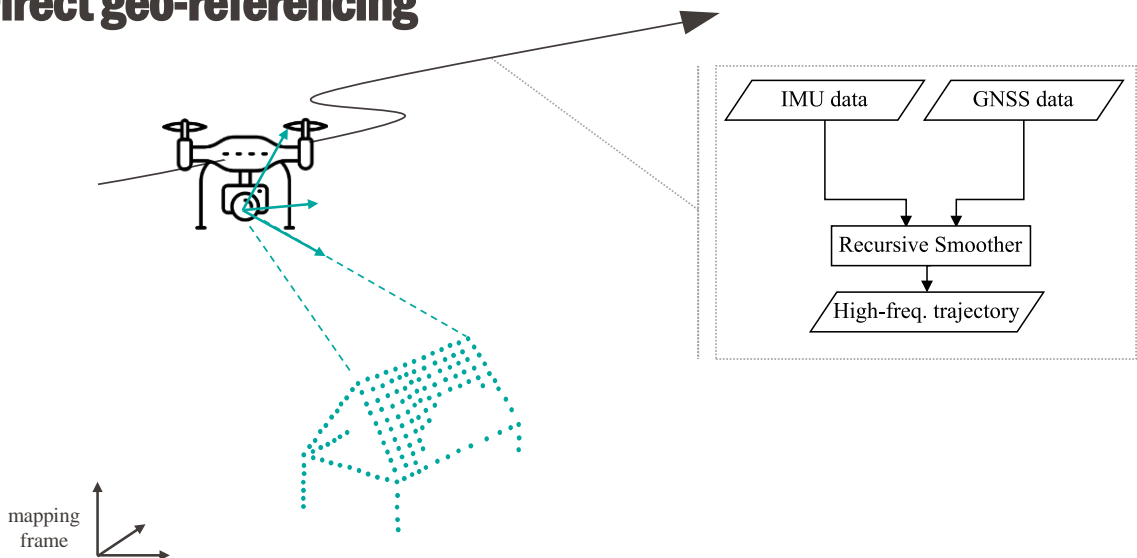# EPFL

Concurrent adjustment of lidar and camera with GNSS and raw inertial data
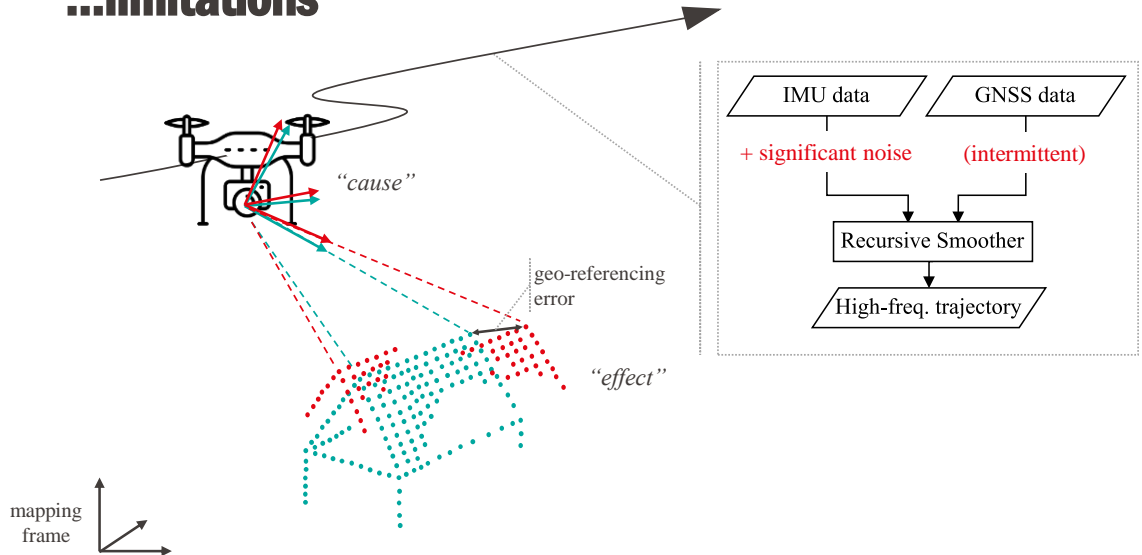
Geodetic Engineering Laboratory - TOPO

Kyriaki Mouzakidou, Davide A. Cucci, Jan Skaloud
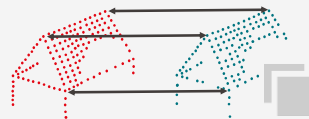

Direct geo-referencing

IMU data

GNSS data

Recursive Smoother

High-freq. trajectory

mapping frame

...limitations

"cause"

geo-referencing error

"effect"

mapping frame

IMU data   GNSS data

+ significant noise   (intermittent)
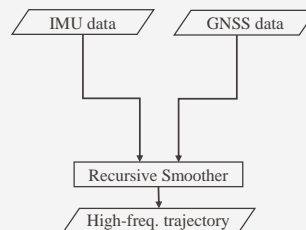
Recursive Smoother

High-freq. trajectory

Correction approaches

👉 Target the "effect"
(point-cloud)

example:
Lidar to dense image matching
point-cloud

👉 Target the "cause"
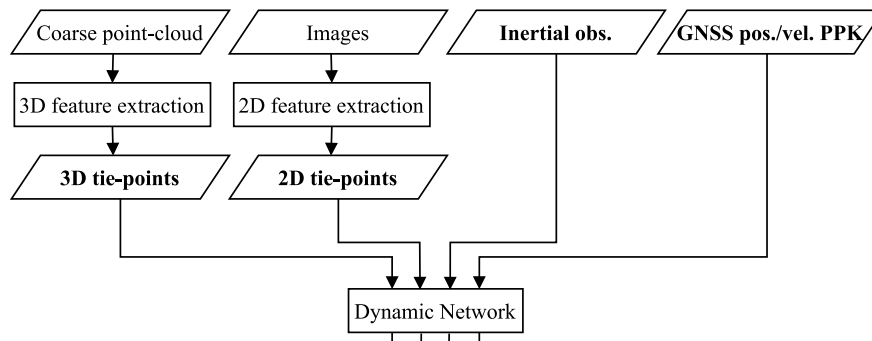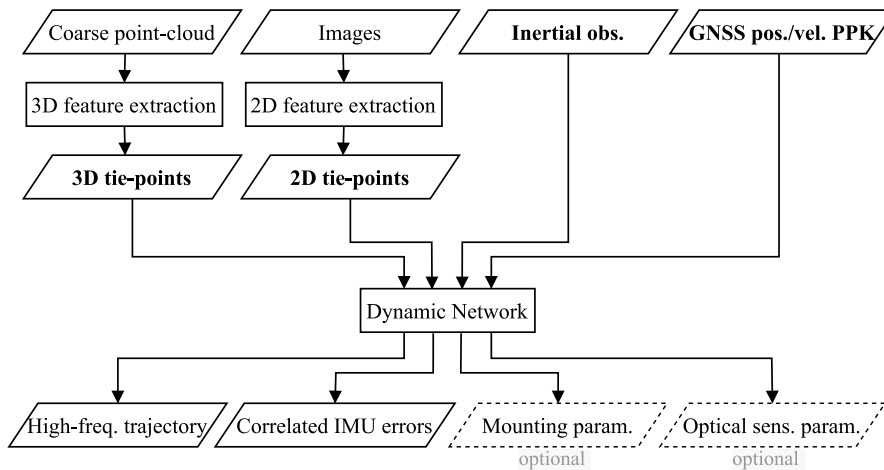*(sensor - trajectory errors)*

IMU data   GNSS data

Recursive Smoother

High-freq. trajectory

Correction approaches

☞ Target the "cause"
(sensor - trajectory errors)

Optical data | IMU data | GNSS data

an extension of conventional geodetic networks → Dynamic Networks → High-freq. trajectory
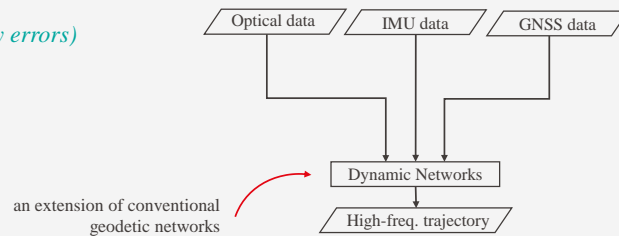
Colomina, I., Blazquez, M., 2004. **A unified approach to static and dynamic modeling in photogrammetry and remote sensing**. ISPRS Archives

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Coarse point-cloud | Images | **Inertial obs.** | **GNSS pos./vel. PPK**

3D feature extraction | 2D feature extraction

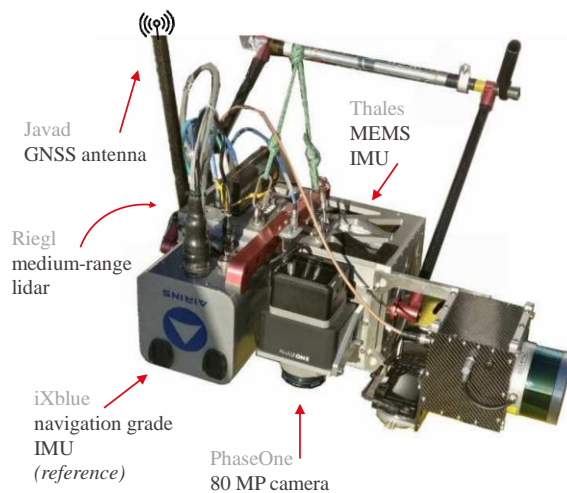**3D tie-points** | **2D tie-points**

Dynamic Network

Cucci, D. A., et al. 2017. **Bundle adjustment with raw inertial observations in UAV applications**. ISPRS Journal

Brun, A., et al. 2022. **LiDAR point–to–point correspondences for rigorous registration of kinematic scanning in dynamic networks**. ISPRS Journal

Experimental evaluation

Javad
GNSS antenna

Thales
MEMS
IMU

Riegl
medium-range
lidar

iXblue
navigation grade
IMU
(reference)

PhaseOne
80 MP camera

Vallet, J., et al., 2020. **Airborne and mobile LiDAR, which sensors for which application?** ISPRS Archives

Legend:
- ● cameras FL2
- ● cameras FL1
- ☐ footprints FL2
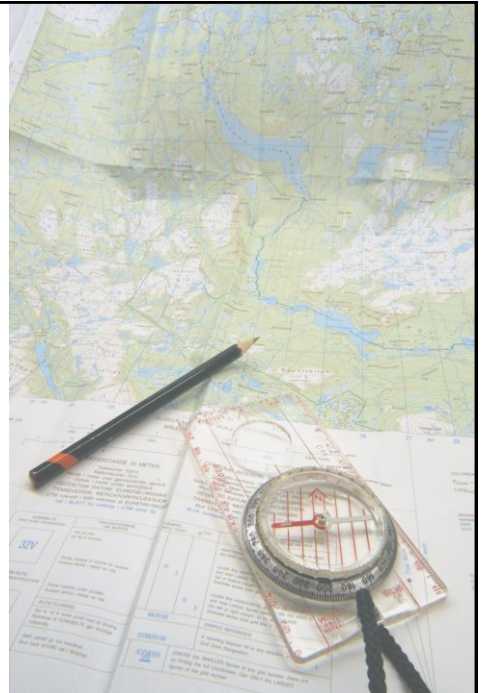- ☐ footprints FL1

50   200 m

Trajectory determination approaches
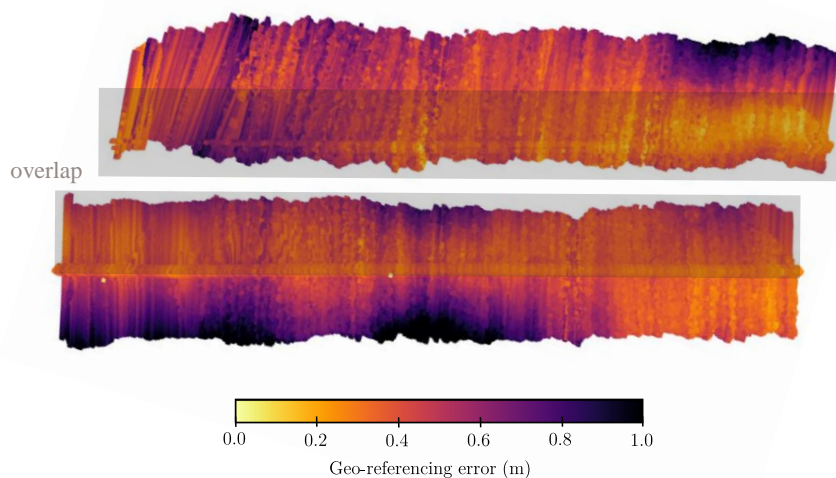
Reference (< 5 cm)
vs
1. MEMS-IMU + GNSS
2. MEMS-IMU + GNSS + Lidar
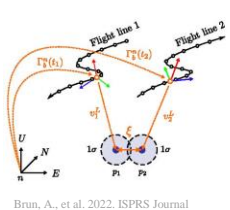3. MEMS-IMU + GNSS + Camera
4. MEMS-IMU + GNSS + Lidar + Camera

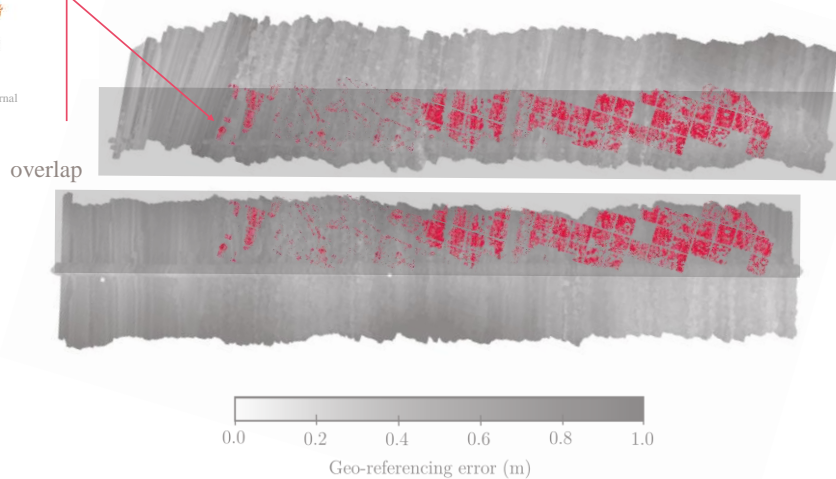# Direct geo-referencing – point-cloud error

MEMS-IMU + GNSS

overlap

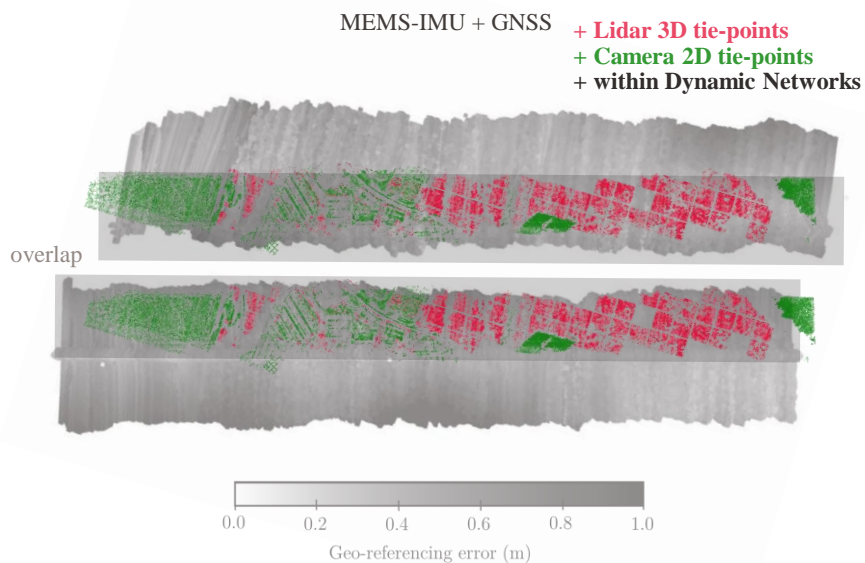0.0   0.2   0.4   0.6   0.8   1.0
Geo-referencing error (m)

Use of 3D tie-points

Brun, A., et al. 2022. ISPRS Journal

MEMS-IMU + GNSS   **+ Lidar 3D tie-points**

overlap
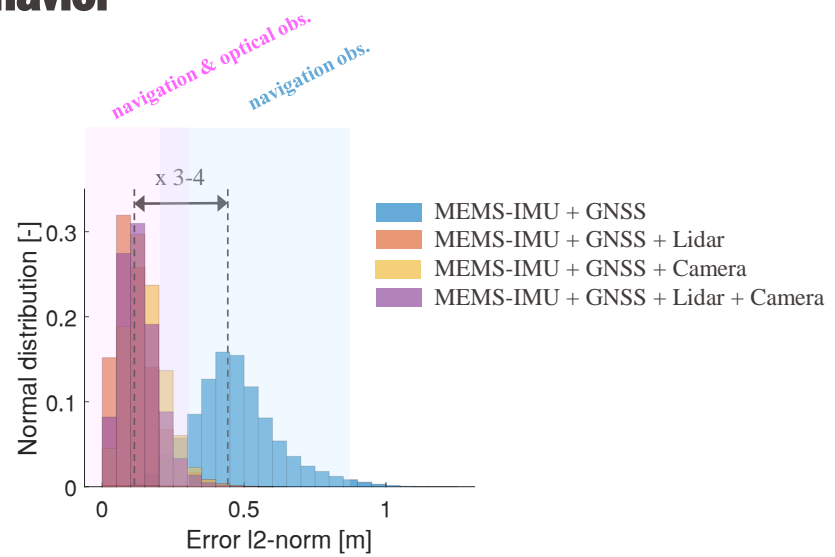
0.0   0.2   0.4   0.6   0.8   1.0
Geo-referencing error (m)

Use of 3D & 2D tie-points

MEMS-IMU + GNSS **+ Lidar 3D tie-points**
+ Camera 2D tie-points
+ within Dynamic Networks

overlap

0.0   0.2   0.4   0.6   0.8   1.0
Geo-referencing error (m)

Improvement in point cloud quality

MEMS-IMU + GNSS   MEMS-IMU + GNSS + Lidar + Camera

overlap

0.0   0.2   0.4   0.6   0.8   1.0
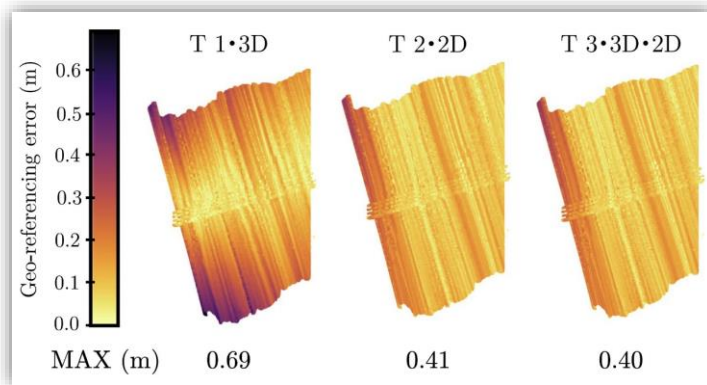Geo-referencing error (m)
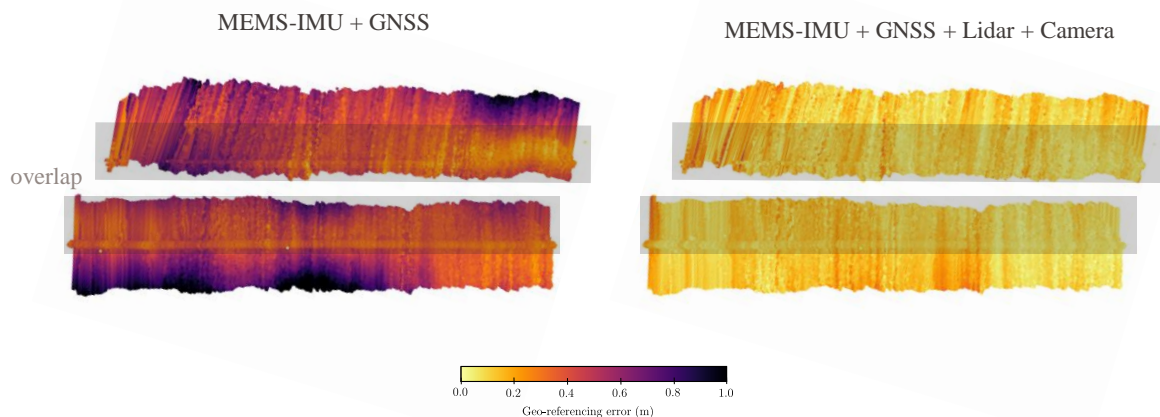
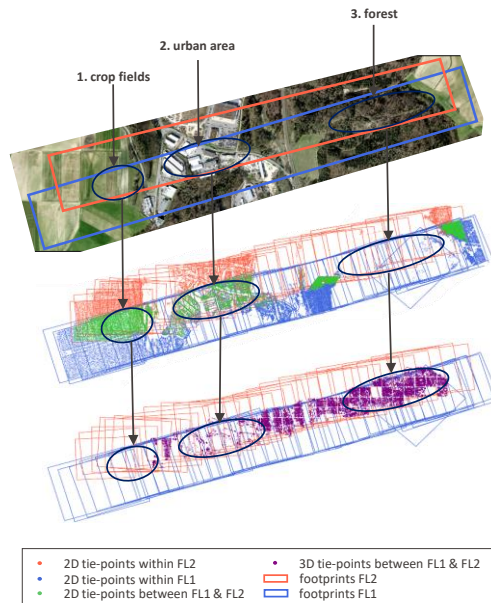# Global behavior

Local behavior

Conclusions

✓ Dynamic Networks
  {single adjustment of optical & navigation data}:
  3-4 times reduced geo-referencing error

✓ complementarity of 2D tie-points & 3D tie-points:
  continuous control along trajectory

Mouzakidou, K., Cucci, D.A., and Skaloud, J., 2022. *On the benefit of concurrent adjustment of active and passive optical sensors with GNSS & raw inertial data.* ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences

Thank you!