Hydraulics and Drones: Observations of water level, bathymetry and water velocity from UAVs

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Hydraulic variables

- **Water level** [m]: water surface elevation above mean sea level (m.s.l.)
- **Bathymetry** [m]: riverbed elevation above m.s.l.
- **Water depth** [m]: water surface elevation above the riverbed
- **Velocity** [m/s]: speed varies along, across the river course and throughout water depth
- **Discharge** [m³/s]: it is generally derived from depth-integrated water speed profiles and water depth.

Hydraulic observations are used to inform open-channel hydrodynamic models.
Platforms

a) multirotor rotary wing (DJI S900): maximum take-off weight 8.2 kg, maximum payload of ca. 2 kg, and a wingspan of ca. 1 m.

b) Hybrid UAV with VTOL capability (SmartUAV): total weight of ca. 15 kg, maximum payload capability of only 1.5 kg, and a wingspan of ca. 5 m.

c) fixed wing (Mini Apprentice S.): maximum take-off weight of ca. 735 g, maximum payload capability of ca. 100 g, and a wingspan of ca. 1.2 m.
Research goal

Orthometric water level (W.L.)

Water depth (and bathymetry)

Surface velocity
Measurements of W.L. (orthometric water height)

- A ranging sensor measures the range to water surface.
- The GNSS (Global Navigation Satellite System) measures the drone height above the reference ellipsoid (convertible into altitude above geoid).
- Water level (elevation of the water surface) is computed by subtracting the range measured by the radar from the GNSS-derived height.
Water surface ranging sensors

We tested different sensors for measuring the range to water surface:
• A radar: Continental-ARS 30X-77 GHz W-band
• A sonar: Maxbotix-MB7386 42 KHz
• The CLDS (camera-based laser distance sensor) prototype developed at DTU
Methodology: **camera-based laser distance sensor**

Image of the water surface showing the two laser dots.

Two laser dots for redundancy
Proof-of-concept: Flight above Furesø lake

+++ high correlation between radar and GNSS curves
-- Sonar observations appear very noisy and with low range capability
-- Few observations with CLDS

Intro
Water level
Bathymetry
Velocity
Case study
Conclusions
Proof-of-concept:

Flight above Furesø lake

++ W.L. measured by GNSS/radar system is almost a constant line, with an estimated accuracy of ≈5-7 cm
-- W.L. measured by GNSS/sonar system shows multiple outliers
-- Few observations with CLDS, but the CLDS has the advantage of a low beam divergence
## Water level observations technology comparison

<table>
<thead>
<tr>
<th>Location</th>
<th>Technique</th>
<th>Ground footprint</th>
<th>Accuracy</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airborne</td>
<td>LIDARs</td>
<td>20 cm-1 m</td>
<td>4-22 cm</td>
<td>(Hopkinson et al., 2011)</td>
</tr>
<tr>
<td>Spaceborne</td>
<td>laser altimetry (ICESat)</td>
<td>50-90 m</td>
<td>10-15 cm</td>
<td>(Phan et al., 2012)</td>
</tr>
<tr>
<td>Spaceborne</td>
<td>radar altimetry (e.g. ERS2, Envisat, Topex/Poseidon)</td>
<td>400 m-2 km</td>
<td>30-60 cm</td>
<td>(Frappart et al., 2006)</td>
</tr>
<tr>
<td>Ground-based</td>
<td>radar/sonar/pressure transducers</td>
<td>mm-cm</td>
<td>1 mm-10 cm</td>
<td>Widely known metrology</td>
</tr>
<tr>
<td>UAV-borne</td>
<td>radar altimetry</td>
<td>dm-m</td>
<td>5-10 cm</td>
<td>Bandini et al., I, II, IV</td>
</tr>
</tbody>
</table>

**Source:** Bandini, F, PhD thesis (2017)
Reference

Journal of Hydrology

Research papers

Measuring water level in rivers and lakes from lightweight Unmanned Aerial Vehicles

Filippo Bandini a, *, Jakob Jakobsen b, Daniel Olesen b, Jose Antonio Reyna-Gutierrez a, Peter Bauer-Gottwein a

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b National Space Institute, Technical University of Denmark, Lyngby 2800, Denmark
Research goal

Orthometric water level (W.L.)

Water depth (and bathymetry)

Surface velocity
Picture of the drone with the tethered sonar flying above
(a) Danish stream
(b) Furesø
Measurements of water depth and bathymetry

- 290/90 kHz, with 15° / 55° beam angles
- The narrower beam is generally used for measuring water depth and bottom structure
- The larger beam can be potentially used for identifying fish
- Water depth can be obtained with an accuracy of 2.1% of the actual depth
- Bathymetry (Orthometric height of the riverbed) can be obtained by subtracting water depth observations from water level (meters above mean sea level)
Observations of river cross sections (1)

(a) 54.676300°, 11.913296°
(b) 54.675507°, 11.913628°
(c) 54.682117°, 11.911957°
(d) 54.681779°, 11.910723° (WGS84 Lat, Long coordinates).

Sydkanalen, Falster (Denmark)

● In situ
● UAV

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Observations of river cross sections (2)

- UAV-borne bathymetry observations in Po river, Italy (2017)
- Ground truth retrieved with a single beam sonar on boat (2012)

Po River cross section at WGS84 coordinates LAT 45.073375°, Long 10.934940° (Italy)
## Water depth technology comparison

<table>
<thead>
<tr>
<th>Technique</th>
<th>Max. water depth (m)</th>
<th>Typical error (m or %)</th>
<th>Applicability</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral signature</td>
<td>1-1.5 m</td>
<td>0.10-0.20 m</td>
<td>Clear water</td>
<td><strong>Satellite:</strong> (Fonstad and Marcus, 2005; Legleiter and Overstreet, 2012)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Aircraft:</strong> (Carbonneau et al., 2006; Legleiter and Roberts, 2005; Winterbottom and Gilvear, 1997)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>UAV:</strong> (Flener et al., 2013; Lejot et al., 2007)</td>
</tr>
<tr>
<td>Through-water photogrammetry</td>
<td>1-1.5 m</td>
<td>0.08-0.2 m</td>
<td>Gravel-bed water bodies with extremely clear water</td>
<td><strong>Aircraft:</strong> (Feurer et al., 2008; Lane et al., 2010; Westaway et al., 2001)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>UAV:</strong> (Bagheri et al., 2015; Dietrich, 2016; Tamminga et al., 2014; Woodget et al., 2015)</td>
</tr>
<tr>
<td>LIDAR</td>
<td>1-1.5 m</td>
<td>≈13 m</td>
<td>Gravel-based water bodies with very clear water: 1-1.5 Secchi Depth</td>
<td><strong>UAV:</strong> (Mandlburger et al., 2016)</td>
</tr>
<tr>
<td></td>
<td>6 m</td>
<td>0.05-0.3 m</td>
<td>Clear water</td>
<td><strong>Aircraft:</strong> (Bailly et al., 2012, 2010; Charlton et al., 2003; Hilldale and Raff, 2008; Kinzel et al., 2007)</td>
</tr>
<tr>
<td>Sonar tethered to UAV</td>
<td>0.5-80 m</td>
<td>≈2.1% of actual depth</td>
<td>All water conditions</td>
<td><strong>UAV:</strong> (Bandini et al., III)</td>
</tr>
</tbody>
</table>
Reference

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Technical note

Bathymetry observations of inland water bodies using a tethered single-beam sonar controlled by an Unmanned Aerial Vehicle

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Research goal

Orthometric water level (W.L.)

Water depth (and bathymetry)

Surface velocity
UAV-borne Water Surface Velocity

- UAV-borne high-resolution video of the water surface
- Video stabilization (high and low frequency vibrations)

**LSPIV**
(Large Scale Particle Image Velocimetry)

Water surface 2D velocity field

Lille Skensved, Sjælland, Denmark
UAV-borne Water Surface Velocity

**Tracers**
- Natural
- Artificial

**Video Stabilization**
- High frequency
- Low frequency

Conversion from pixel units to metric units
- Radar
- GCPs

Lille Skensved, Sjælland, Denmark

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Department of Environmental Engineering
Water surface velocity

- **4 GCPs** to convert pixel units into metric units
- **No artificial seeding.** Cross-correlation on natural tracers

≈15% accuracy in surface velocity when compared to in-situ probe

Video processed by [http://www.photrack.ch/](http://www.photrack.ch/)
From surface velocity to discharge

- Bulk average velocity can be computed from surface velocity
- A velocity vertical profile can also be estimated from surface velocity
- Velocity vertical profile and bathymetry allow for computation of discharge

Video processed by [http://www.photrack.ch/](http://www.photrack.ch/)
Flowchart

In flight

- Radar
  - Water level
- Sonar
  - Bathymetry
- Camera
  - Velocity
- Navigation
  - (UAV position and angle)

- BeagleBoardBlack

In office

- MATLAB Post-Processing Toolbox
- C# interface
- MIKE11-MIKE SHE

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River hydrodynamic model

- 1D water level node
- centerline
- river banks
- Cross section
- later flow (e.g. tributary)
Calibration of an hydrological model with UAV-borne water level observations

- Mike 11-SHE model of Mølleåen stream and its integrated catchment
Workflow

• We retrieve **UAV-borne W.L. observations** in some stretches of Mølleåen stream

• We perform a **synthetic** study to evaluate if W.L. observations retrieved with high spatial resolution can improve model estimates
• We calibrated against these W.L. observations with DREAM algorithm
• We evaluated the improvement in sharpness and reliability of the estimates of GroundWater (**GW**) - SurfaceWater (**SW**) interaction
A flight to retrieve WSE of a river

- Flight route over Mølleåen (Sjælland, Denmark)
- Flight time: ≈400 seconds
- Flight height: 30 m above ground level with σ=5 m.
WL and its slope along the surveyed stretch

Accuracy:
- In situ RTK-GPS rover station observations: 3-5 cm
- UAV-observations: 5-10 cm
Calibration against synthetic W.L.

- The green dots: perturbed synthetic water level observations
- Dark grey colour: 95% confidence intervals of the output prediction due to parameter uncertainty.
- Light-grey region: remaining 95% prediction uncertainty
SW-GW exchange flux time series

(a) Calibration against discharge observations only
(b) Calibration against discharge and W.L. observations

- Sharpness: improved by \(\approx 55\%\)
- RMSE (Root Means Square Error) improves by \(\approx 75\%\)
- Brier score improves by \(\approx 70\%\)

After W.L. calibration

Dark grey colour: 95% confidence interval of the output prediction

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Reference

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RESEARCH ARTICLE

Water level observations from unmanned aerial vehicles for improving estimates of surface water–groundwater interaction

Filippo Bandini¹ | Michael Butts² | Torsten Vammen Jacobsen² | Peter Bauer-Gottwein¹
Conclusions

• UAVs equipped with a W-band radar and GNSS system can measure **water level** at high spatial resolution with an accuracy better than 5-10 cm.

• **Water depths** can be monitoring by a tethered sonar system, controlled by the UAV, with an accuracy of ca. 2.1 % of the actual depth for depths potentially up to 80 m. For depths up to 30 m, this relative error is in agreement with the 1st level accuracy of the IHO standards.

• **2D surface velocity** field can be measured with the UAV-borne LSPIV with an accuracy of ≈15% of actual surface velocity.

• UAV can indirectly estimate **discharge**
Thanks for attending