FIG WORKING WEEK 2025
AND Locate25 THE NATIONAL GEOSPATIAL CONFERENCE
Collaboration, Innovation and Resilience: Championing a Digital Generation
FIG Geospatial Council of Australia
Brisbane, Australia 6–10 April

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Future challenge in the calibration of high-resolution hydrographic multi-sensor systems

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High-resolution underwater instruments

Use in shallow water environments

Kongsberg (2024)

Acoustic	
	Kongsberg EM 2040P MKII
Beam width	≥ 0.6° (@ 700 kHz)
Number of pings	256
Swath width	100 – 120°(@600 kHz)

Fraunhofer IPM (2024)

Optical	
	Under water laserscanner (ULi)
Spatial Resolution	Depends to meas. configuration
Scan rate	100,000 Points/s
Opening angle	44 °

Calibration of a hydrographic multi-sensor system

Geo-referenced measurement data

$$\boldsymbol{x}^{nav}_{\text{meas}}(t_{sys}) = \boldsymbol{t}^{nav}_{b}(t_{sys}) + \mathbf{R}_{zyx}\left(\psi(t_{sys}), \theta(t_{sys}), \varphi(t_{sys})\right) \cdot \boldsymbol{x}^{b}_{\text{meas}}(t_{sys})$$

Determination of

$$\boldsymbol{x}^{b}_{\text{meas}}(t_{sys}) = \boldsymbol{t}^{b}_{sens} + \mathbf{R}(\Delta\psi^{b}_{sens}, \Delta\theta^{b}_{sens}, \Delta\varphi^{b}_{sens}) \cdot \boldsymbol{x}^{sens}_{meas}(t_{sync})$$

φ, θ, ψ – roll, pitch, heading

$\boldsymbol{t}^{nav}_{b}$ – translation vector

$\boldsymbol{x}^{sens}_{\text{meas}}$ – measurements (instrument related)

$\boldsymbol{x}^{b}_{\text{meas}}$ – measurements (platform related)

t_{sys} – time reference

$\boldsymbol{t}^{b}_{sens}$ - Sensor positions in the ship coordinate system (lever-arms)

$\Delta\varphi^{b}_{sens}, \Delta\theta^{b}_{sens}, \Delta\psi^{b}_{sens}$ - Installation angles (roll, pitch, yaw)

$t_{sync} = t + \Delta t$, Δt - latency

Component-wise calibration: Vessel survey

In-situ calibration: Patch-Test or MIBAC + LAAC

Workflow: Determination of lever-arms

Definition: Ship coordinate system $\mathbf{x}^b$

Concepts to handle challenges

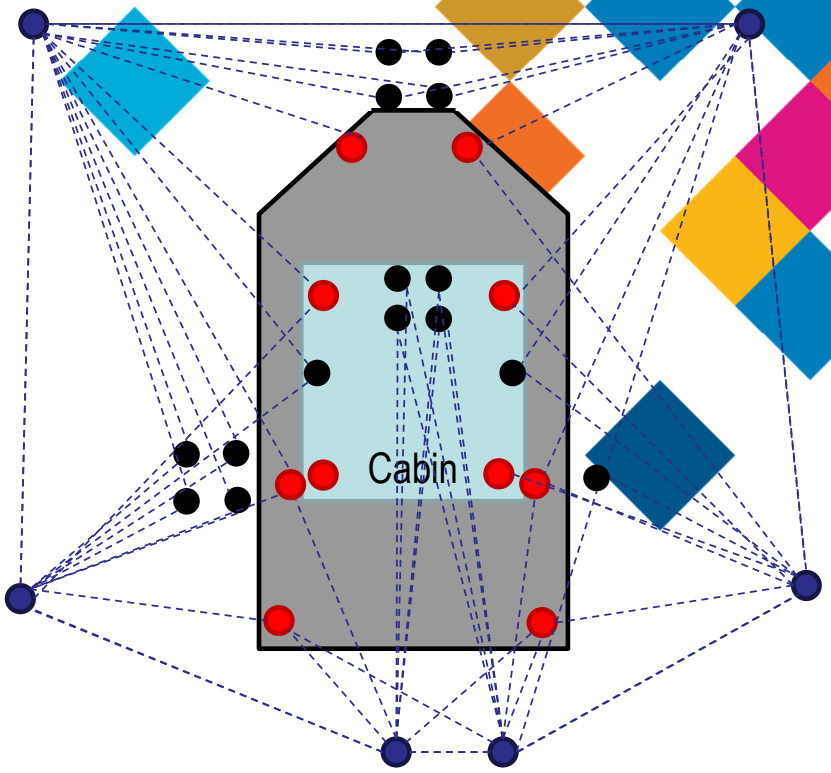
Calibration procedure

Survey set-up → Survey → Processing

Calibration parameters $\boldsymbol{t}^b_{sens}$
(+ initial $\Delta\psi^b_{sens}, \Delta\theta^b_{sens}, \Delta\varphi^b_{sens}$)

Calibration: Survey

- Objective: 3D accuracy ≤ 5 mm or even 0.5 mm (Brüggemann 2013)
- Use of a high-precision **total station (TS)** or a laser tracker (LT)
- Set-up of a geodetic network around the ship
  → clear line-of-sight to each sensor point from multiple instrument stations
  → measurements in both faces and multiple sets
- Defined fixed points on the ship
  ➔ transformation into ship coordinate system

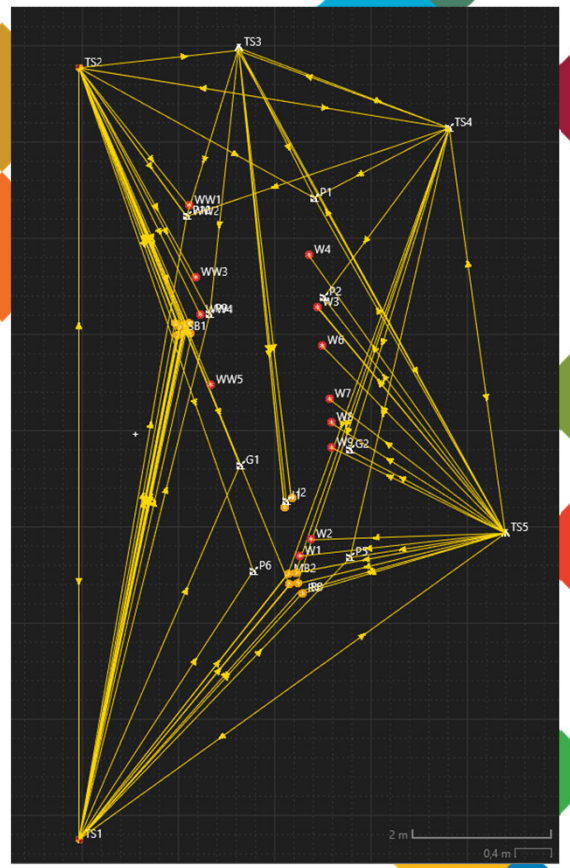


Processing

- Objective: Determination of the coordinates by network adjustment
  → requires elimination of outliers (e.g. instable points)
- Strategies: Depending to the measurement site
  → Constrained Adjustment
  → Free Adjustment: Control of fixed points

Challenges:

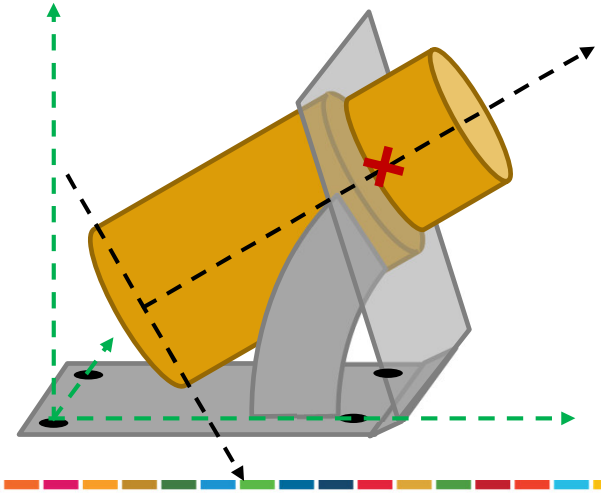
- Points which are difficult to access/hidden
- Instable points
- Limited space
- …



Software: Leica Infinity

Concept: ULi reference point

- ULi reference point inside the housing
  problem: no marked known points
- Idea: Calibration with adapter frame
  → four known points available (ship coordinate system)



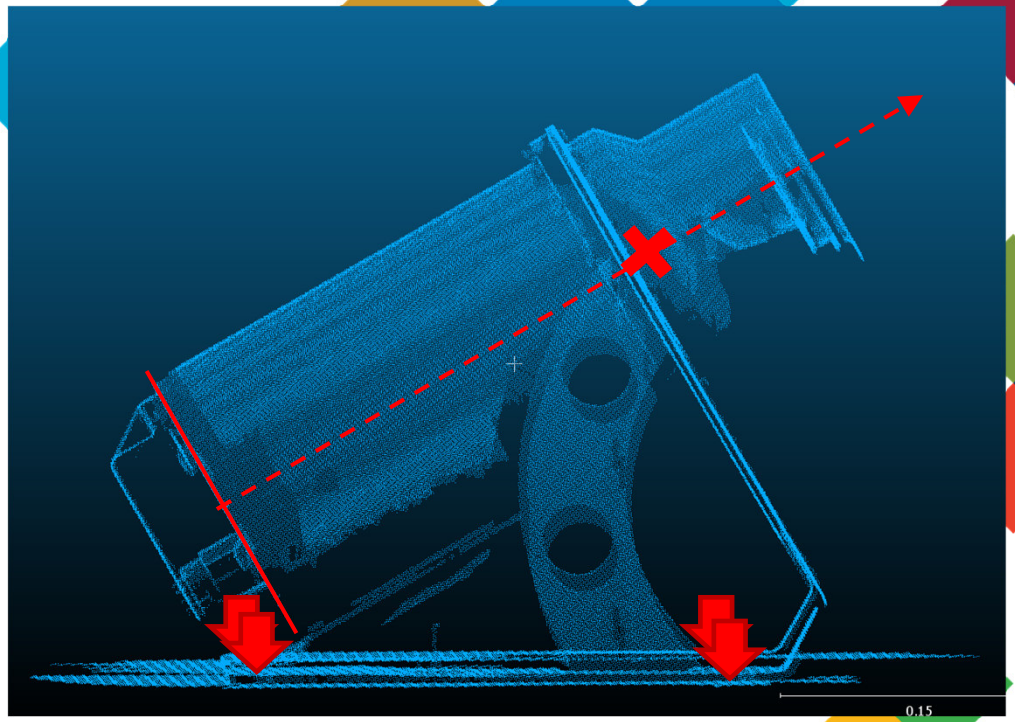
Concept: ULi reference point

Calibration with adapter frame

- Scan of the instrument and adapter frame
  → use of a high-precision scanner

  here: AS1 / Laser tracker AT960 (Hexagon)

- Determination of
  - the cylinder axis → Uli reference point
  - Screw fitting positions
    → known points in the ship coordinate system



Summary & Outlook

- Calibration of a hydrographic multi-sensor system is required regularly and if e.g.,
  - The instrument configuration has been changed
  - New Instruments are installed

  ➔ Efficient calibration procedure is required
- Determination of calibration parameters for a surveying vessel requires high-precision instruments (total station and/or laser tracker)
- Line-of-sight obstructions and limited space on the vessel require special concepts to acquire all measurement points with the required accuracy
- **Future:** Design and realization of a mobile underwater test field for shallow water applications
  → In-situ calibration

References

Brüggemann, T. (2013). Ingenieurgeodätische Fragestellungen bei der Einmessung von Vermessungsschiffen. In: Bundesanstalt für Gewässerkunde (ed.): Neue Entwicklungen in der Gewässervermessung. Colloquium on Nov. 21./22. 2012 in Koblenz, Germany, pp. 32-40, Veranstaltungen 5/2013, Koblenz, May 2013. DOI: 10.5675/BFG_Veranst_2013.5

Fraunhofer IPM (2024). Underwater LiDAR System Optical inspection of underwater infrastructure. URL: https://www.ipm.fraunhofer.de/de/gf/objekterfassung-laserscanning/anw/unterwasser-laserscanning/unterwasser-infrastruktur.html (last access 2025-03-29)

Kongsberg (2024). EM 2040P MKII – Multibeam Echo Sounder. URL: https://www.kongsberg.com/discovery/seafloor-mapping/em/EM2040P-MkII/ (last access 2025-03-29)

Thanks for your attention!

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The most relevant SDGs related to the presentation and theme of this session

1st relevant SDG

2nd relevant SDG

3rd relevant SDG

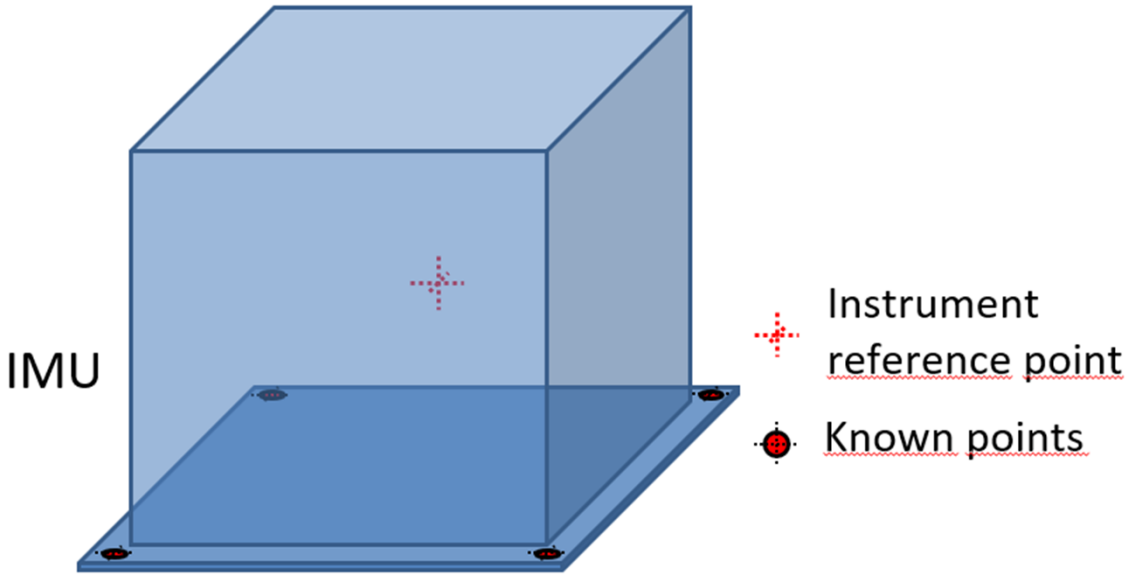
SUSTAINABLE DEVELOPMENT GOALS

International Federation of Surveyors supports the Sustainable Development Goals

STEP 1: SELECT HERE THE THREE MOST RELEVANT SDGs
STEP 2: COPY THE SDG INTO PREVIOUS SLIDE

Concept: IMU reference point

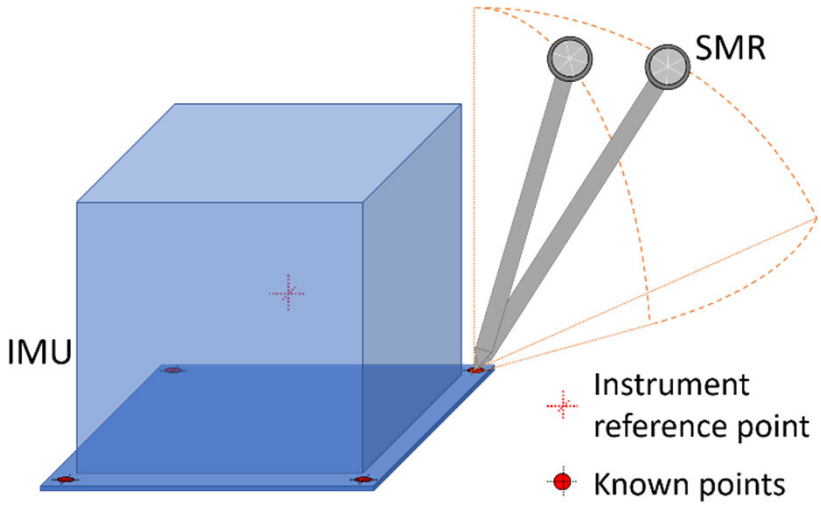
Reference point of the Inertial Measurement Unit (IMU) ➔ 3D coordinate transformation by using known points



Concept: IMU reference point

Concept 1

- Idea: SMR is located on a sphere‘s surface
  → sphere center represents the known point
- MonteCarlo Simulation: Requierements concerning
  - Number of points
  - Reflector type / accuracy



	Narrow sphere segment			Middle-sized sphere segment		
	20 points	**10 points**	**6 points**	**10 points**	**6 points**	**4 points**
SMR ($\sigma = 0{,}2$ mm)	21.8 mm	23.1 mm	30.3 mm	2.5 mm	2.9 mm	3.8 mm
Mini prism ($\sigma = 1$ mm)	36.9 mm	38.7 mm	49.2 mm	4.0 mm	4.5 mm	6.0 mm

Concept: IMU reference point

Concept 2:

- Design of a attachable frame with 4 spherical mounted reflectors (SMR)
  → calibrated with respect to the instrument reference point

- Advantage: extended plane
  → less prone to outliers
  → only four measurement points