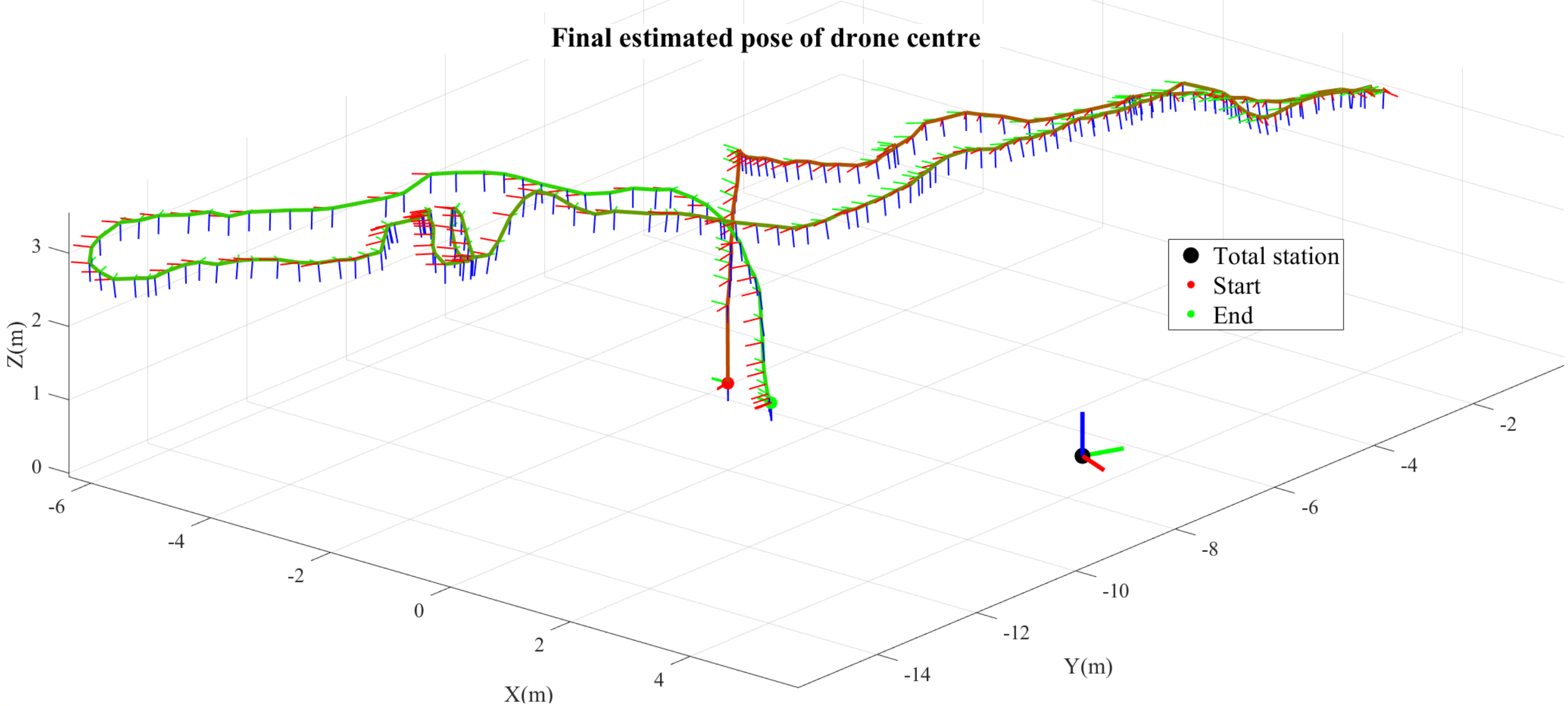
Experiment results

Final estimated pose of drone center

- Integrate interpolated EKF orientation with total station measurements
- Final result: drone center position calculated from:

$$\mathbf{t}_{lb}^{(enu)} = \mathbf{R}_{lt}\,\mathbf{p}_t + \mathbf{t}_{lt} - \mathbf{T}_{ned}^{enu}\,\mathbf{R}_{lb}\,\mathbf{p}_b$$

Resection Total station tracking EKF orientation Calibration



Experiment results

Accuracy evaluation

- Datasheet:

Leica Nova TS 60
Angle: 0.5”
Distance: 0.6mm + 1ppm

Pixhawk Cube
3 × commercial-grade MEMS IMU
output covariance

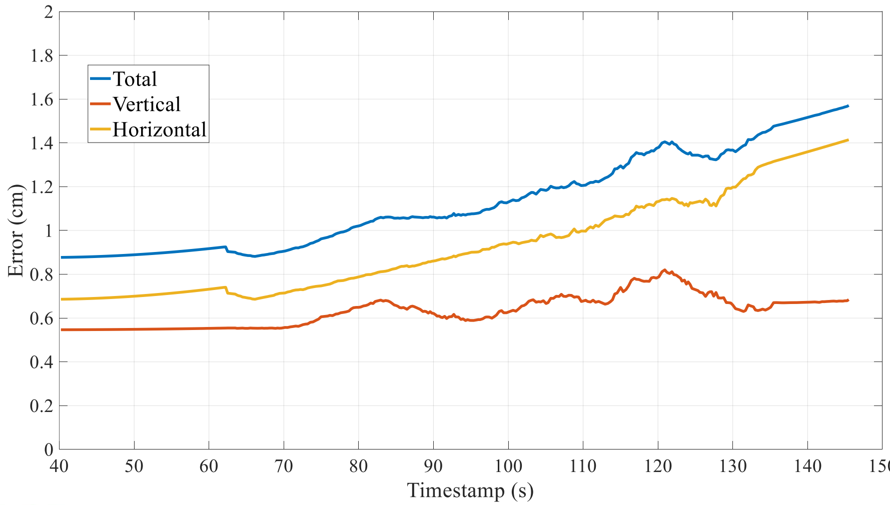
Trimble GPS with SwiPos
H: 8 mm , V: 15 mm

Offline calibration
0.5 mm

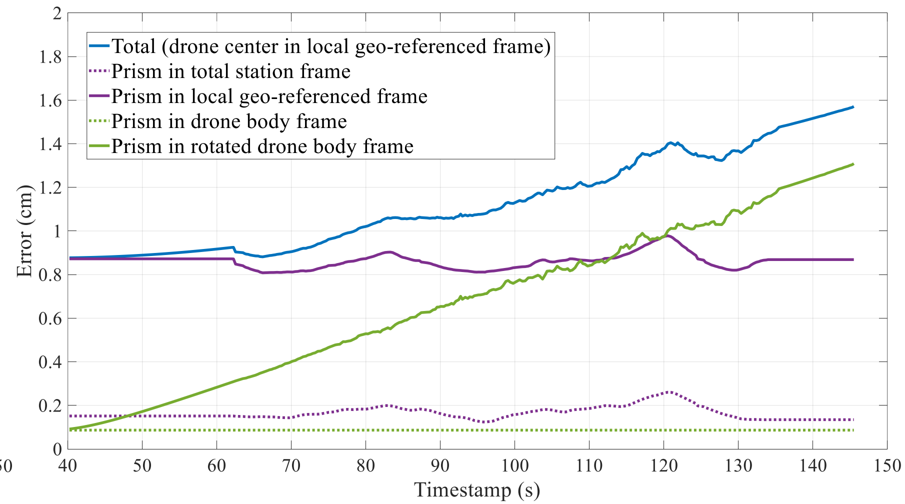
- Error estimation by covariance propagation:

Ref.: A tutorial on SE(3) transformation parameterizations and on-manifold optimization

- Different error direction:

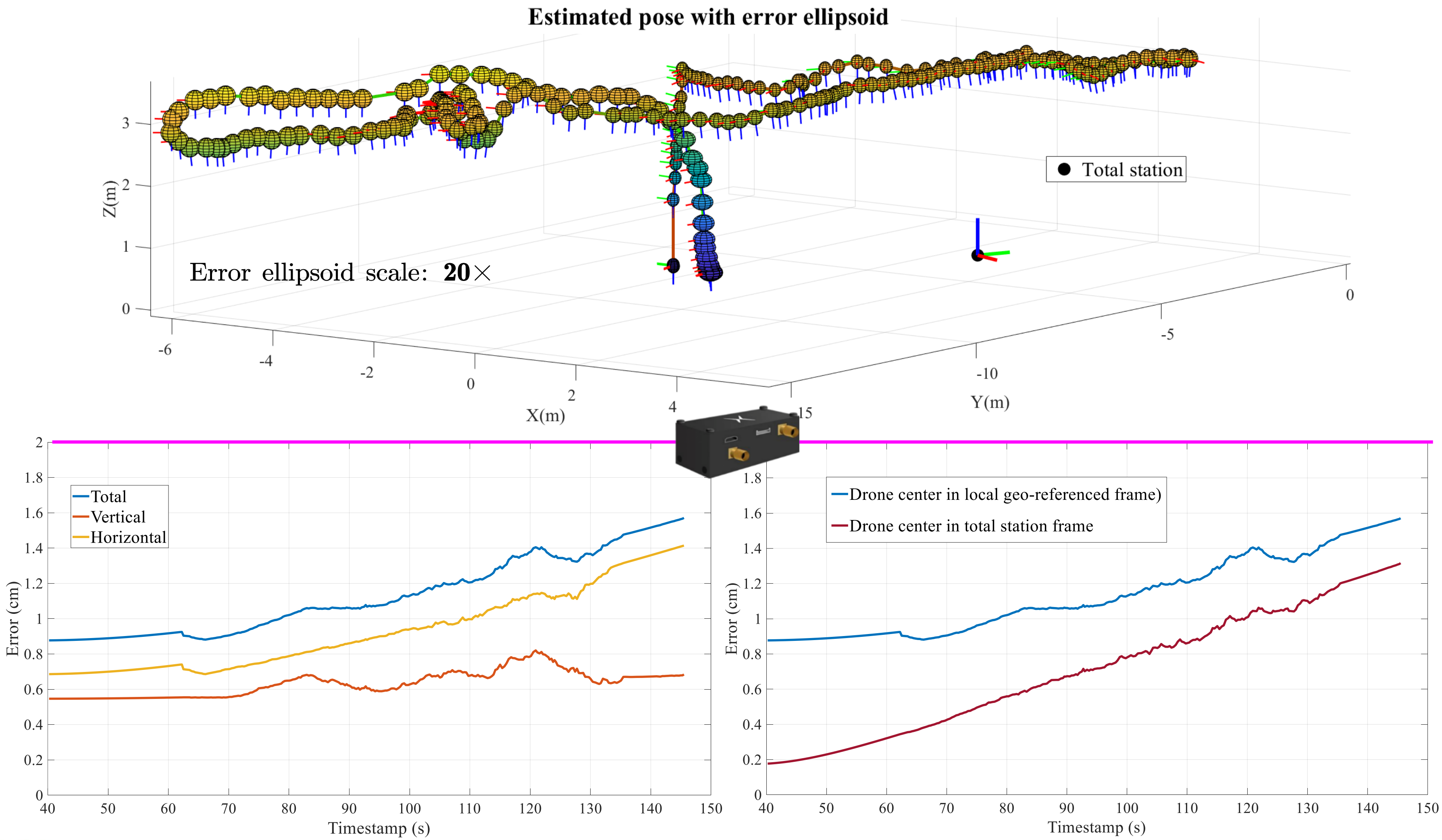


- Different error source:



Experiment results

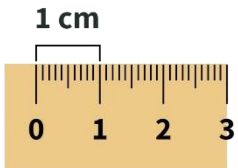
Accuracy evaluation



Conclusion

Contributions

- **Methods for:**
  - Measuring drone trajectory using total station and IMU with high accuracy
  - Synchronizing total station, IMU and cameras jointly



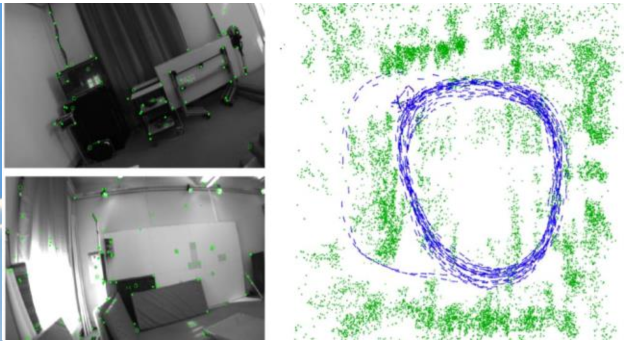
- **A dataset for:**
  - Evaluating the visual drone trajectory reconstruction algorithm
    - Current situation: Final dataset is not ready yet due to hardware issue (drone under repair)

Outlooks

- Multiple drones
- Challenging scenarios: with(out) cloud, occlusion
- Use onboard camera: VIO

https://fcw.com/articles/2020/08/20/rockwell-diu-domestic-drones.aspx

https://pxhere.com/en/photo/1446051



Christian Forster, et al., 2015, IMU Preintegration on Manifold for Efficient Visual-Inertial Maximum-a-Posteriori Estimation

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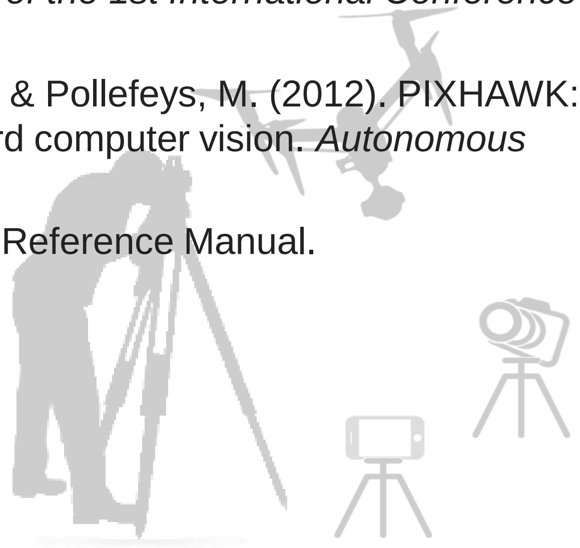

Q & A

Thanks for your attention