Bathymetry from Images, LiDAR, and Sonar

From Theory to Practice

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Accepted: 27 April 2021 / Published online: 2 June 2021

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Precise knowledge of underwater topography, also referred to as bathymetry, is of high social, environmental, and economic relevance. Up-to-date nautical charts are a prerequisite for safe ship navigation in coastal as well as inland water areas, and the underwater geometry of rivers and coastal waters is the prime input for flood simulations and the basis for respective protection measures. Environmental applications include eco-hydraulics, habitat modelling, river restoration, and monitoring of fluvial morpho-dynamics and littoral vegetation.

For area-wide, high-resolution mapping of bathymetry, Sonar (Sound Navigation And Ranging), LiDAR (Light Detection And Ranging), multimedia stereo-photogrammetry, and spectrally derived bathymetry (SDB) have proved most suitable. While Sonar bears the advantage of large depth penetration, optical remote sensing methods are most suitable for shallow waters. Especially in the context of climate change, monitoring of the sensitive littoral area, i.e., the underwater biosphere, evolved from a niche topic to an indispensable Earth Observation discipline. Improving the quality of underwater maps requires coordinated development in different areas, such as sensor and platform technology, understanding of the complex signal interactions in water, data processing, machine learning, and software development. Beyond pure research aspects, the federal authorities responsible for maintaining the waterways and coastal area play an important role, as they act as a bridge between science and policymakers. They define new use cases and, together with the commissioned companies, push technological development in the bathymetry domain.

This special issue constitutes a collection of scientific papers and reports mainly focussing on optical methods for

bathymetry derivation including airborne laser bathymetry, multimedia photogrammetry, and spectrally derived depth estimation. Following the current trends in computer science and data analysis, several articles concentrate on artificial intelligence and machine learning to improve coverage and accuracy of bathymetric data. Other contributions focus on strict geometric modelling and advanced signal processing of the captured data aiming at improving the quality of the derived 3D point clouds and of derivatives such as submerged dunes. A common topic of both branches is the use of simulated data, which are used as an error free data source for either training of machine-learning approaches or for validation of geometric approaches. Two reports from German authorities bring in the user perspective and round up the special issue demonstrating that bathymetric data acquisition has arrived in federal administration and, thereby, document the relevance and importance of large-scale bathymetric mapping for various fields of application.

Mandlbürger et al. and Agrafiotis et al. both employ machine-learning approaches. Mandlbürger et al. use an image-based processing pipeline for deriving water depths by combining spectrally derived bathymetry estimation and photogrammetric data processing for a strict correction of refraction effects via ray tracing. They introduce BathyNet, a deep convolutional neural network (CNN) trained with concurrently captured airborne laser bathymetry data as a reference to overcome the shortcomings of traditional SDB methods and improve coverage and reliability of underwater DEMs. Their CNN can be extended to perform joint classification and bathymetry estimation in a single network. Agrafiotis et al. in contrast use machine learning for correcting the refraction effect of 3D point clouds derived from through-water multimedia photogrammetry. They demonstrate the great potential of using simulated data as error free ground truth for training their networks resulting in 3D point clouds fulfilling rigid accuracy limits of the International Hydrographic Organization (IHO). They, furthermore,

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show that the use of simulated data has a positive impact for images acquired from both manned and unmanned platforms.

Lorenz et al. also employ simulated data to find optimal post-processing parameters for deriving underwater DEMs from Sonar data sources minimizing measurement uncertainties. Their target application is morphological analysis of the riverbed to compute bedload transport rates via reliable detection and tracking of dune shapes. While nominal dune parameters can be reproduced with centimetre accuracy if suitable processing parameters are used, the derived dune parameters deviate in the decimetre range when choosing inadequate parameters. Simulated ground truth data also play a role in the contribution of Richter et al., who present enhanced approaches for geometric modelling of airborne laser bathymetry data. In their comprehensive model, they incorporate various components focusing on an accurate representation of the wavy water surface geometry and taking into account the diffuse reflection at the water bottom. By subdividing the finite laser beam into many sub-beams, they are able to quantify the errors resulting from the use of overly simplified, locally planar water surface models and from assuming identical outbound and inbound laser beam paths.

Turbidity is the main limiting factor for every optical depth retrieval method. This especially applies to laser bathymetry, where the sensor manufacturers usually specify the penetration performance of an instrument in multiples of the Secchi depth. Extending the achievable depth penetration is hence a topic of utmost interest and importance. Against this backdrop, Mader et al. achieve a depth penetration increase of around 30% by applying stacking of multiple adjacent laser waveforms. While full waveform stacking generally entails coarsening of the spatial resolution, the authors only use waveform stacking for identifying weak bottom signals and perform the actual ranging within a limited search corridor within the individual laser waveforms.

That is way, they achieve better depth penetration while preserving the spatial resolution of the original data. Waveform processing is also one of the core topics addressed in the software suite HydroVISH presented by Steinbacher et al. In their paper, they describe the software concept and the underlying HDF5-based data structure, which enable them to store arbitrary point attributes efficiently and to visualize bathymetric laser waveforms in an interactive display environment. Near real-time rendering of the feature-rich point clouds also facilitates the choice of suitable data processing parameters for tasks such as refraction correction or semantic segmentation of the bathymetric LiDAR point cloud.

Two articles by the Waterways and Shipping Office (WSA Dresden; Kühne) and the Schleswig–Holstein State Agency for Coastal Protection, National Park and Marine Conservation (LKN.SH; Christiansen) provide insight into the use of laser bathymetry data in the daily work of federal water-related authorities in Germany. In her article, Kühne describes data acquisition of the river Elbe during the extreme low discharge period in 2018 with bathymetric LiDAR, where a total river length of around 580 km was surveyed in only 3 days. Christiansen, in turn, reports about past and recent laser bathymetry activities of LKN.SH, replacing ship-based hydrographic surveys in the shallow water areas of the Wadden Sea and the coastal areas of the North Sea and the Baltic Sea.

To sum it up, the Special Issue “Bathymetry from images, LiDAR, and Sonar” combines contributions from basic research to practical application and, as such, provides a panoramic view of bathymetric mapping activities in and around Germany. As guest editor and chair of the DGPF Working Group “Application: Geology and Hydrography”, I want to cordially thank the authors for their valuable contributions and the reviewers as well the editorial team for the effort in preparing this issue. I hope you will enjoy reading.