Photogrammetry and traditional bathymetry for high-resolution underwater mapping in shallow waters

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Aims

Accurately mapping submerged areas is crucial for several reasons (e.g., environmental monitoring and water resource management):

- **Traditional techniques** (e.g., traditional topographic survey, acoustic soundings) face challenges with spatial continuity.
- **UAV-based photogrammetry** is a powerful tool for shallow waters, but it underestimates true depths due to light refraction at the air-water interface.

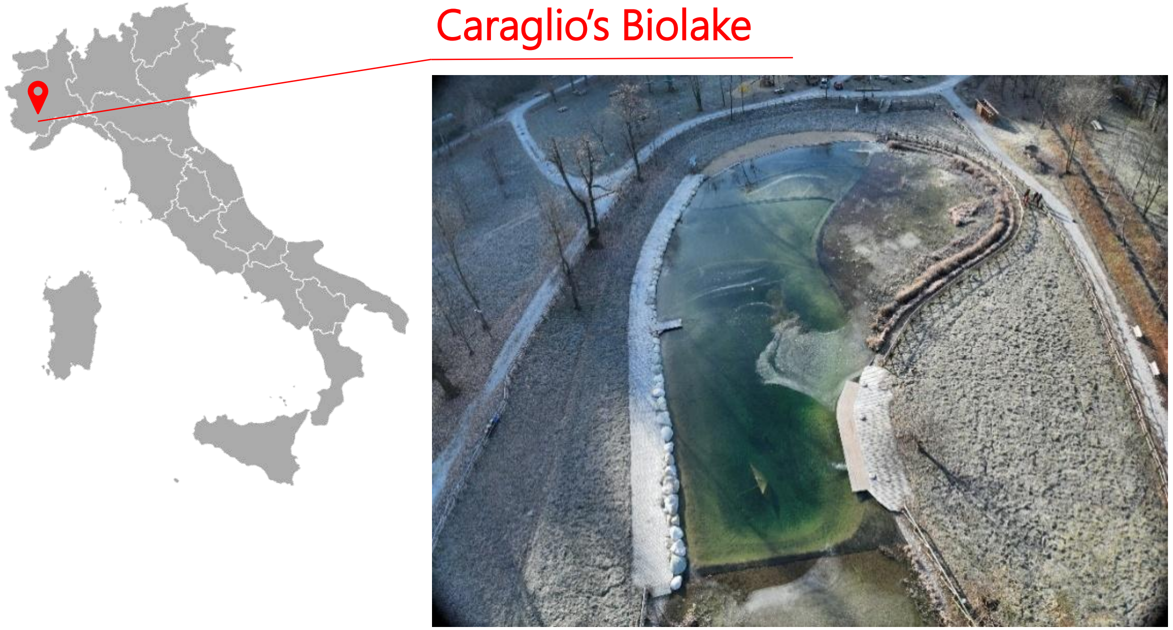
Our Objective:

To *propose* and *evaluate* a *multi-sensor workflow* that integrates the strengths of traditional techniques and UAV-based methods to produce an *accurate* and *high-resolution bathymetric model* in clear shallow water.

Case Study

Caraglio's Biolake, Piedmont, Italy ~4000 m^2

- Artificial ecosystem that simulates a natural environment;
- **Natural water purification system** that utilizes plants and gravel instead of traditional chemical treatments;
- **Clear water, minimal surface waves, no surface reflections**.



Data Acquisition

Traditional Topographic Survey

GNSS receiver: Leica System 1200
Total Station: Leica Nova MS60

- Topographic network for **models georeferencing (GCPs)**
- **Reference data** for validation and model comparisons.

Single-Beam Echo Sounder on USV

USV: Bluerobotics BlueBoat
Ecosounder: STX-Echos, Stonex

- **Direct depth measurements** along predefined trajectories
- *Depth Range*: 0.2-200 m
- σ_{XY}: 8mm, σ_{Z}: 15 mm
- *Acquisition angle*: 8°

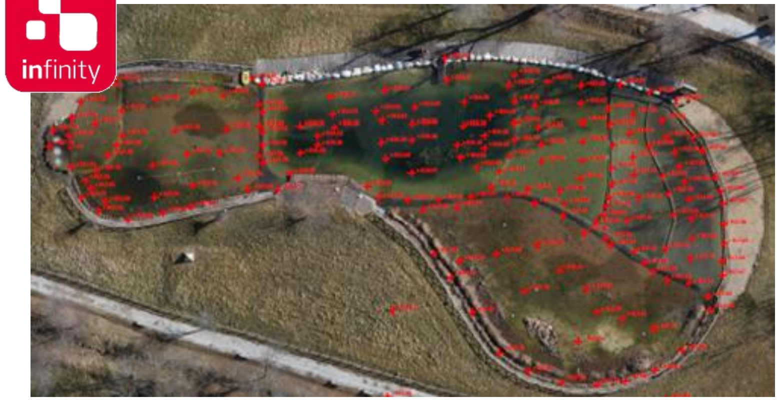
UAV Photogrammetric Survey

UAV: DJI Matrice 300 RTK + Zenmuse P1

- *Flight altitude*: 40 m
- *GSD average*: 7mm
- *N. images*: 700

Data Post-Processing

Traditional Topographic Survey



Accuracy (XY)	Accuracy (Z)	Coverage
≤ 5 mm (vertices) ± 1 cm (detail)	≤ 1 cm (vertices) ± 2 cm (detail)	Discrete points (370 points)

✓Accurate water depth measurement

✕Smart planning acquisition, time-consuming and not suitable for an extensive area

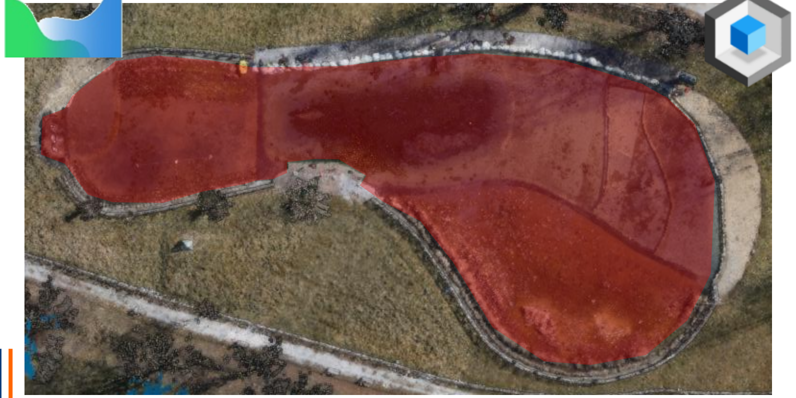
Single-Beam Echo Sounder on USV

Accuracy (XY)	Accuracy (Z)	Coverage
± 2 cm, depends on GNSS on USV	± 2 cm	Discrete lines (3.000 points)

✓ Direct depth measurements, independent of water conditions

✕ Limited spatial linear profile resolution, depth-dependent

UAV Photogrammetric Survey

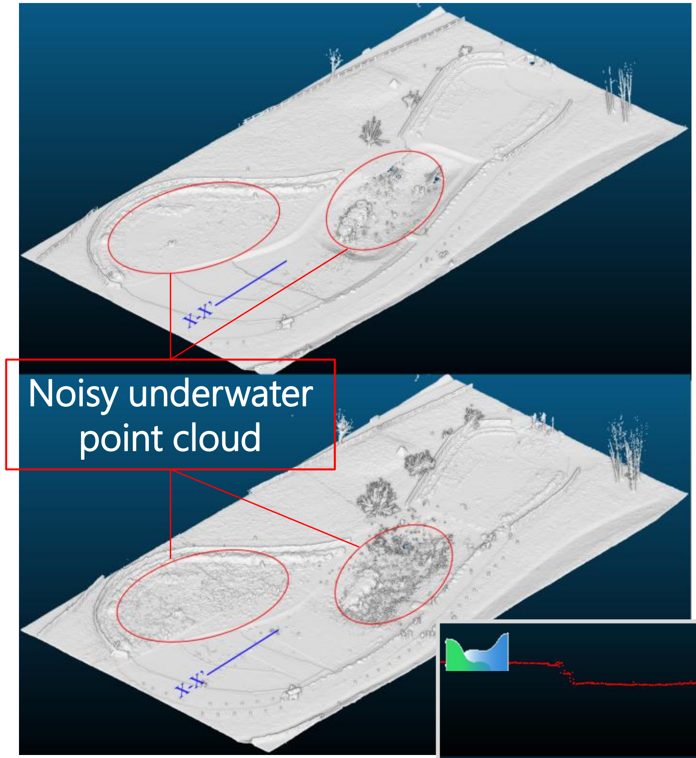


Accuracy (XY)	Accuracy (Z)	Coverage
± 2 cm 7 mm average GSD	Underestimation function of depths (pre-correction)	Continuous, high-resolution (800.000 point, one each 5 cm)

✕ Requires favorable environmental conditions, needs refraction correction processing

Refraction Correction – Dietrich, 2017

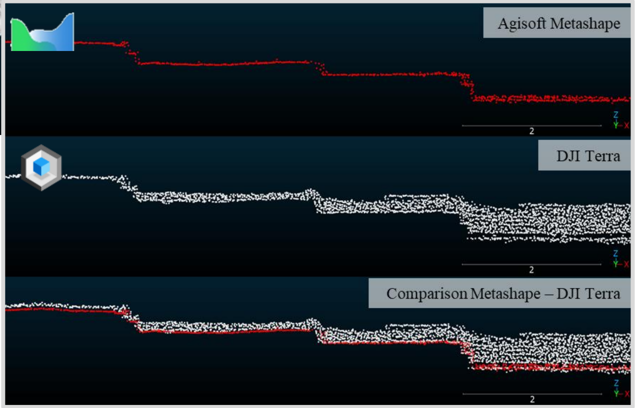
Software Comparison



Metashape

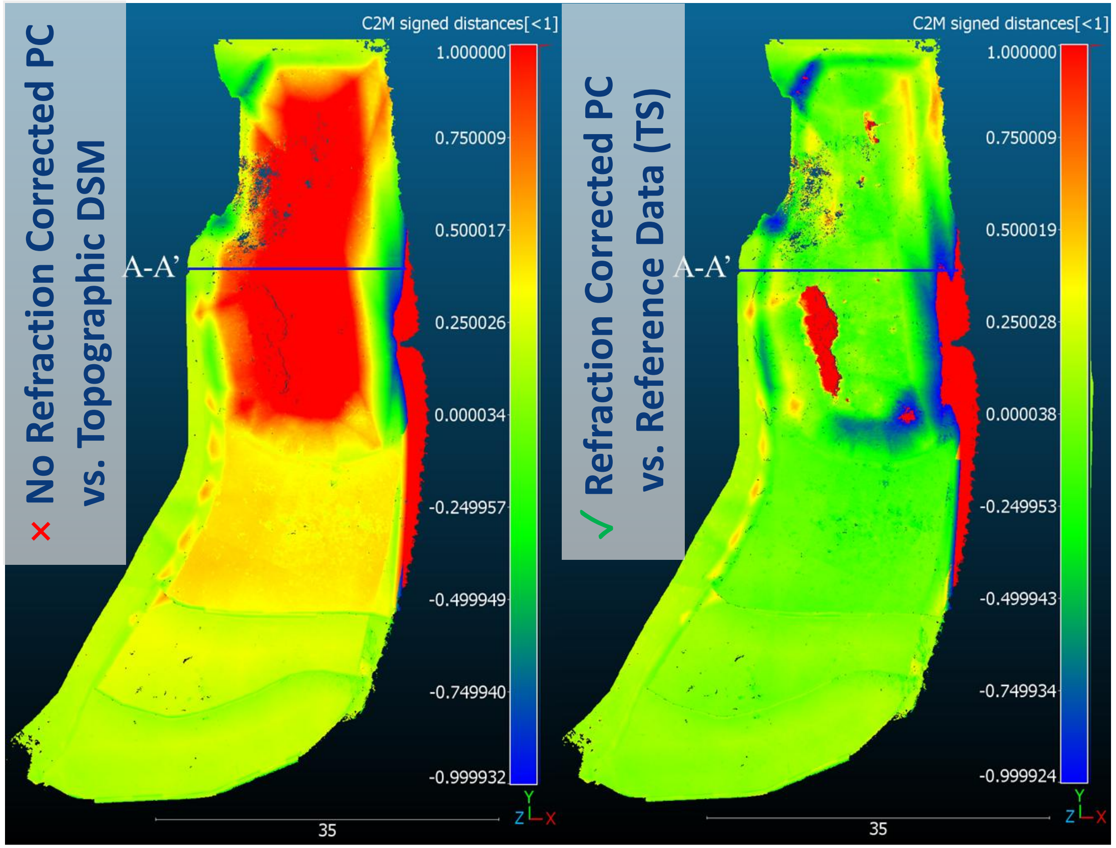
VS

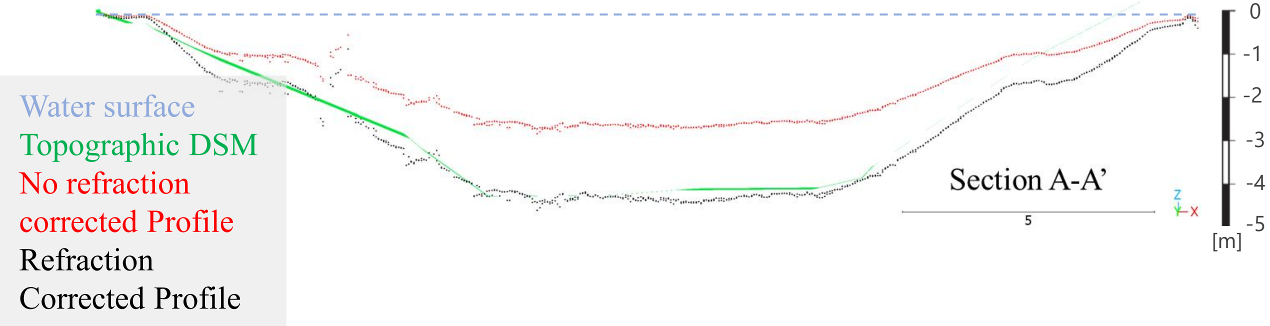
DJI TERRA



Section X-X'

Cloud-to-Cloud analysis





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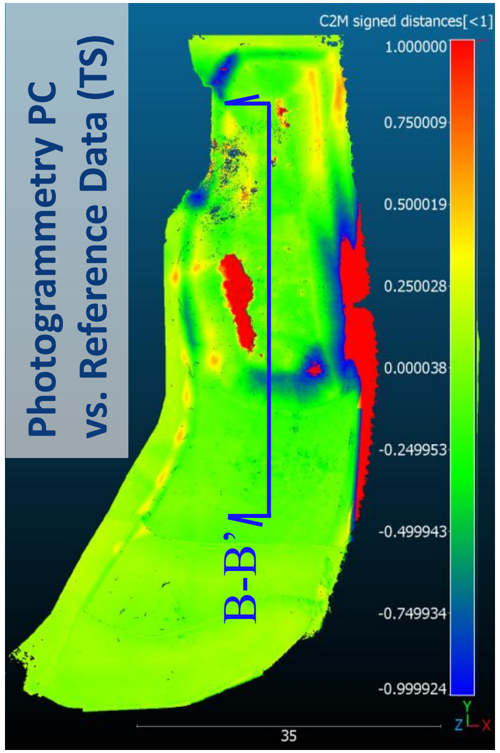
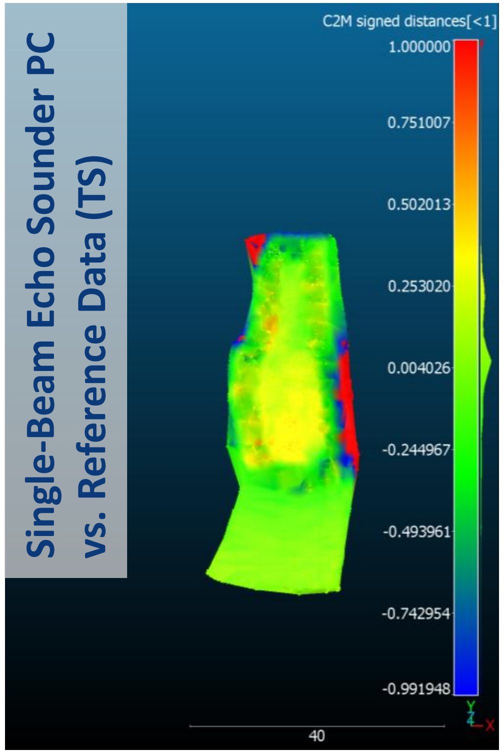
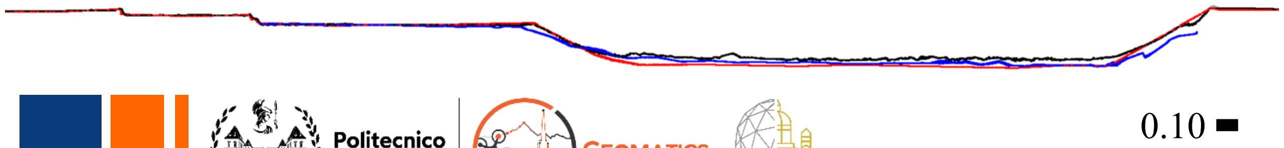
Data Validation & Comparisons





Topographic DSM survey
Single Beam-UVS DSM
Photogrammetric DSM-
Refraction Corrected

Section B-B'



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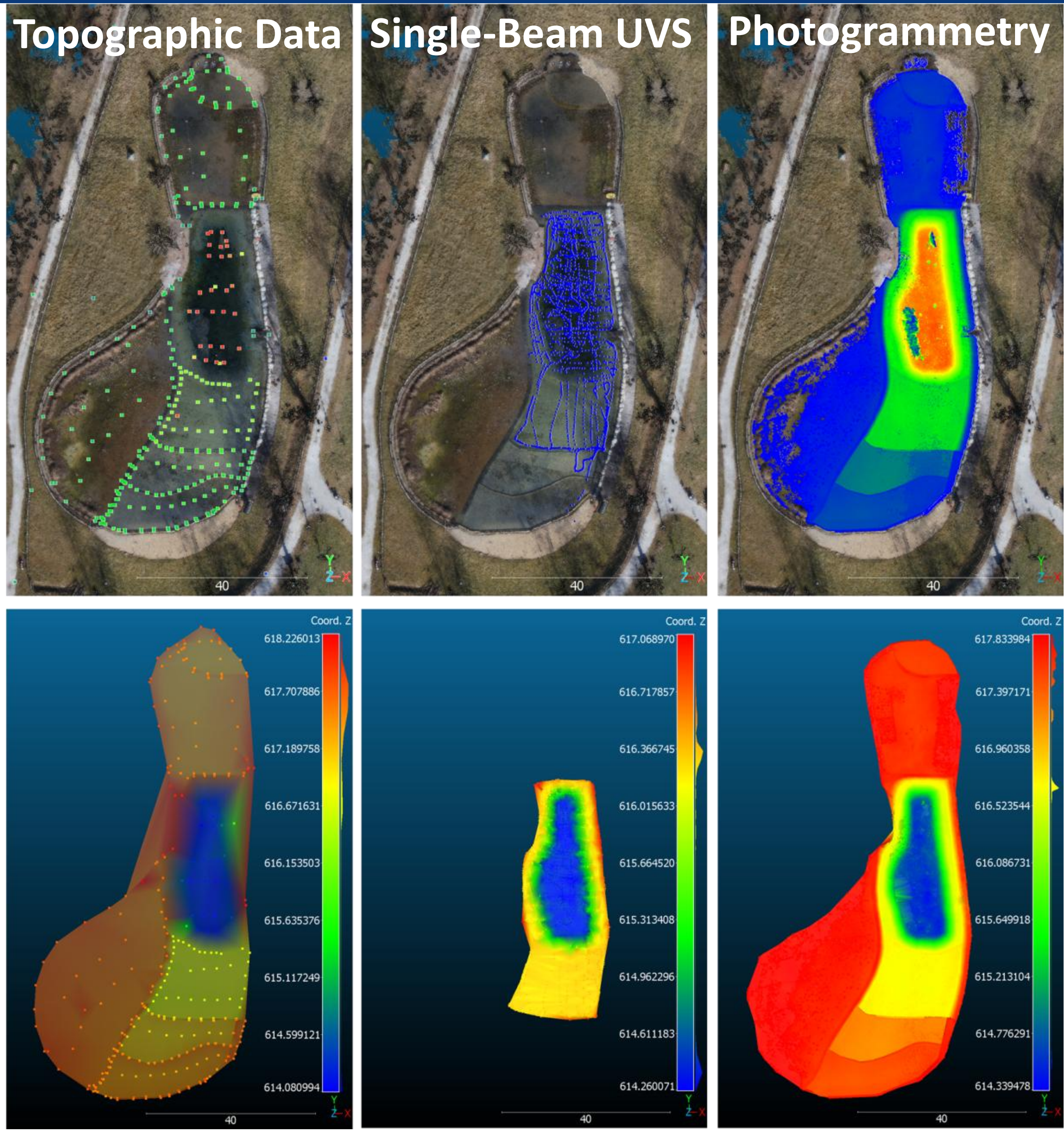
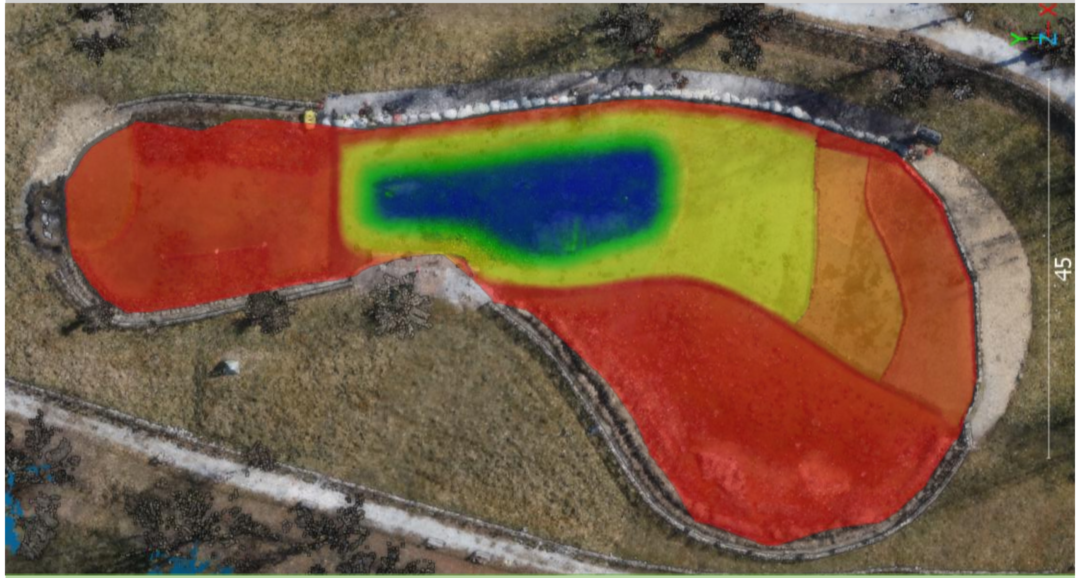


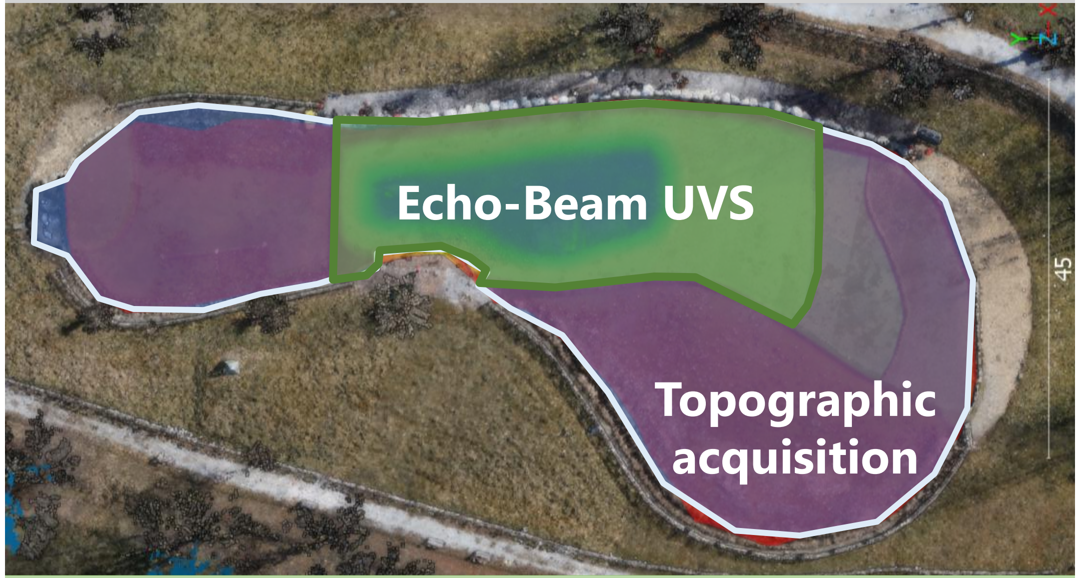
Data Fusion

Clear shallow water – Optimal condition



Continuous High-Resolution Model

High Turbidity condition



Interpolated Model from Point and Lines

✓**Photogrammetry bathymetry** reconstruction – refraction corrected with an accuracy of 5 cm.

✓ **Topographic acquisition** for water surface reconstruction and data validation.

✓ **Topographic acquisition** for very shallow and flat water surface reconstruction with easily achievable accuracy of 1-2 cm.

✓**Echo-beam USV** for deeper and slope changes, water bathymetry reconstruction with an accuracy of 2-3 cm.

Conclusion

The integrated multi-sensor approach is an **effective**, **robust**, and **accurate solution** for mapping shallow lacustrine environments.

- The final model achieved an **RMSE of 4 cm**, meeting the accuracy standards for a **1:200 representation scale**.
- The methodology **overcomes the limitations of individual methods**, optimizing coverage, density, accuracy, and operational efficiency.
- The **operational range** of bathymetry reconstruction using **UAV photogrammetry** was successfully extended to **depths of 4-5 meters** in optimal clear water conditions.

Future steps

- **Adaptive Data Fusion** to dynamically assign reliability weights to topographic, single-beam, and photogrammetric data based on local conditions, ensuring a more robust final model.
- Test other **Refraction Correction methods** to predict and correct refraction effects;
- **Seabed Classification** utilizes high-resolution photogrammetric data, enriching the bathymetric model with valuable thematic information.
- Validation in **Complex Scenarios**, alpine lakes, fluvial or coastal application.

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Thanks!

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