Potential of UAV-based topo-bathymetric LiDAR for demanding hydrographic survey situations

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1. Introduction

Since the introduction of the first commercial airborne systems for bathymetric surveying in the coastal shallow water zone in the1990ies, both the requirements for combined topo-bathymetric surveying and the technological possibilities have drastically evolved and as a result, also new operational methods have emerged. As such, for example, over the last decade, UAV-based data acquisition has grown into an undisputed method in professional surveying. In parallel to the availability of ever more performant uncrewed aircraft, astonishingly concurrent compact and lightweight surveying systems have entered the market as a complement to systems designed for integration into crewed aircraft for efficient large area mapping from higher flight altitudes. We provide general considerations concerning UAV-based LiDAR survey in the hydrographic context and discuss requirements, limitations, and potentials. By comparing datasets from crewed airborne and UAV-borne data acquisition missions and different sensors used, we will exemplify typical fields of application.

1.1 LiDAR Shallow-water Topo-Bathymetry

The strength of Airborne LiDAR Bathymetry (ALB) is to provide reliable coverage of the dynamic topography in the land-water transition area, be it in coastal situations or in inland water environments. ALB provides a continuous dataset of topographic and bathymetric survey from one single data acquisition. The maximum achievable water depth penetration depends on water turbidity and water bottom characteristics.
ALB is closing the gap between boat-based survey and satellite based remote sensing of water and it is also the bridge to the inland topographic survey of shorelines.

1.2 UAV-based LiDAR

When UAVs entered the playground of the professional survey market by integrating miniaturized sensing systems, it was soon made clear that they were not to be mistaken as toys. Quite on the contrary, the use of UAVs was predestined for areas where it was too dangerous, too costly, or simply impossible to go for crewed aircraft (or boats). For LiDAR survey, the new perspectives of the UAV allowed to cover shadowed areas in airborne or ground-based survey and to produce unrivalled point density in dynamic data acquisition. Based on the significant impact UAV-based data acquisition had fast gained, interest in using LiDAR on uncrewed sensor platforms also in the hydrographic context arose. *RIEGL* proposed a first miniaturized profiler as early as 2016 as a proof of concept of the challenges for a bathymetric LiDAR system with a compact form factor and set to use in close vicinity of the water surface. At the same time, the flight over open water requires specific considerations in the UAV flight planning, for example concerning emergency procedures and flight autonomy. Based on experience and feedback from the hydrographic society, compact topo-bathymetric LiDAR scanning systems for integration in smaller UAVs followed soon. Today, UAV-borne systems are a valuable part of water surveying, especially for small-scale and spatially complex situations, hazardous areas, and they are also used to survey industrial facilities and reservoirs, harbour infrastructure, and underwater engineering facilities.

2. System Concept

2.1 *RIEGL* VQ-840 Series and *RIEGL* VQ-860-G

Systems of the *RIEGL* VQ-840 series as well as the *RIEGL* VQ-860-G are fully integrated compact airborne laser scanners for combined topographic and bathymetric surveying. The instruments can be equipped with an integrated and factory-calibrated IMU/GNSS system and with an integrated industrial camera, thereby implementing a full airborne laser scanning system.
The laser scanners comprise a frequency-doubled IR laser, emitting pulses with about 1.5 ns pulse duration at a wavelength of 532 nm and at a PRR of 50-200 kHz (max.100 kHz for VQ-840-GE and VQ-860-G). At the receiver side, the incoming optical echo signals are converted into an electrical signal, they are amplified and digitized at a digitization rate of close to 2G samples/s. The laser beam divergence can be selected between 1 mrad and 6 mrad in order to be able to maintain a constant energy density on the ground for different flying altitudes and therefore balancing eye-safe operation with spatial resolution.
These compact scanner systems employ a Palmer scanner generating an elliptical scan pattern on the ground. The scan range is ±20° across and ±14° along the intended flight direction and consequently, the laser beam hits the water surface at an incidence angle with low variation. The scan speed can be set between 10–100 lines/s to generate an even point distribution in the centre of the swath. Towards the edge of the swath, where the consecutive lines overlap, an extremely high point density with strongly overlapping footprints is produced. The onboard distance measurement is based on time-of-flight measurement through online waveform processing of the digitized echo signal. A real-time detection algorithm identifies potential targets within the stream of the digitized waveform and feeds the corresponding sampling values to the signal processing unit, which is capable of performing System Response Fitting (SRF) in real-time at a rate of up to 2.5M targets per second. These targets are represented by the basic attributes of range, amplitude, reflectance, and pulse shape deviation and are saved to the storage device, which can be the internal SSD, a removable CFast© card, or an external data recorder via an optical data transmission cable.

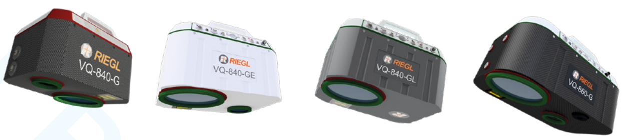

Figure 1. *RIEGL* topo-bathymetric LiDAR product portfolio.

2.2. Integration Options

A large operational envelope with regards to flight altitudes allows high flexibility for the user: the systems can be employed from drones as well as from crewed helicopter or fixed wing aircraft – thanks to the high scan speed, excellent point density is achieved even in the latter case.
For integration into UAVs, the VQ-840 series instruments (weight between 9.5 kg and 12 kg) are especially suited also for use on smaller, electrical multi-rotor systems, while the VQ-860-G (15 kg) requires higher payload capacity.

Figure 2. Examples for the integration on different types of UAVs.

3. Project Examples

Typically, the above-mentioned LiDAR systems are flown at a flight altitude of 70 m to 120 m above the water surface when integrated into UAV. This flight altitude is low in comparison to crewed airborne data acquisition, yet high enough to result in a reasonably large swath width to cover the area of interest reliably and cost-efficiently. Furthermore, the relative slow flight of the UAV provides extremely high point density and thus enables recognition of natural objects (like vegetation, deadwood, or even animals) and artificial ones (like for example industrial infrastructure or underwater archaeological artefacts) on the sea-ground but also in the waterbody. UAV-borne topo-bathymetric LiDAR therefore also enlarges the field of applicability from pure depth measurement in classic bathymetry to interest in features in the water column.
We show examples from coastal and riverine projects to portray the data quality of UAV-borne topo-bathymetric LiDAR in comparison to, and in its quality to complement, crewed airborne LiDAR and data from other sources.

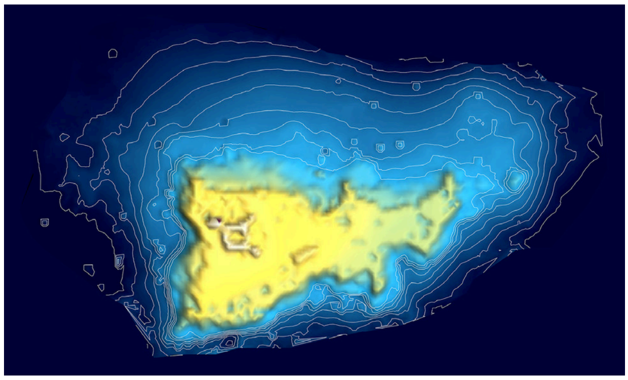

Figure 3. Topo-bathymetric LiDAR survey of island If in the French Mediterranean Sea, top view.

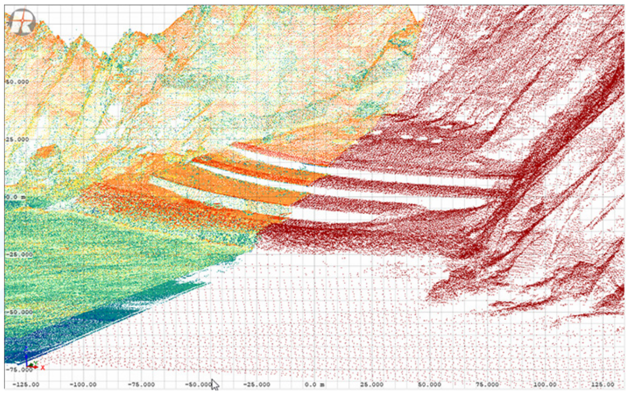

Figure 4. Comparison of LiDAR data point density from general coastal survey (red) and close-up survey from lower flight altitude in high resolution (multicolour).

References

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