Natural surface floaters in image-based river surface velocimetry

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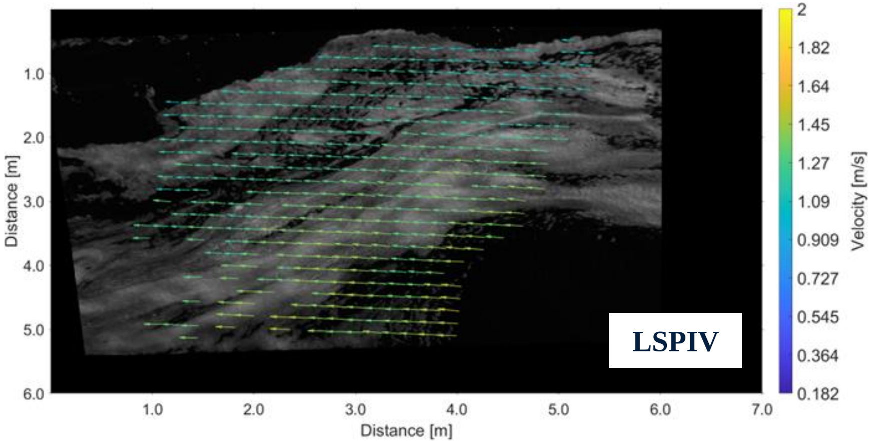
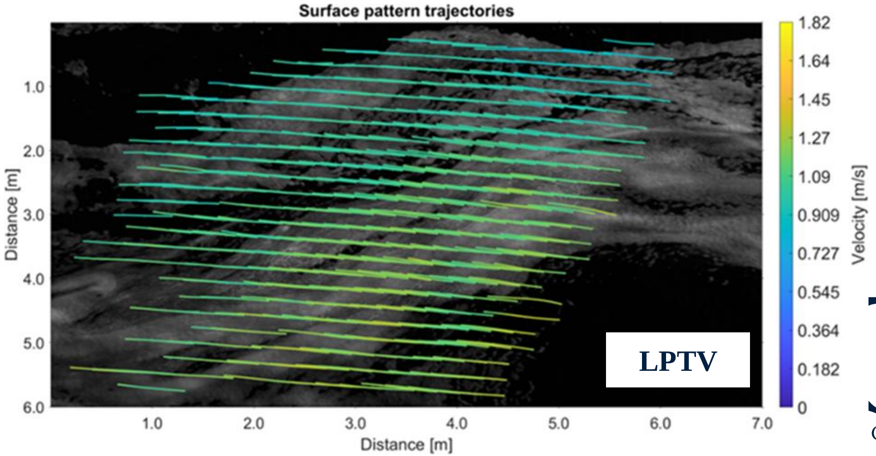
Background

Significance of stream velocity measurement

- Provides actual data
- Forms the basis for forecasting and validates forecasting model
- Essential for immediate decisions
- Current conditions assessment
- Optimizing hydropower plant efficiency and power output calculations
- …..

Water surface particles and surface velocity measurement





- Lagrangian Pattern Tracking Velocimetry (LPTV)
- Large-scale Particle Image Velocimetry (LSPIV)

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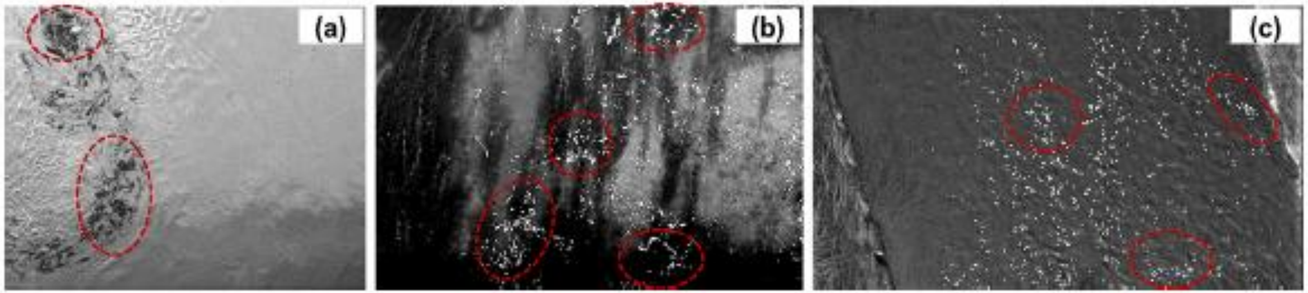
Background

- Optical sensing technique (photogrammetry) for stream surface velocities
- Optical surface velocimetry tracks movement of water surface features, strong influence of tracer characteristics



Natural seeding **Artificial seeding** **Artificial seeding**

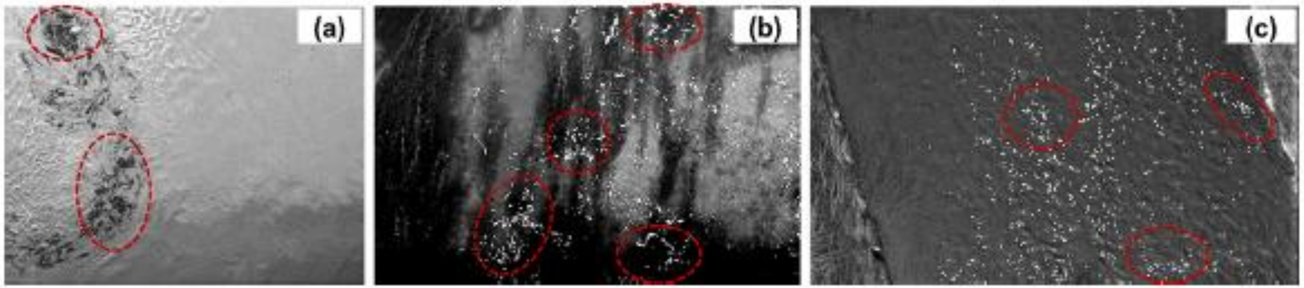
Moving and clustering structures on the water surface

- Feature inconsistency (variable sizes and shapes)
- Temporal intermittency (features appear/disappear)
- Spatial variability (uneven distribution)

Tauro, F., Piscopia, R., and Grimaldi, S.: Streamflow Observations From Cameras: Large-Scale Particle Image Velocimetry or Particle Tracking Velocimetry?, Water Resour. Res., 53, 10374–10394, 2017.
Detert, M., Johnson, E. D., and Weitbrecht, V.: Proof-of-concept low-cost and non-contact synoptic airborne river flow measurements, Int. J. Remote Sens., 38, 2780–2807, https://doi.org/10.1080/01431161.2017.1294782, 2017.

Research goals

- Validate optical approaches for river surface measurements
- Understanding how tracer properties affect measurement accuracy
- Evaluating effective natural surface features :
    - Image characteristic analysis
    - Algorithm performance assessment



Natural seeding **Artificial seeding** **Artificial seeding**

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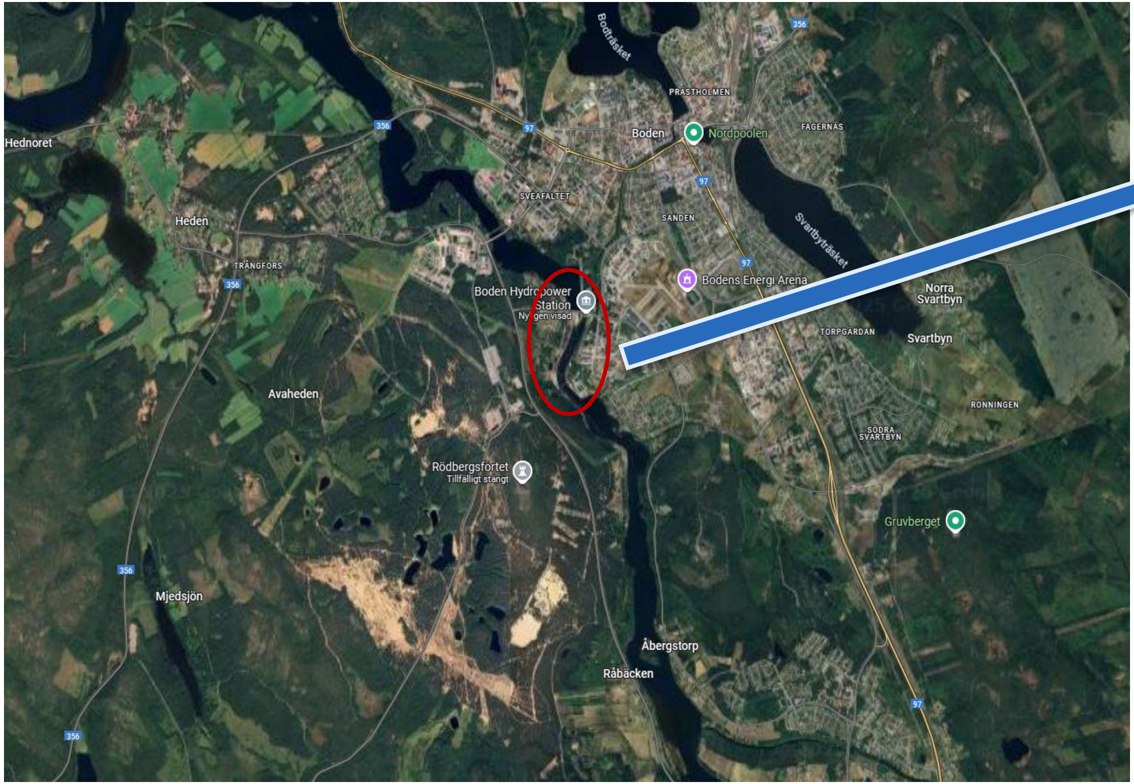
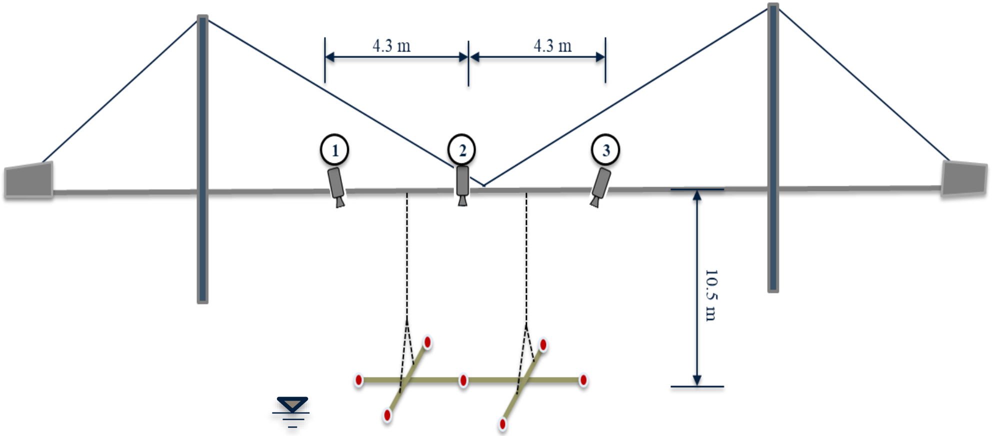
Measurement in Lule river

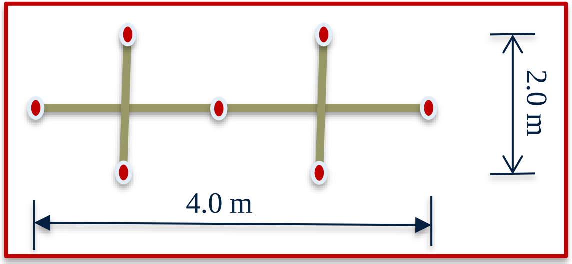


Measurement campaign—Svedjebron, Boden, Sweden (Google maps)

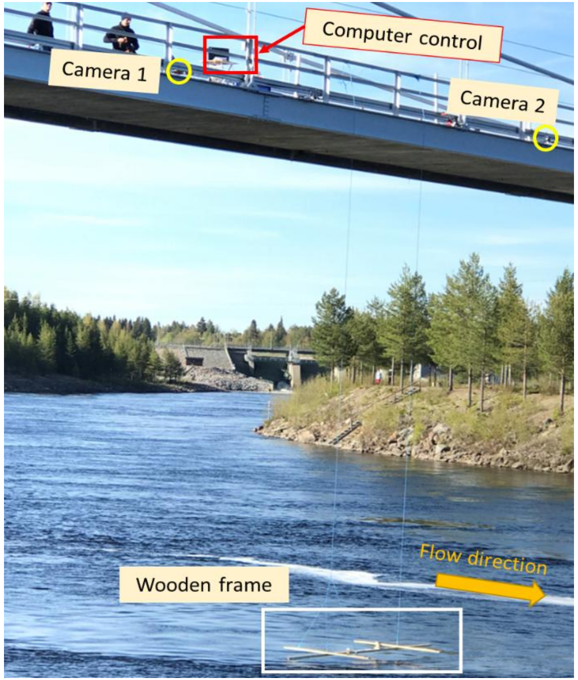
Measurement in Lule river: data collection

Measurement setup





Reference frame
with control points



Measure surface velocity from
a stationary camera system

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Measurement in Lule river: natural surface patterns

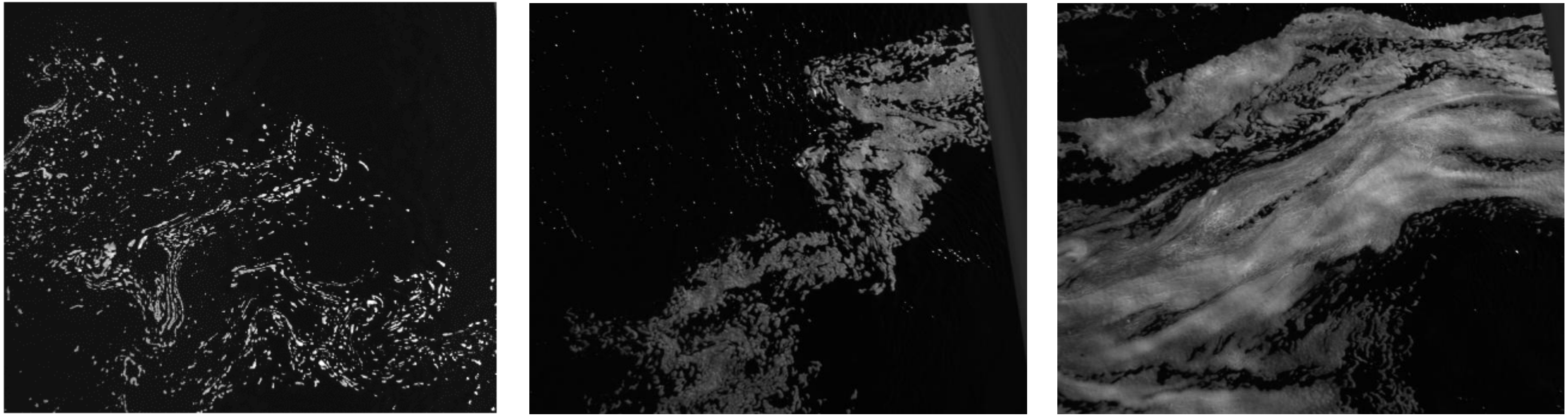

Image analyses → 3D velocity field using all cameras in the system
2D velocity field using orthorectified images of single camera

Surface pattern analyses → Surface pattern and uncertainty of measured velocity

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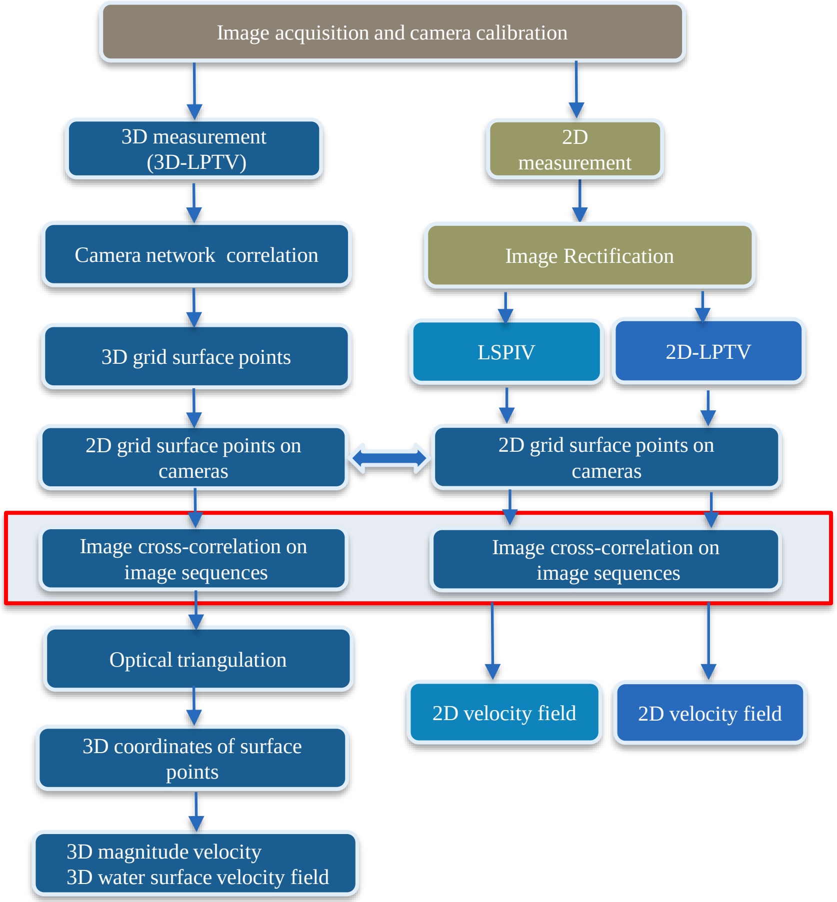
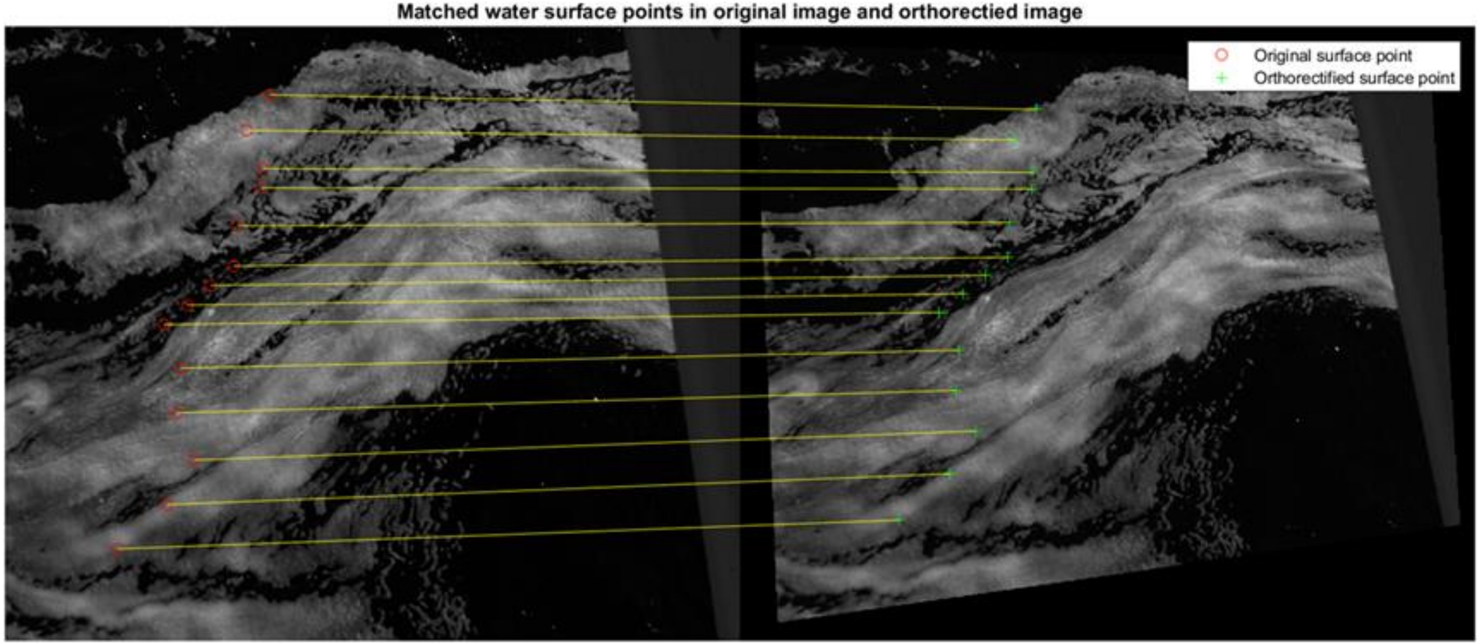
Image processing framework for 3D and 2D surface velocity measurements



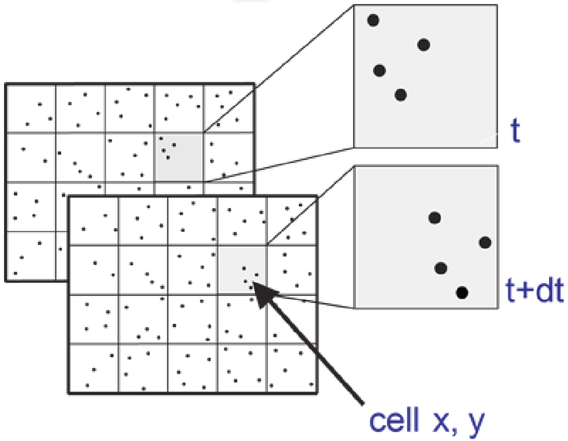
Single camera

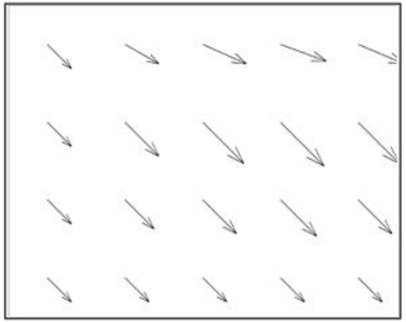
Calibrated-image orthorectification (2D-PTV and LSPIV)

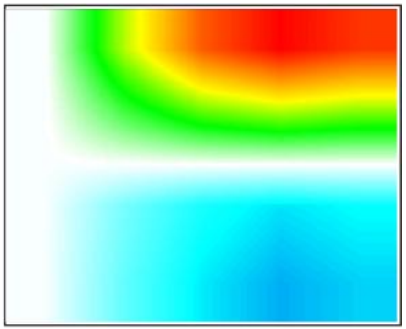


An example of corresponding river surface points in original image (left) and orthorectified image (right)

Image correlation to velocity of surface features

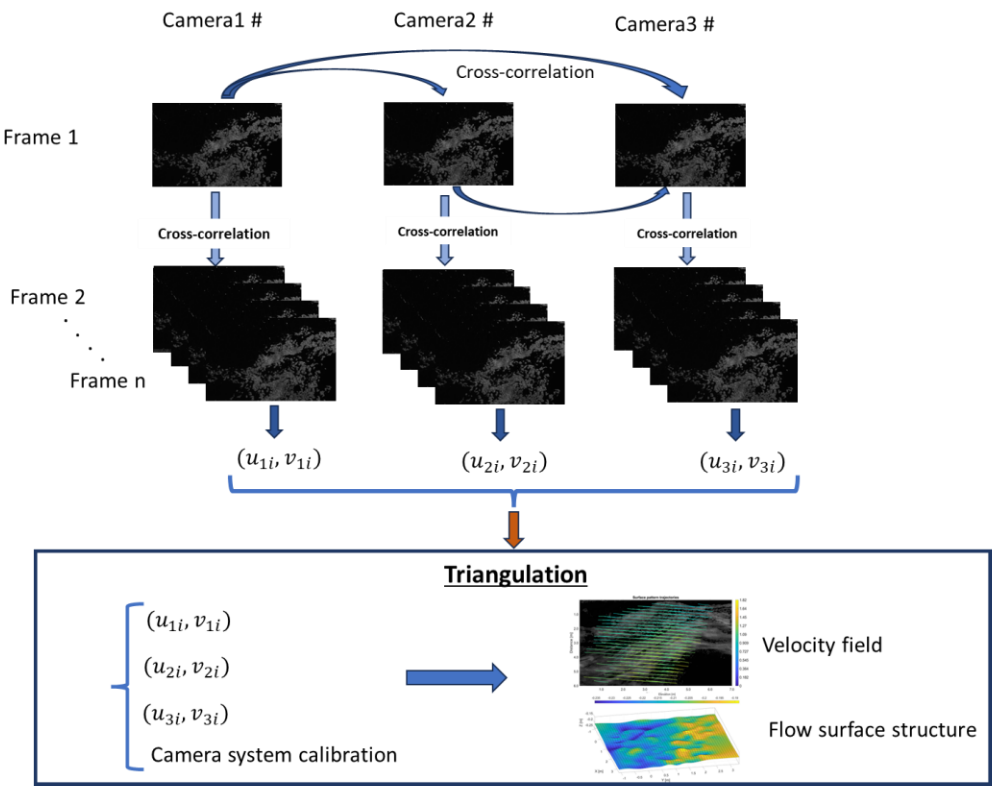






Multiple cameras

Image processing procedure



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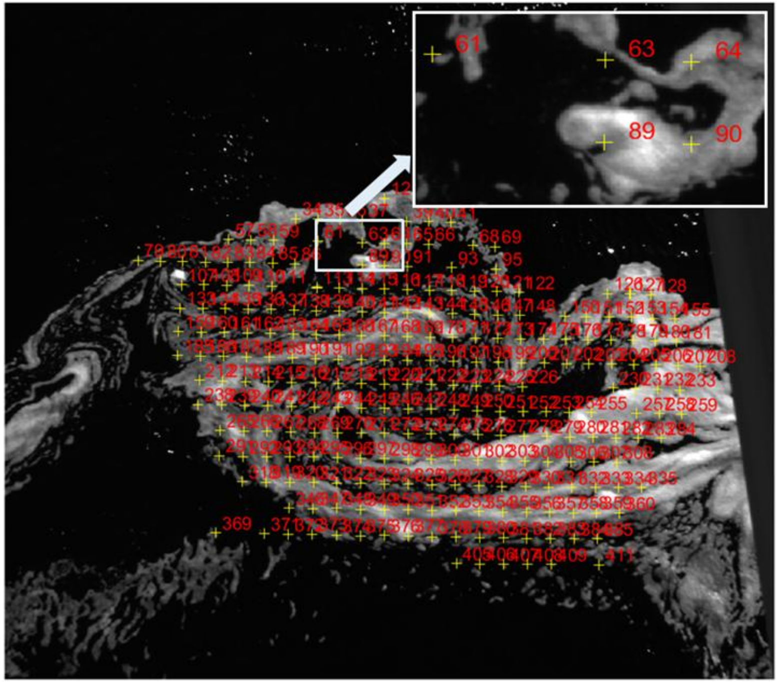
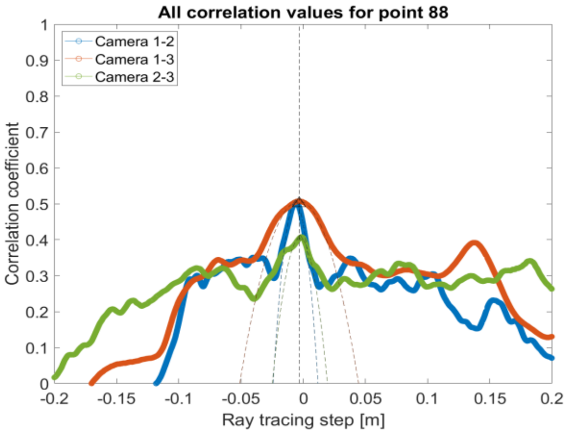
Multiple cameras

Camera network correlation and define grid surface: <u>3D measurement</u>

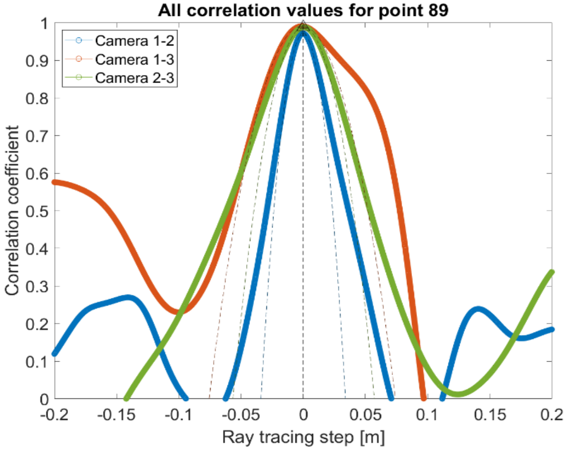


3D water surface points estimated by camera network correlation

Invalid surface point

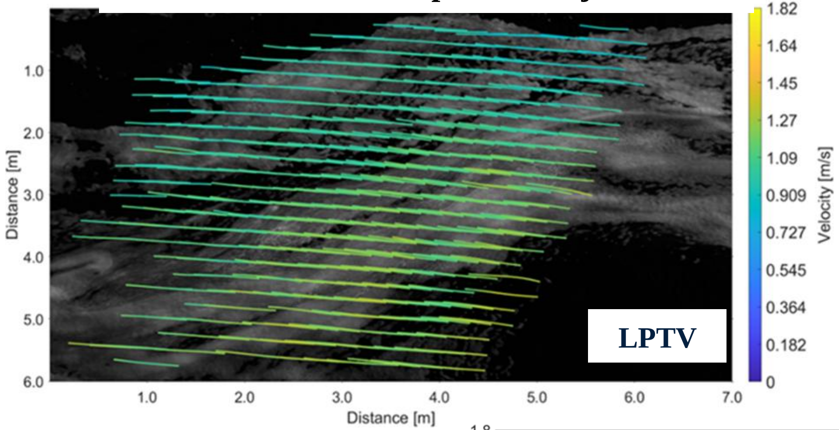


Valid surface point

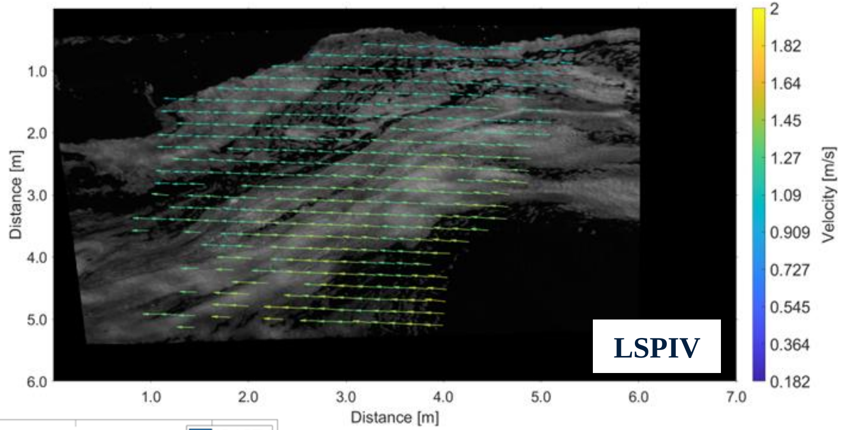


Results: surface velocity

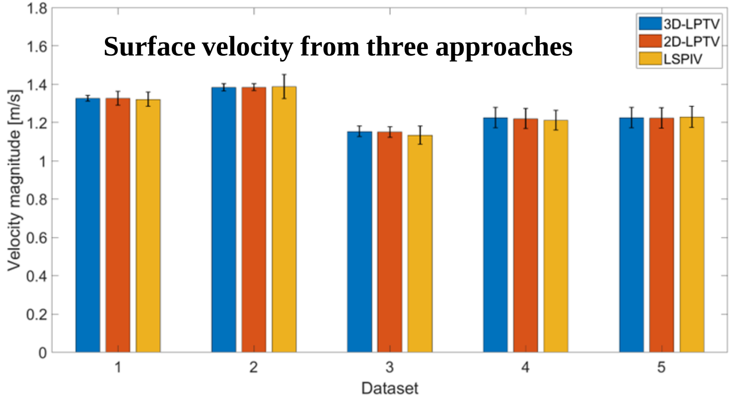
Reconstructed surface pattern trajectories



Water surface velocity field

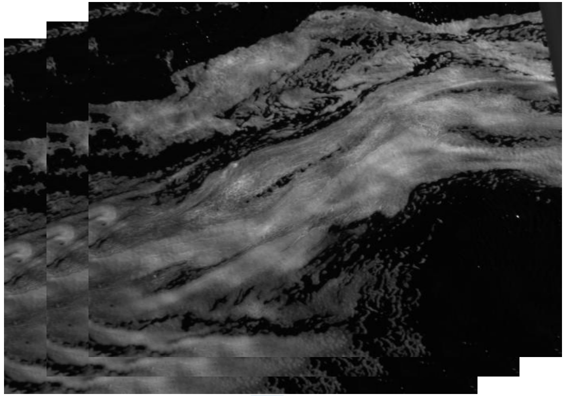


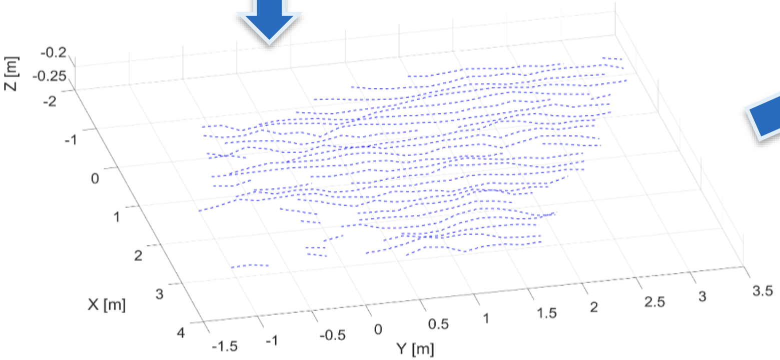
Surface velocity from three approaches

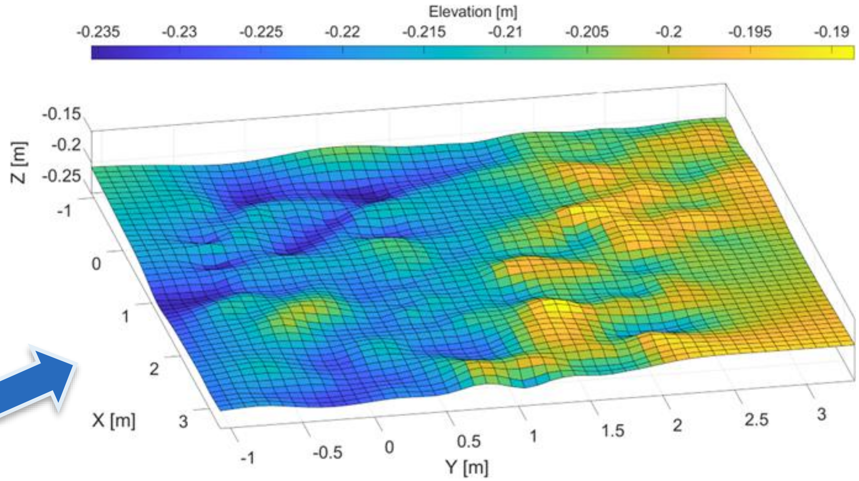


Average measured velocity and standard deviation from five datasets

Results: Multiple cameras - River surface reconstruction







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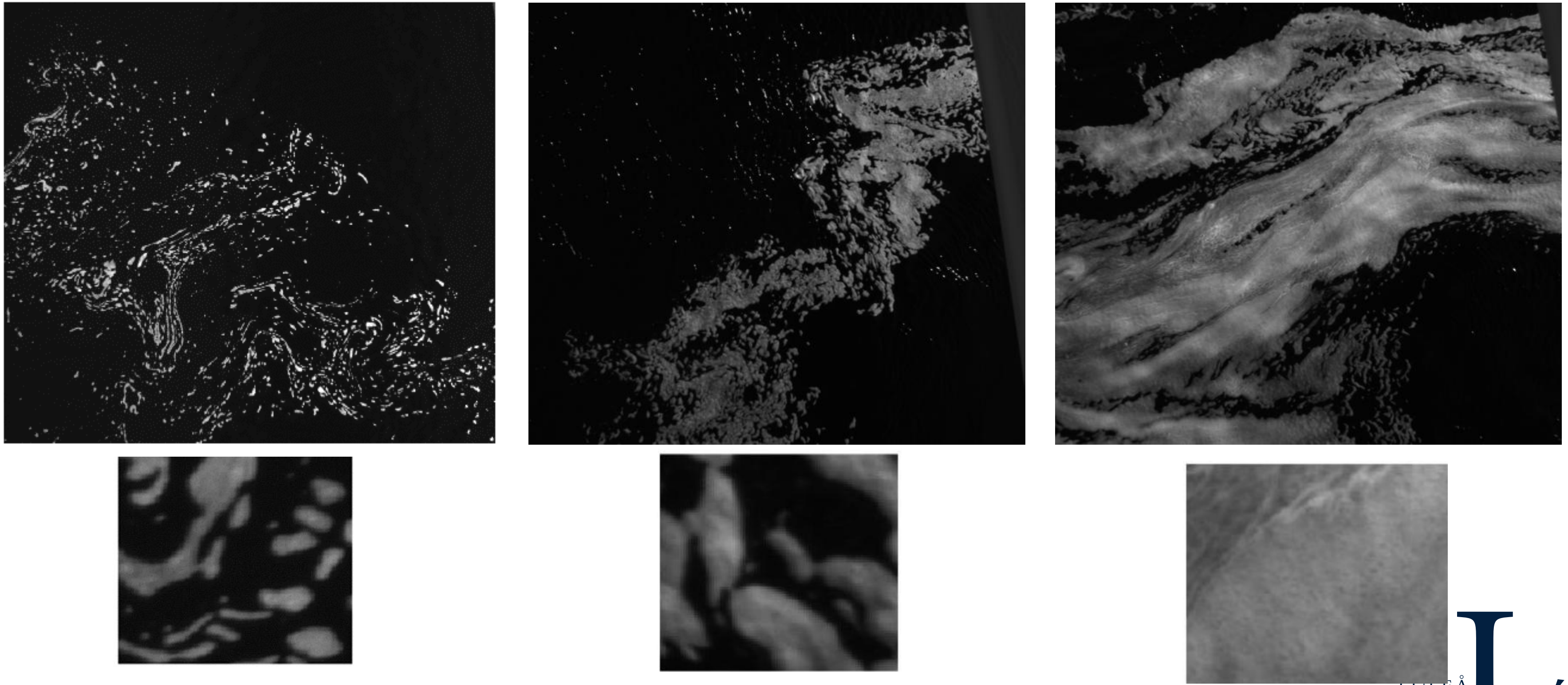
Results: Surface pattern and uncertainty of measured velocity



Lule river: natural surface patterns

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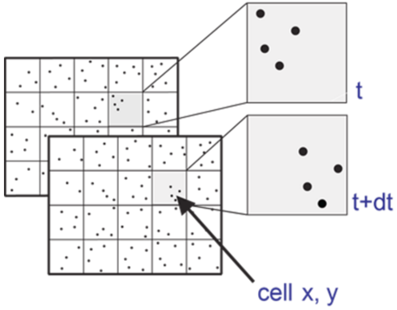
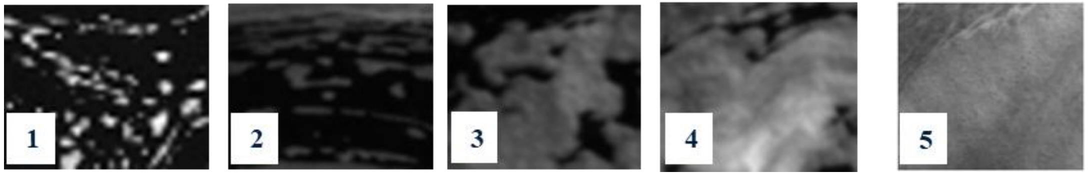
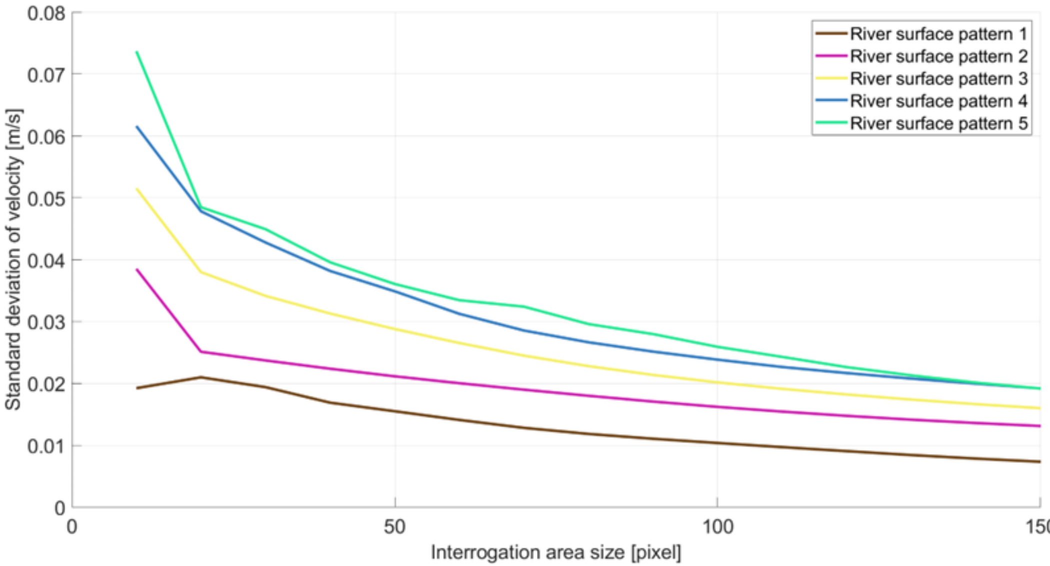
Results: Standard deviation of measured velocities for five datasets vs. interrogation area sizes

- Interrogation area size:
  - Search window used to track surface patterns
  - Defines area for pattern matching between image pairs





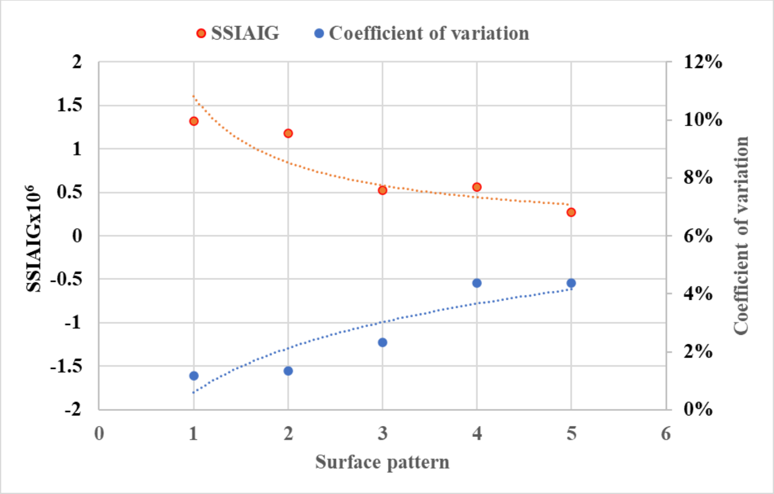


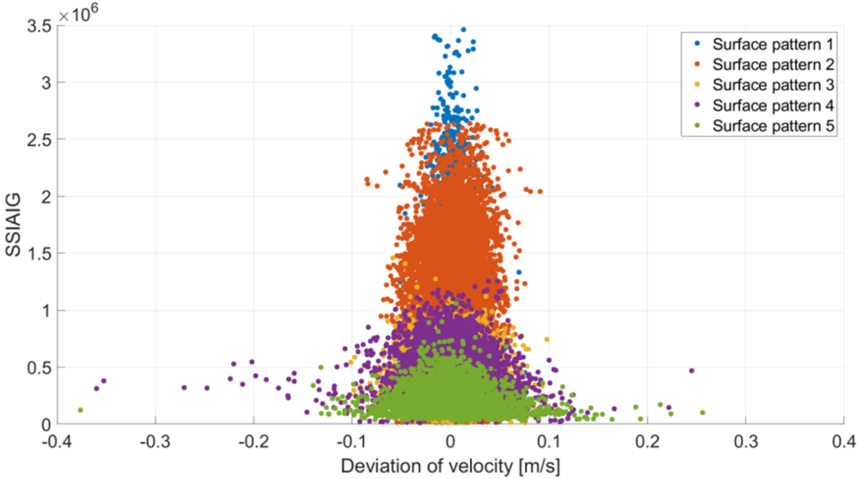
Results: Image intensity gradient and uncertainty of measured velocity

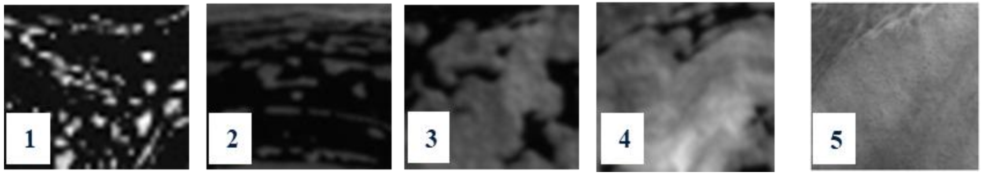
Sum of square of interrogation area intensity gradient (SSIAIG)

$$SSIAIG = \sum\sum|\nabla G(x,y)|^2$$

where $|\nabla G(x,y)| = \sqrt{G_x^2 + G_y^2}$, with G_x and G_y are the local intensity gradient in interrogation area in x and y direction, respectively.







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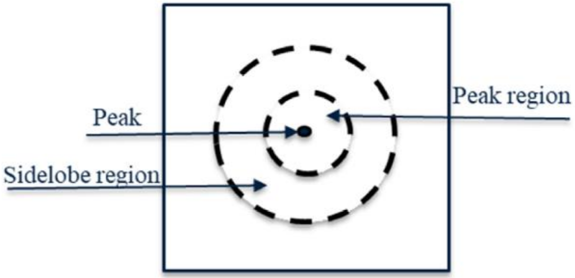
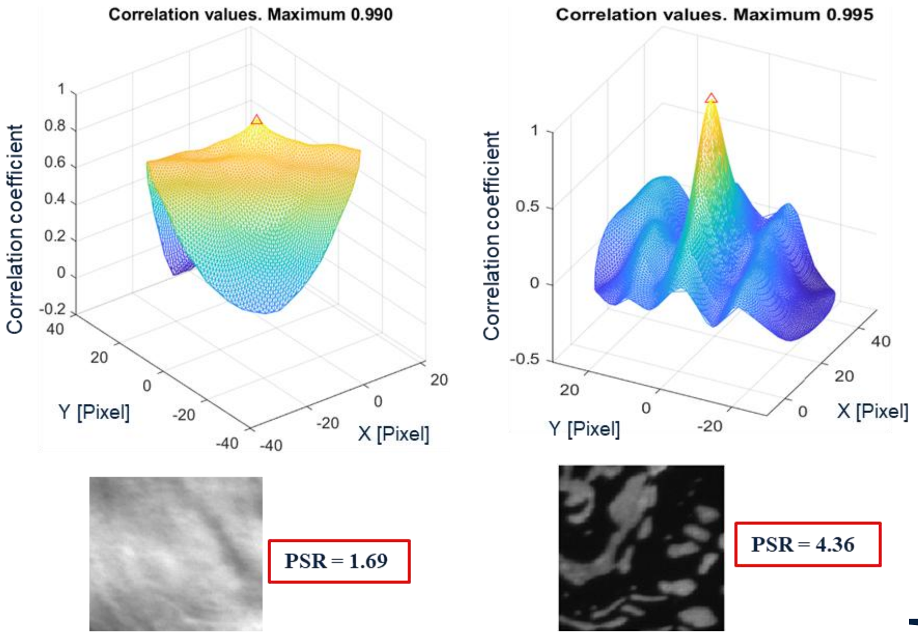
Results: Peak to sidelobe ratio (PSR) of cross-correlation map

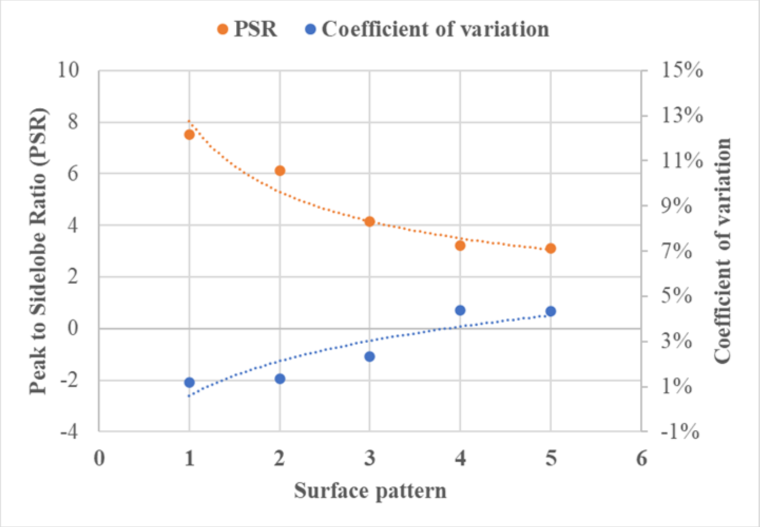


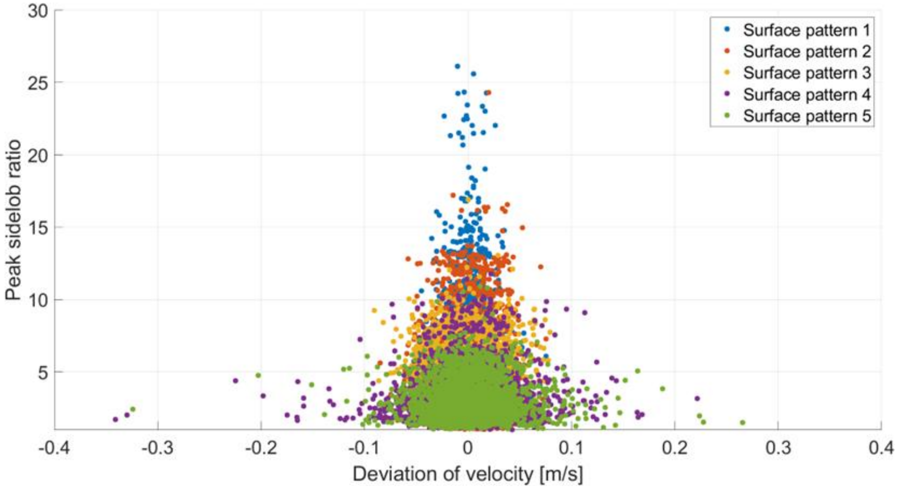
$$PSR = \frac{peak - mean}{standard\ deviation}$$

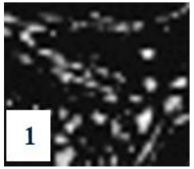


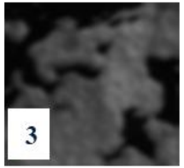
Visualization of cross-correlation map corresponding to two interrogation areas of surface patterns and their PSR values

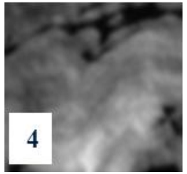
Results: Peak to sidelobe ratio of cross-correlation map and uncertainty of measured velocity

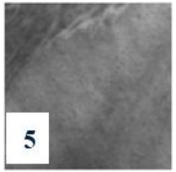












Summary

- **Multiple-camera system successfully tracks intermittent surface patterns**

  - All methods (3D-LPTV, 2D-LPTV, LSPIV) show good velocity agreement

  - 3D approach enables surface reconstruction and water level monitoring

- **Water surface feature analysis**

  - Small, evenly distributed features yield higher precision

  - SSIAIG and PSR metrics: Assess surface feature quality and optimize analysis parameters

- **Contact: hang.trieu@ltu.se**

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