RESILIENT NAVIGATION WITH MULTI-SENSOR DATA FUSION

AUTHORS

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RESILIENT NAVIGATION WITH MULTI-SENSOR DATA FUSION IN GNSS-DENIED ENVIRONMENT

FELIX WENK, MAY 23, 2022

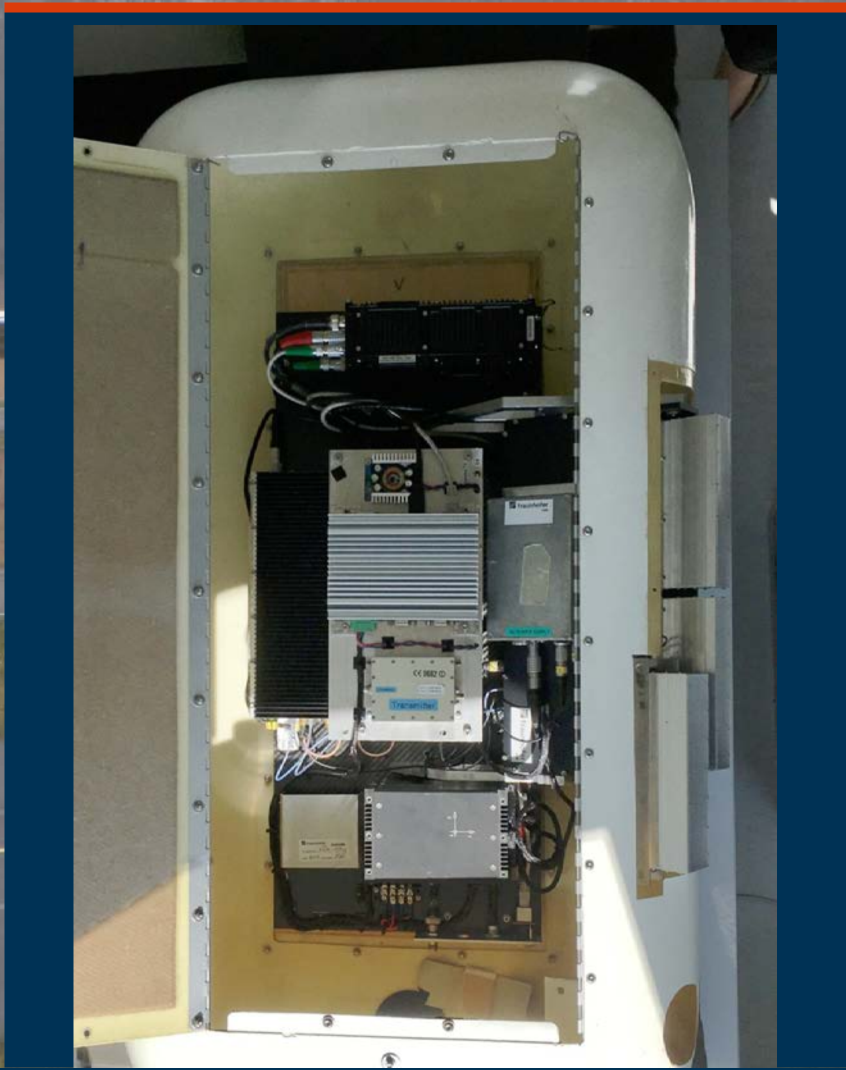
RESILIENT NAVIGATION WITH MULTI-SENSOR DATA FUSION

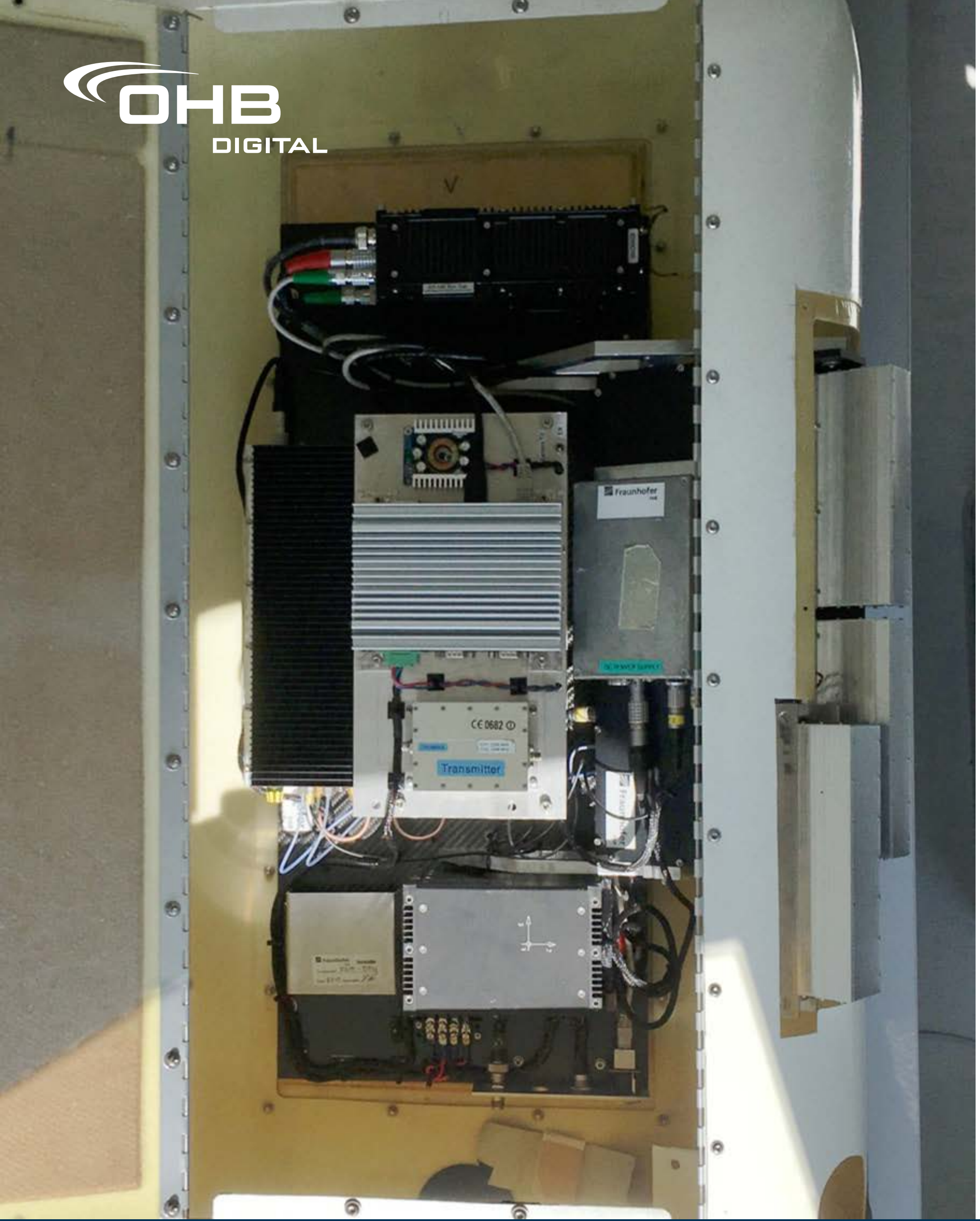
WHY?

- “Situational Awareness is NATO’s prerequisite to lead, to protect, to act. To this end, comprehensive situation pictures are required that exploit the full electromagnetic spectrum (ESM) for comprehensive sensing.”
- Sensors such as Multi-Spectral Pushbroom Scanners or Synthetic Aperture Radar (SAR) are typically mounted on aircrafts and require an estimate of their platform’s position to form images from the raw sensor data.
- Positioning / Ego-Motion Estimation is needed for Navigation
- Ego-Motion Estimate is usually obtained from INS+GNSS.

TYPICAL SETUP

AIRCRAFT WITH PAYLOAD AND AUXILIARY SENSORS IN POD MOUNTED BELOW A WING.

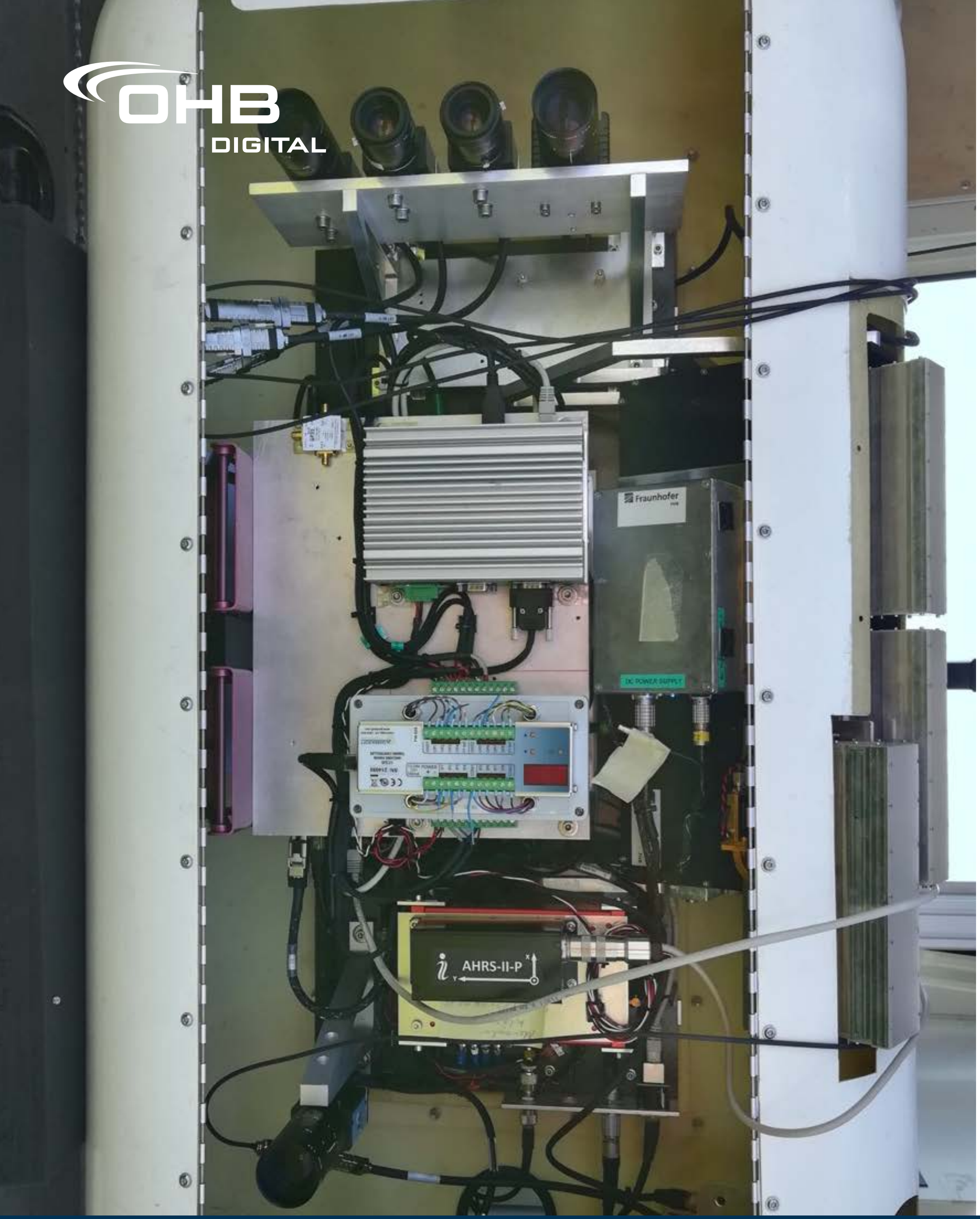




TYPICAL SETUP

TO OBTAIN EGO-MOTION ESTIMATE USING INS+GNSS

- Here: Payload Sensor: Synthetic Aperture Radar
  - Similar issues for other sensors requiring an estimate of the ego-motion of the carrying platform.
- GPS receiver
- Precise Inertial Measurement Unit
- GNSS may be spoofed or jammed.
  - Renders payload sensor useless.
  - Disables navigation.
- IMU is large, **heavy** and very expensive.
  - Limits usability on small UAV.
- Different approach to ego-motion estimation?

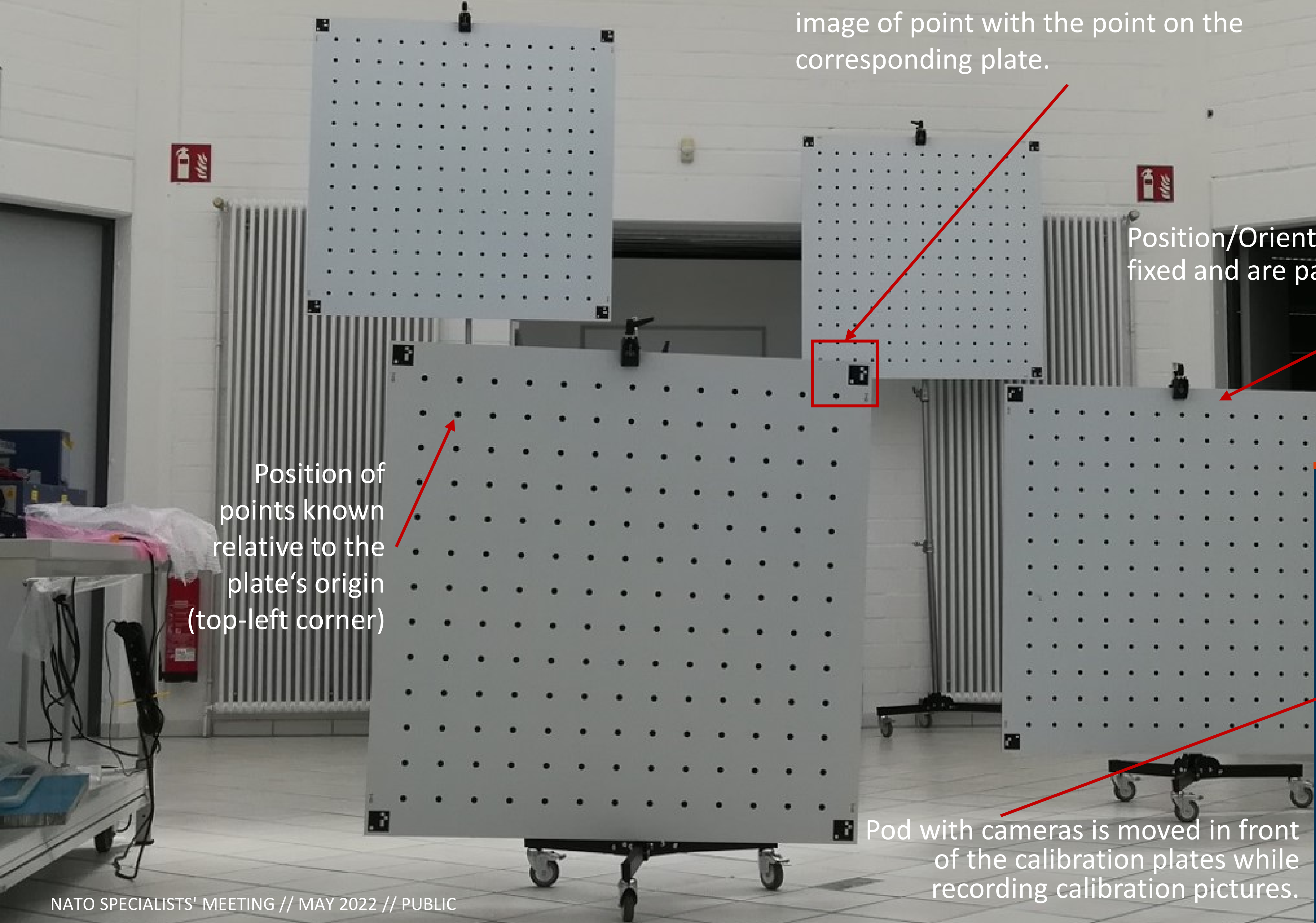


EXPERIMENT SETUP

TO ESTIMATE EGO-MOTION FROM CAMERA PICTURES WITHOUT GNSS

- Here: Payload Sensor: Synthetic Aperture Radar
- INS+GNSS for reference data.
- (Cheap and light) MEMS Inertial Measurement Unit
- Stereo camera pair
  - 60 cm Baseline
  - 12 MPixels, 75 mm focal length.
- Overview cameras (12 MPixels, 35 mm focal length)
- Infrared Camera (SWIR,
  640 x 480 Pixels, 75 mm focal length)
- Need Calibration
  - Observe a known scene, estimate internal and external parameters until expected projection agrees with actual image.

CAMERA CALIBRATION



Markers encode identifiers to associate image of point with the point on the corresponding plate.

Position/Orientation of the plates are unknown but fixed and are part of the calibration problem.

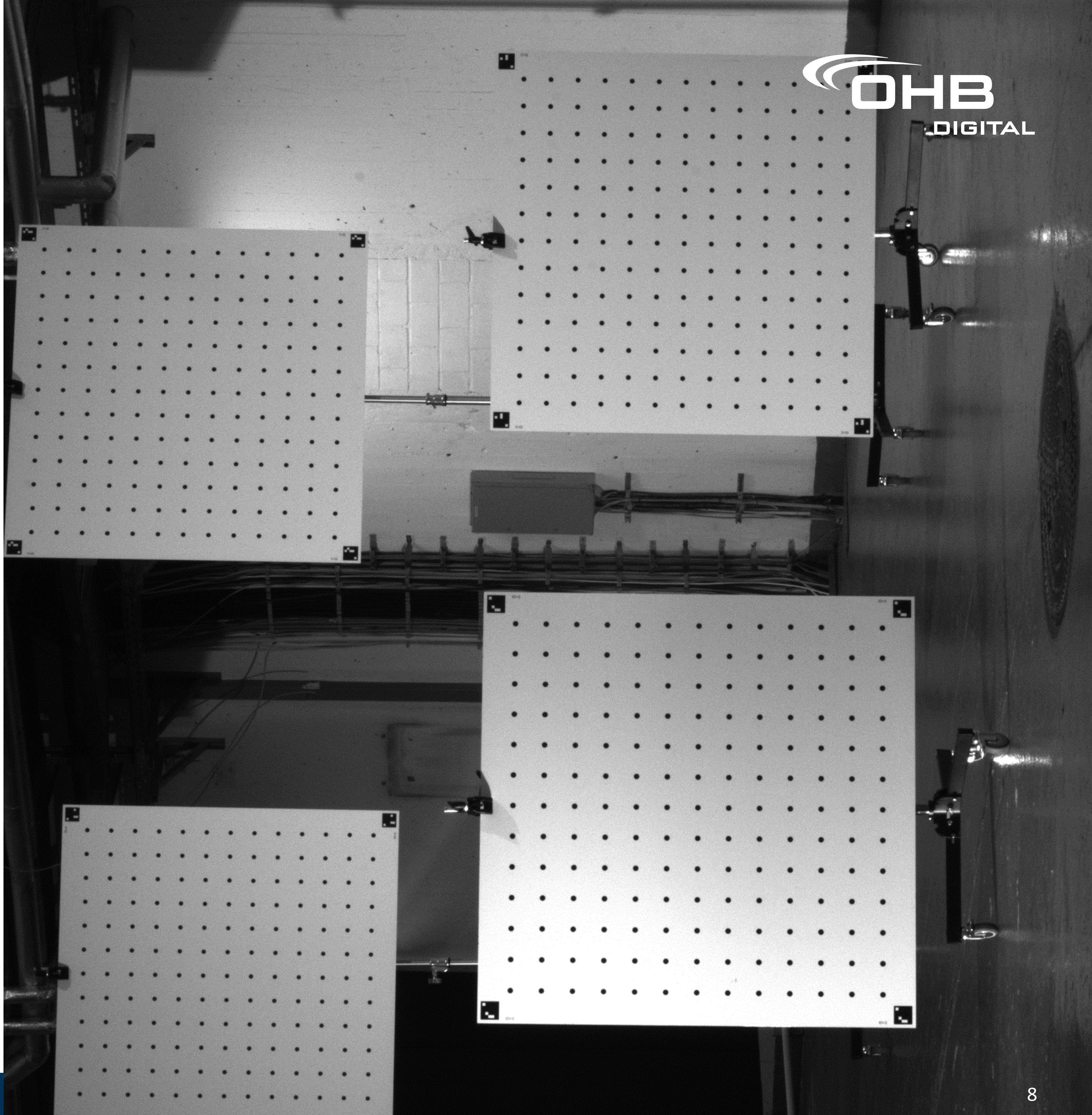
Position of points known relative to the plate's origin (top-left corner)

Pod with cameras is moved in front of the calibration plates while recording calibration pictures.

CAMERA CALIBRATION

PROBLEM SETUP

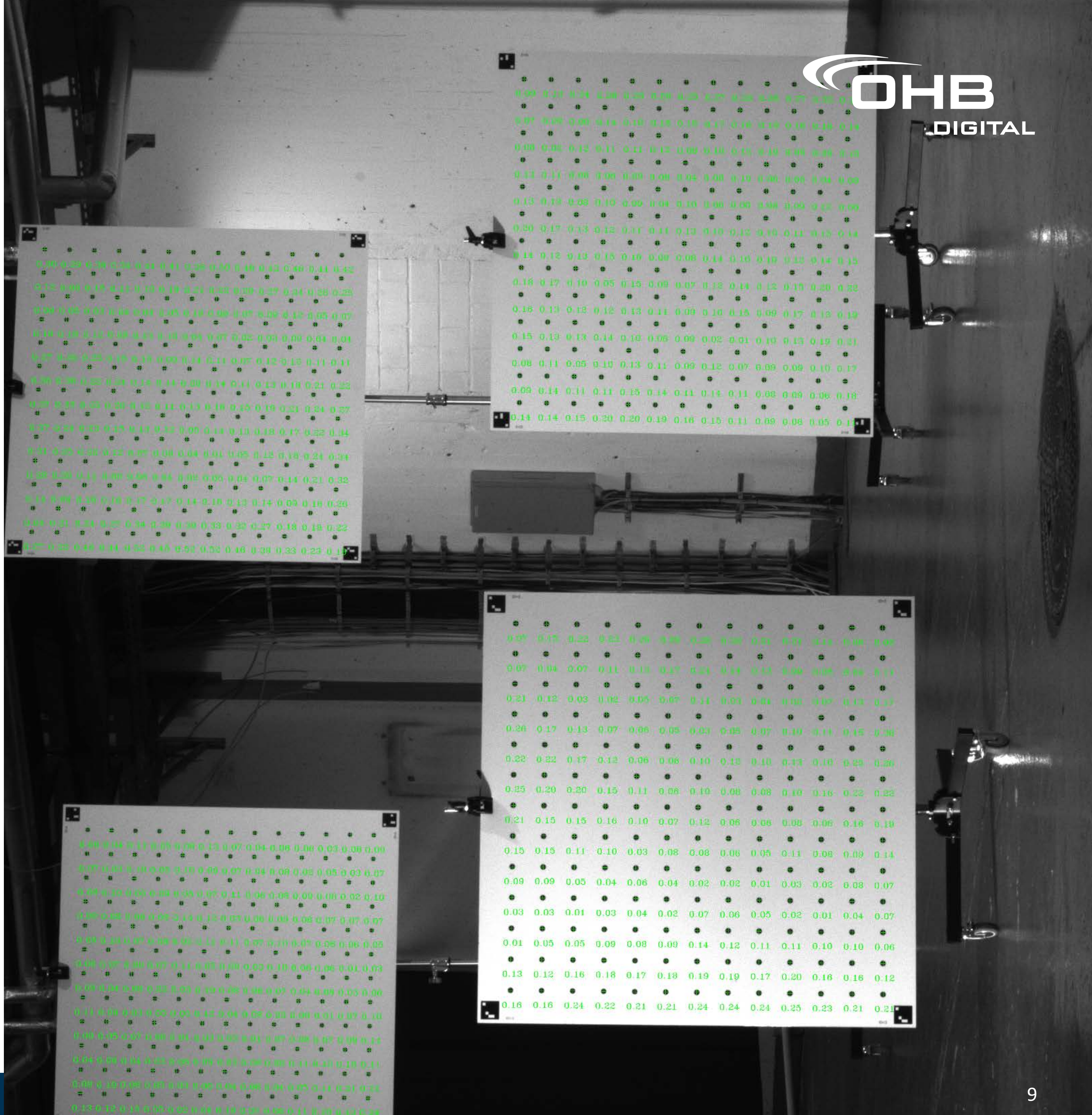
- Internal parameters:
  - Focal lengths (in both dimensions)
  - Location of camera center.
  - Radial distortion
    (first coefficient of OpenCV's (division) model).
- External parameters:
  Pose (orientation and position)
  relative to the pod's origin.
- Pod's origin: Pose of one of the stereo cameras or MEMS IMU.
- Poses of calibration plates.



CAMERA CALIBRATION

RESULTS

- Internal parameters:
  - Focal lengths (in both dimensions).
  - Location of camera center.
  - Radial distortion
    (first coefficient of OpenCV's (division) model).
- External parameters:
  Pose (orientation and position)
  relative to the pod's origin.
- Pod's origin: Pose of one of the stereo cameras or MEMS IMU.
- Poses of calibration plates.
- Reprojection error usually well below 1 pixel.



RECOGNIZE THE SCENE IN CAMERA PICTURES

BY COMPUTING THE OPTICAL FLOW OF PAIRS OF PICTURES

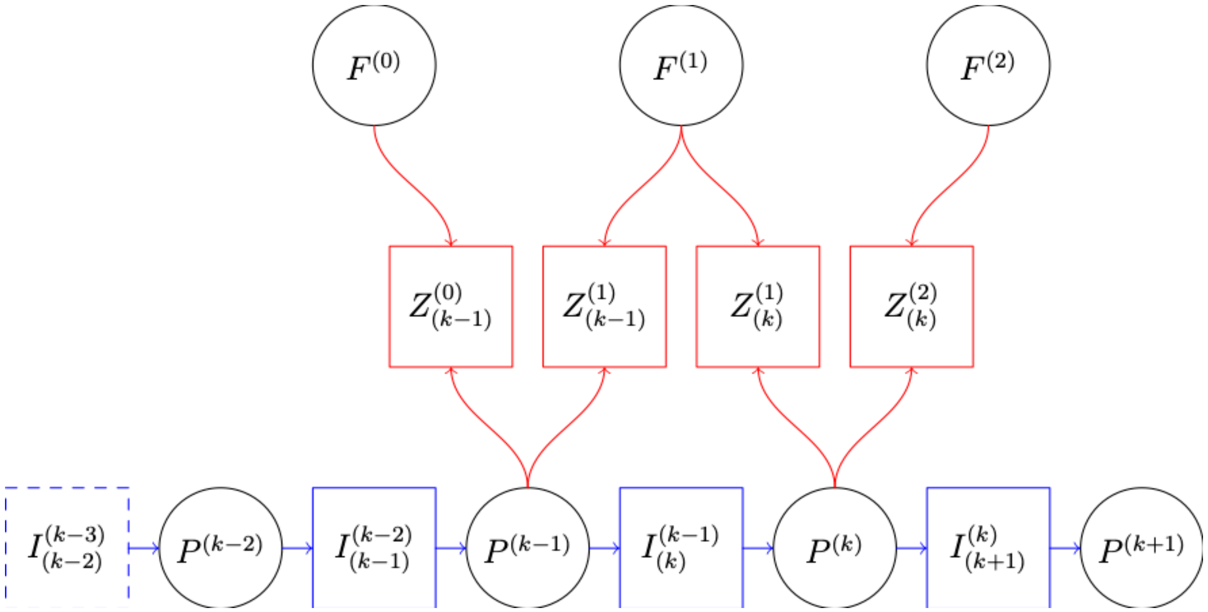
- Physical Scene: Very dense set of 3D points.
- Picture: Grid of 2D images of points of the scene.
- Automatically find recognizable points: Corners.

- Optical Flow: Movement of the image of an individual scene point from one camera picture to the other.
- Result: Images of points corresponding to the same scene point.

ESTIMATE THE EGO-MOTION: AIRPLANE POSES

BY SOLVING FOR THE ASSIGNMENT

- Set up probability densities:
  - $Z_{(k)}^{(i)}$: Projection measurement given Position of Feature $F^{(i)}$ and Airplane Pose $P^{(k)}$
- $I_{(k)}^{(k-1)}$: Either
  - Zero acceleration and zero angular velocity with white noise over the duration between (k-1) and (k) given Airplane Poses and Velocities (k-1) and (k)
  - Integrated MEMS-IMU measurements given Poses and Velocities at (k-1) and (k)
- Want Maximum Likelihood assignment of $P^{(*)}$ and $F^{(i)}$
  - Find P and F maximizing the probability of the measurements.
  - Minimize $-\log(Likelihood)$; I.e. minimize sum over all I and Z.



FLIGHT CAMPAIGN

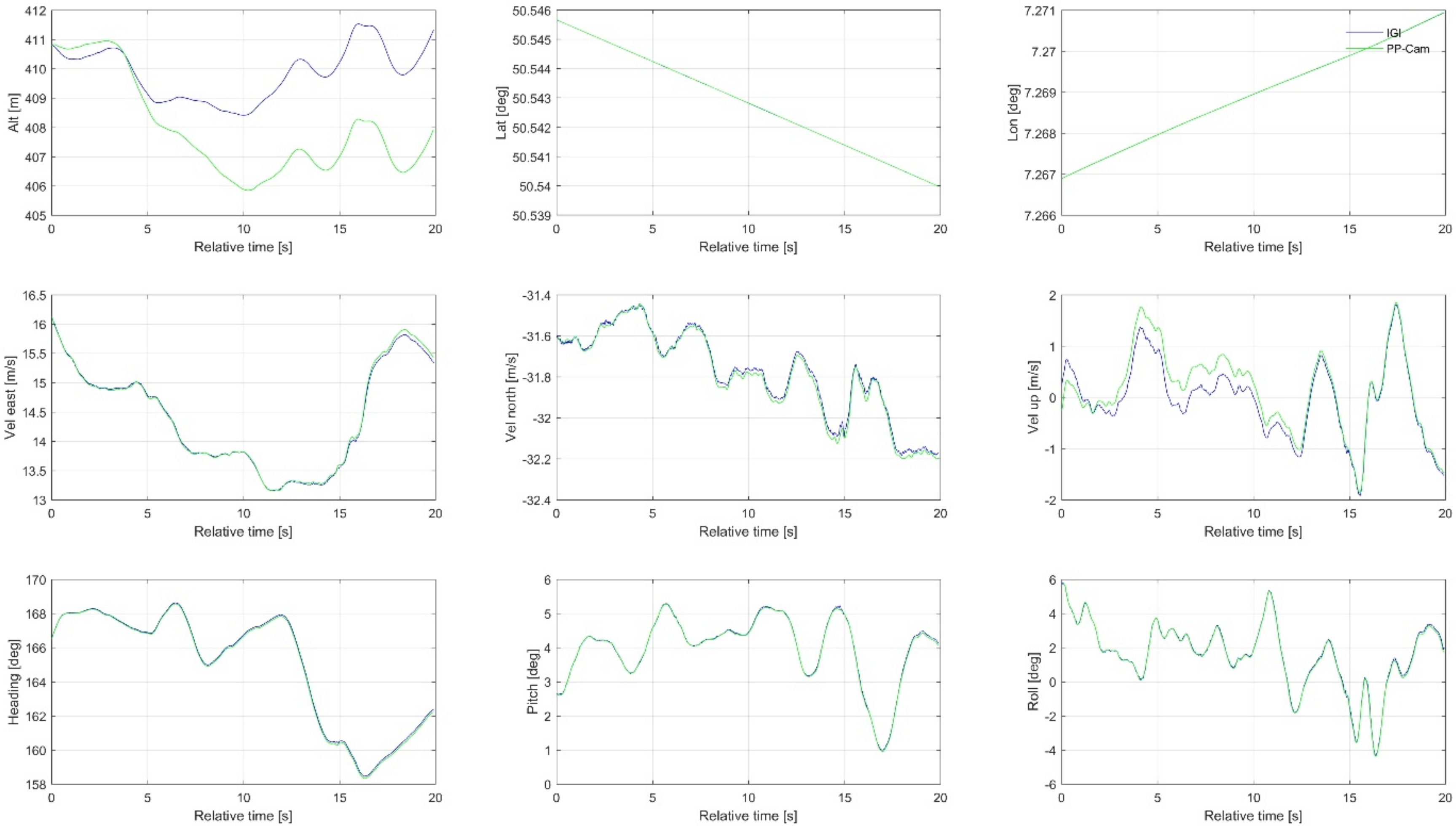
3 DAYS

RESULTS

EGO-MOTION FROM CAMERAS VS. REFERENCE FROM GNSS

RESULTS

EGO-MOTION FROM CAMERAS VS. REFERENCE FROM GNSS



SWIR (20 Hz) based estimation

IGI-IMU reference data

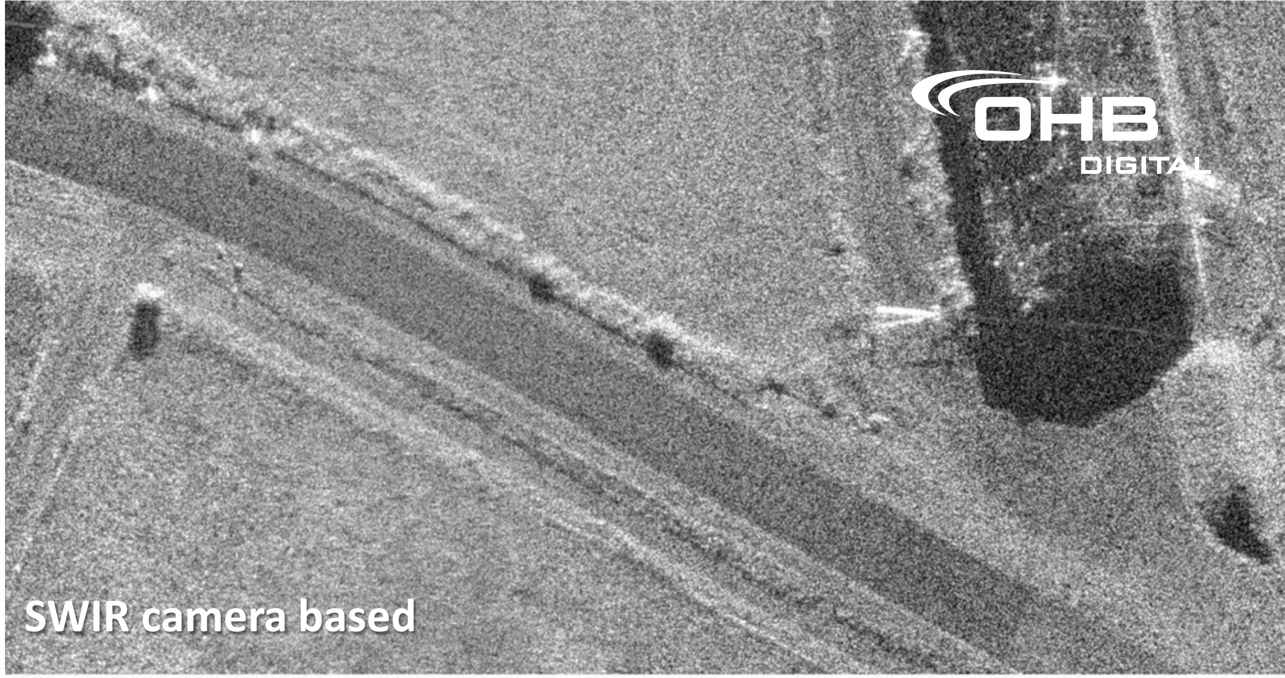
SAR IMAGE EXAMPLE: RINGEN

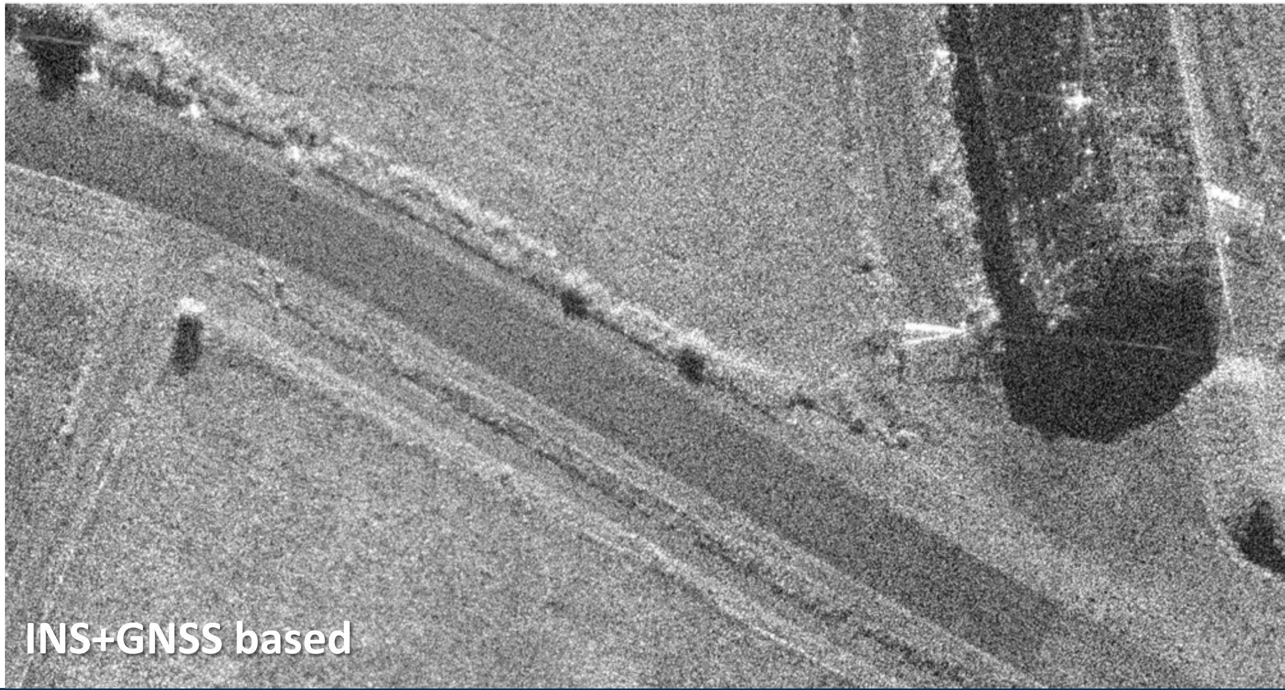
SAR IMAGE EXAMPLE: RINGEN

CONCLUSION

SAR IMAGE FORMATION USING EGO-MOTION FROM CAMERAS VS. REFERENCE FROM GNSS

- SAR Image Formation possible using camera-based ego-motion estimates, even with infrared.
  - In particular under benign flight conditions.
- Ego-Motion Estimation with Cameras + MEMS IMU has little drift w.r.t. GNSS reference.
- Automatic positioning feature extraction from images.
  - Add loop closures to reduce drift in relative positioning.
  - Add geo-referenced (e.g. Satellite) images to enable absolute positioning to enable GNSS-free navigation.





THANK YOU!

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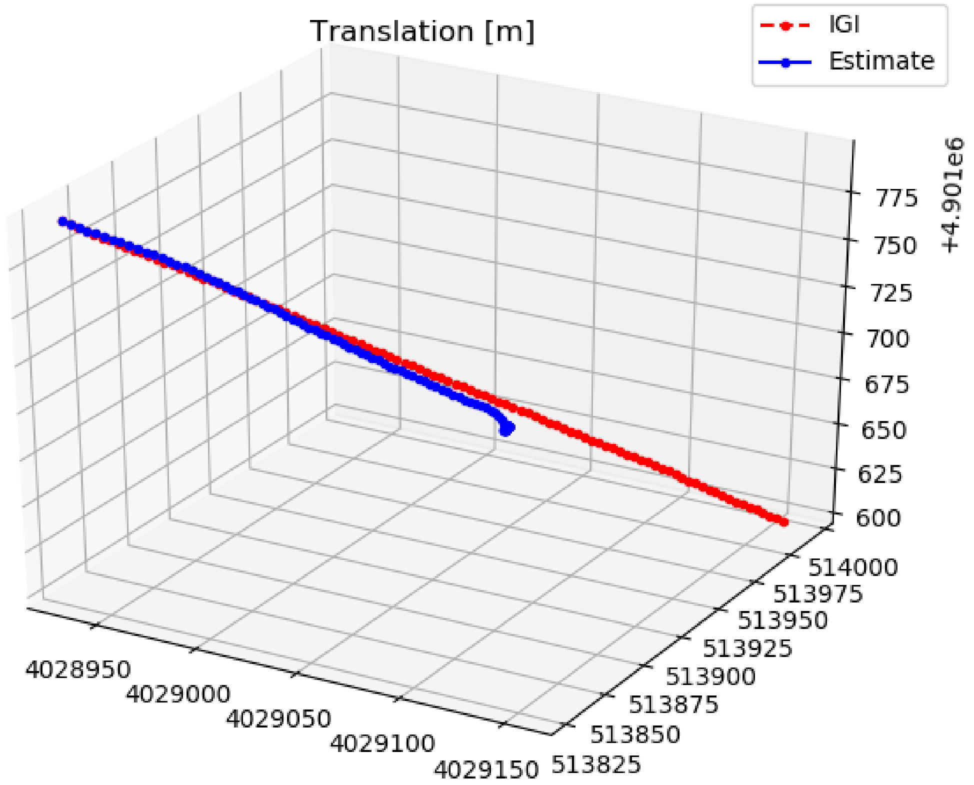
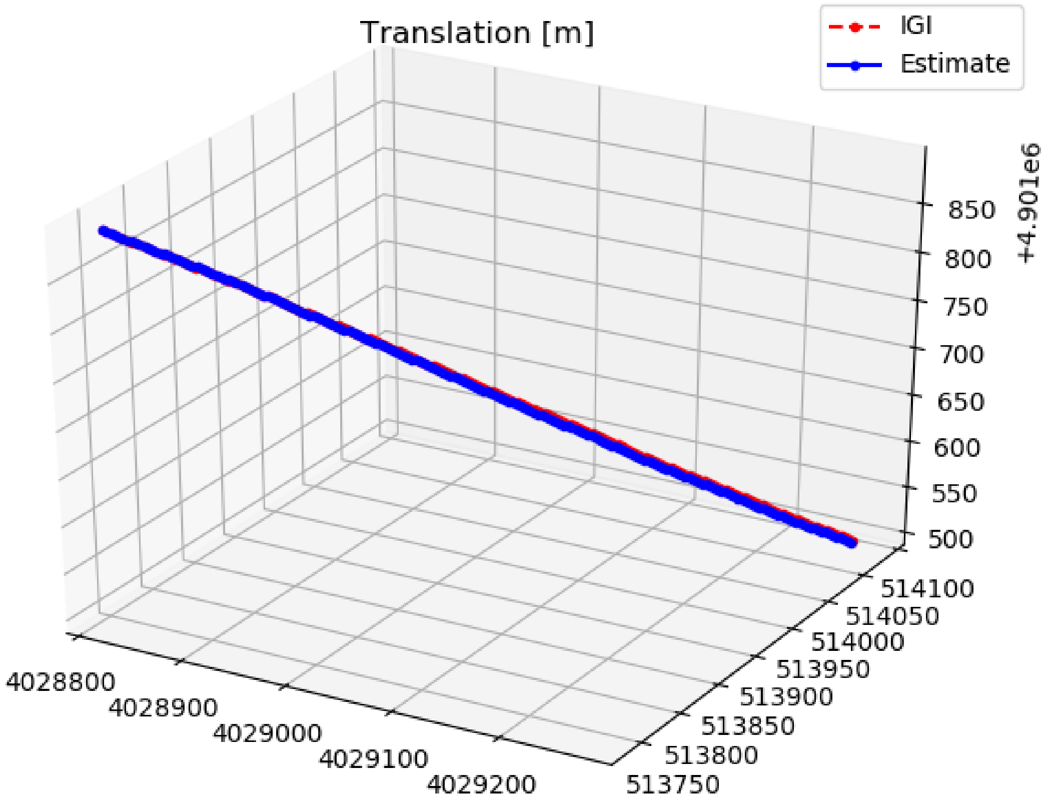
RESULTS

INCREASED ROBUSTNESS BY INTEGRATING MEMS IMU MEASUREMENTS

- White noise acceleration model.
- Estimator easily tripped up by false point correspondences.

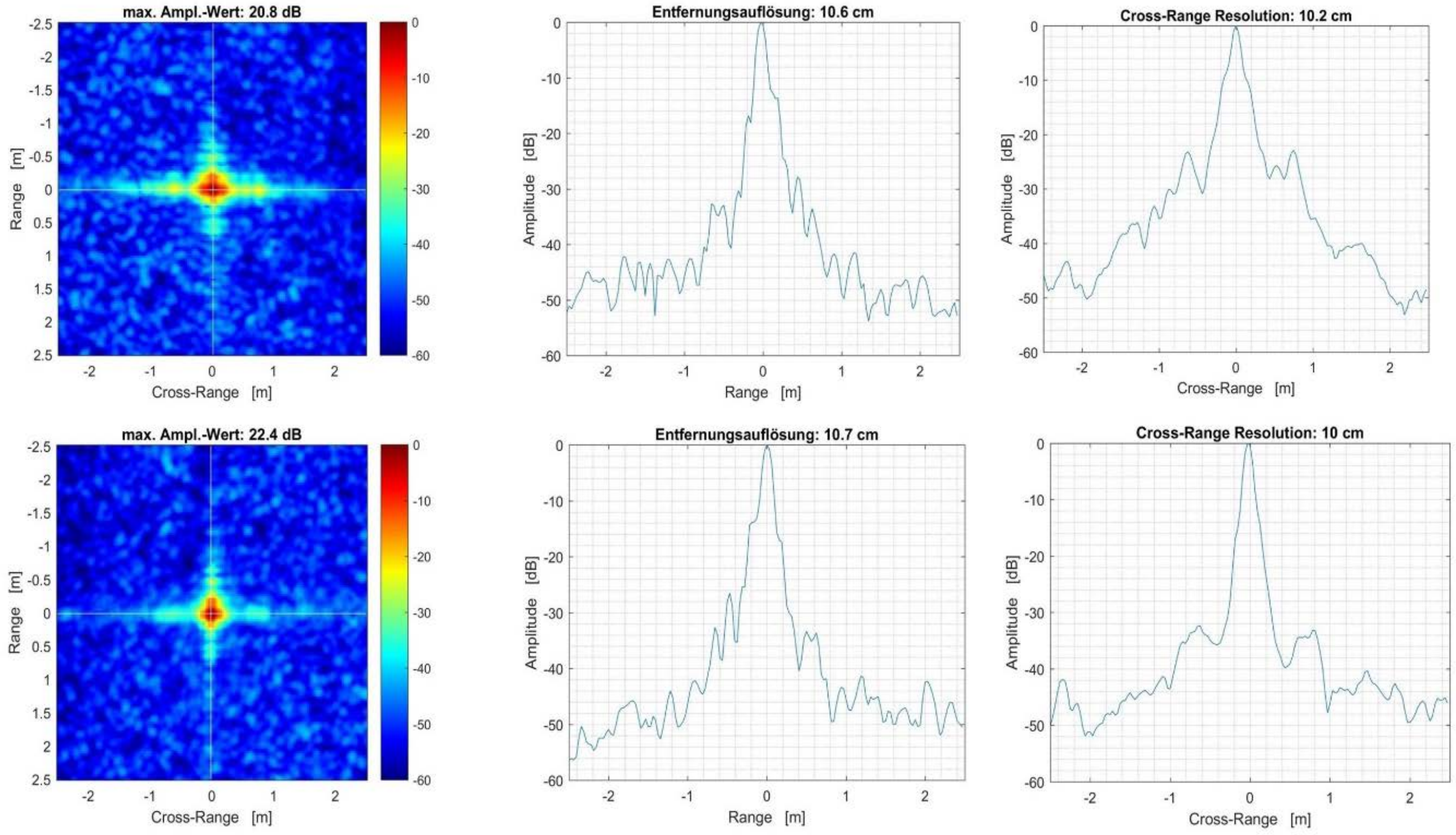


- Robustness improved by integrating MEMS IMU measurements.



RESULTS

SAR POINT TARGET RESPONSE USING EGO-MOTION FROM CAMERAS VS. REFERENCE FROM GNSS



RESULTS

SAR POINT TARGET RESPONSE USING EGO-MOTION FROM CAMERAS VS. REFERENCE FROM GNSS

	Max Amplitude Value			Range			Azimuth		
Datensatz	**VIS**	**SWIR**	**IGI-IMU**	**VIS**	**SWIR**	**IGI-IMU**	**VIS**	**SWIR**	**IGI-IMU**
D01	15.6 dB	15.3 dB	**19.5 dB**	10.9 cm	10.4 cm	**10.5 cm**	13.0 cm	17.3 cm	**11.1 cm**
A01	17.0 dB	20.8 dB	**22.4 dB**	11.3 cm	10.6 cm	**10.7 cm**	14.1 cm	10.2 cm	**10.0 cm**
B01	7.1 dB	10.9 dB	**15.6 dB**	11.3 cm	10.3 cm	**9.8 cm**	25.5 cm	15.0 cm	**10.9 cm**

- SWIR: Azimuth resolution varies between 10-40 cm
  - Typically several centimeters below the theoretical optimum of 10 cm
- VIS: Azimuth resolution is 2-15 cm lower than reference data
  - Target resolution between 10-25 cm is possible
- Maximum point target amplitude is 2-6 dB lower (SWIR) and 4-8 dB lower (VIS)
- Range resolution is not affected as expected