MEASURING THE TOPOGRAPHY OF SUBMERGED ARCHAEOLOGICAL SITES FROM THE AIR

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1. INTRODUCTION

Detailed knowledge of underwater topography is essential for many research fields, including hydraulics, hydro-morphology, and hydro-biology. In archaeology, this is a foundation for understanding the organization and distribution of archaeological sites along and within water bodies. Here, special attention has to be paid to intertidal and inshore zones where, due to sea-level rise (Lambeck *et al.*, 2004), coastlines have changed and many former coastal sites are now submerged in shallow water (depth < 10 m). Mapping the relief within these areas is therefore important to be able to reconstruct former coastlines, identify sunken archaeological structures and recognize navigable areas, which can help to locate potential former harbour sites.

Until now, archaeology has lacked suitable methods to provide detailed maps of the topography of inshore underwater bodies. Due to practical constraints and depending on the pulse length (DeJong, 2002, 322), waterborne echo sounding has its limitations at shallow water depths. Terrestrial surveys are extremely time-consuming, small-scale, and do not feature the necessary details. Currently existing hydrographic airborne laser scanning systems are designed for maximum water penetration and the moderate pulse repetition rate results in a rather rough ground sampling distance of several meters (Cunningham *et al.*, 1998; McNair, 2010, 24ff.).

Using the latest airborne laser bathymetry (ALB) system, it is now possible to measure underwater surfaces over large areas in high detail (ground sampling distance < 50 cm). Airborne laser scanning (ALS) systems for the acquisition of the topography operate in the near or short-wave infrared wavelength (typically 1064 nm or 1550 nm), which is significantly absorbed by water bodies (Curcio *et al.*, 1951). To allow water penetration, ALB instruments utilize a laser wavelength in the visible domain (typically green with 532 nm) with a very short pulse length (approximately 1 ns) for good range discrimination and low beam divergence (1 mrad). The effective measurement rate of current systems is approximately 200 kHz. Due to eye-safety reasons, the penetration depth is a compromise between a small footprint (narrow laser beam allowing a high sensing detail) and high laser energy (allowing deeper penetration). Depending on the water quality, water penetration up to one Secchi depth can be achieved with current systems (RIEGL 2012).

2. MATERIALS AND METHODS

Currently existing ALB systems are designed for maximum penetration of water bodies using high-energy laser pulses with a typical repetition rate of 1 kHz. For eye safety reasons, the green laser beam has to be spread to a diameter of several meters. This results in ground sampling distances of 4 – 5 m at typical flying heights between 200 and 500 m (Guenther *et al.*, 2000).

For the archaeological research presented here, a higher resolution was desirable. Therefore, a different system had to be used. The hydrographic laser scanner (VQ®-820-G), manufactured by the company RIEGL Laser Measurement Systems GmbH in cooperation with the University of Innsbruck, Unit of Hydraulic Engineering, is designed to yield ground sampling distances less than 1 m. This is achieved using very short laser pulses (1 ns) in the green wavelength domain (532 nm) with small footprints (in our case 0.45 m at a flying height of 450 m) and a high effective measurement rate (200 kHz). A test flight operated by the company Airborne Technologies GmbH on the 29th of March around 12:30 local time with calm water conditions (Figure 1) resulted in a point cloud with 6 points (all echoes) per square meter.

Figure 1: *Simultaneously acquired orthophoto-mosaic of Kolone, Croatia.*

To guarantee eye safety, the energy has to be adjusted to a low energy mode with a special instrument setting provided by RIEGL. This results in a reduced water penetration capability of 1 Secchi depth (i.e. the maximum depth at which a 20 cm diameter black and white colour disk can be can be seen by the human eye). The above-mentioned test over Adriatic coastal areas and fresh-water lakes demonstrated that depending on the clarity of the scanned water body, this distance can be between 0 m and 10 m.

Deriving the range between scanner and sub-water surface and assigning coordinates to the reflecting objects is difficult. To calculate the range and refraction correction due to signal propagation in air and water requires a good model of the contemporaneous conditions and shape of the water surface as the speed of light differs for atmosphere and water. While the system already gave good results, remaining systematic errors between the strips could be minimized using least square adjustment of the individual ALB strips (Kraus *et al.*, 2008; see also Figure 2).

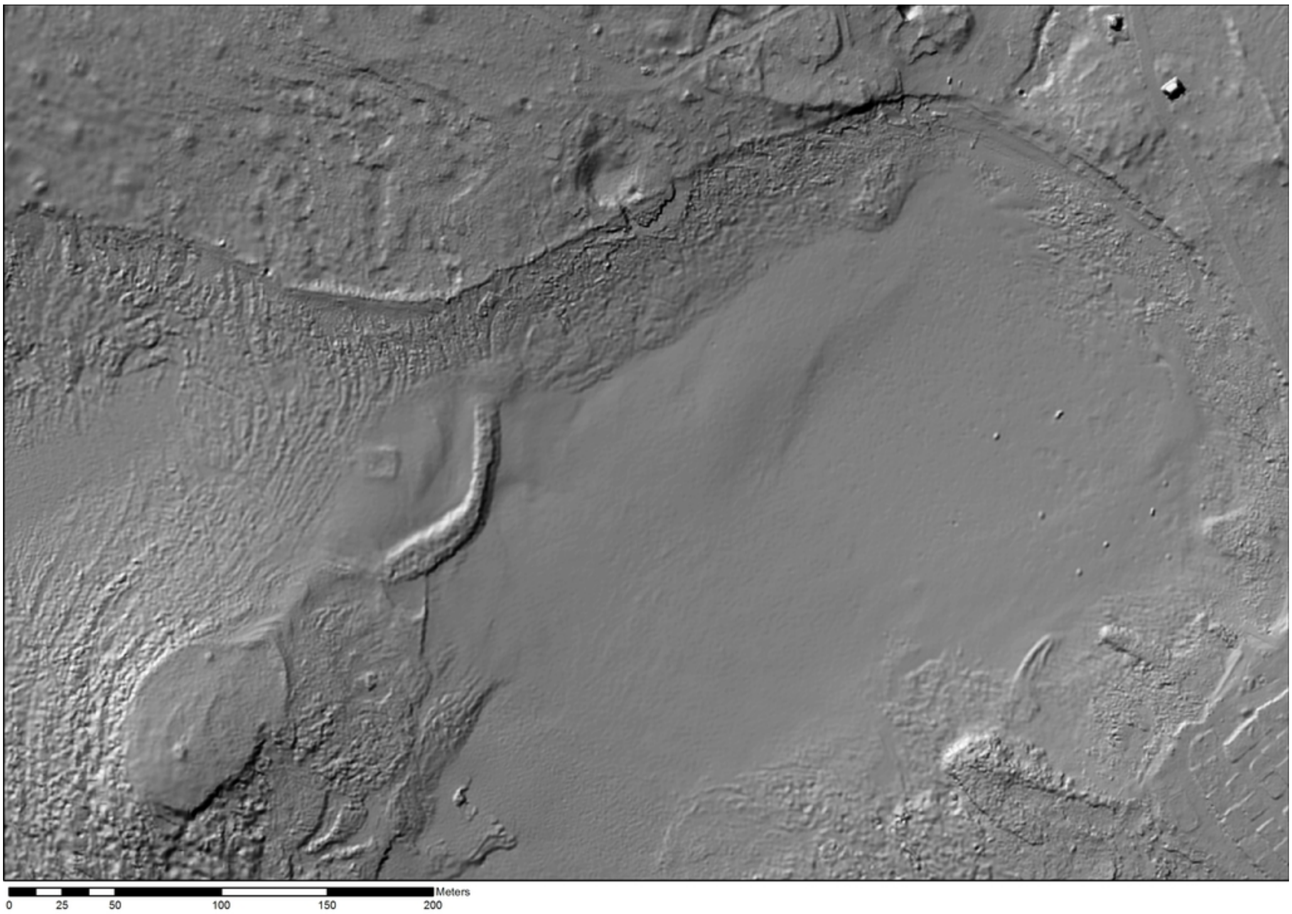

Figure 2: *Shaded digital surface model generated from the filtered and strip-adjusted ALB-point cloud over the Roman harbour site of Kolone, Croatia.*

3. THE CASE-STUDY OF KOLONE, CROATIA

In a pilot study, a RIEGL VQ-820-G ALB system was operated over the coastal area in Kolone, a Roman harbour site in the southwest of Croatian Istria. The measurements resulted in a digital model of the underwater topography with a planimetric resolution of 50 cm in waters at depths of up to 10 m. The GIS-based analysis of the data reveals a Roman embankment and breakwater walls in their topographical context (Figure 3).

The results clearly demonstrate that by using this active remote sensing technique, it becomes possible to shift the measurement border from the water-land boundary into the water. This allows including shallow-water zones, which can otherwise hardly be mapped in detail, into topographic documentation. We anticipate this technique also as a major break-through for scientific fields that are in need of detailed topographic maps of intertidal zones and shallow-water bodies. Furthermore, multi-temporal ALB missions could reveal environmental change regarding underwater sedimentation and erosion rates, as well as changes in underwater vegetation. In the field of archaeology, the results will have an important impact because, with the exception of sunken ships, underwater archaeology often deals with submarine archaeological structures that are located in shallow-water zones.

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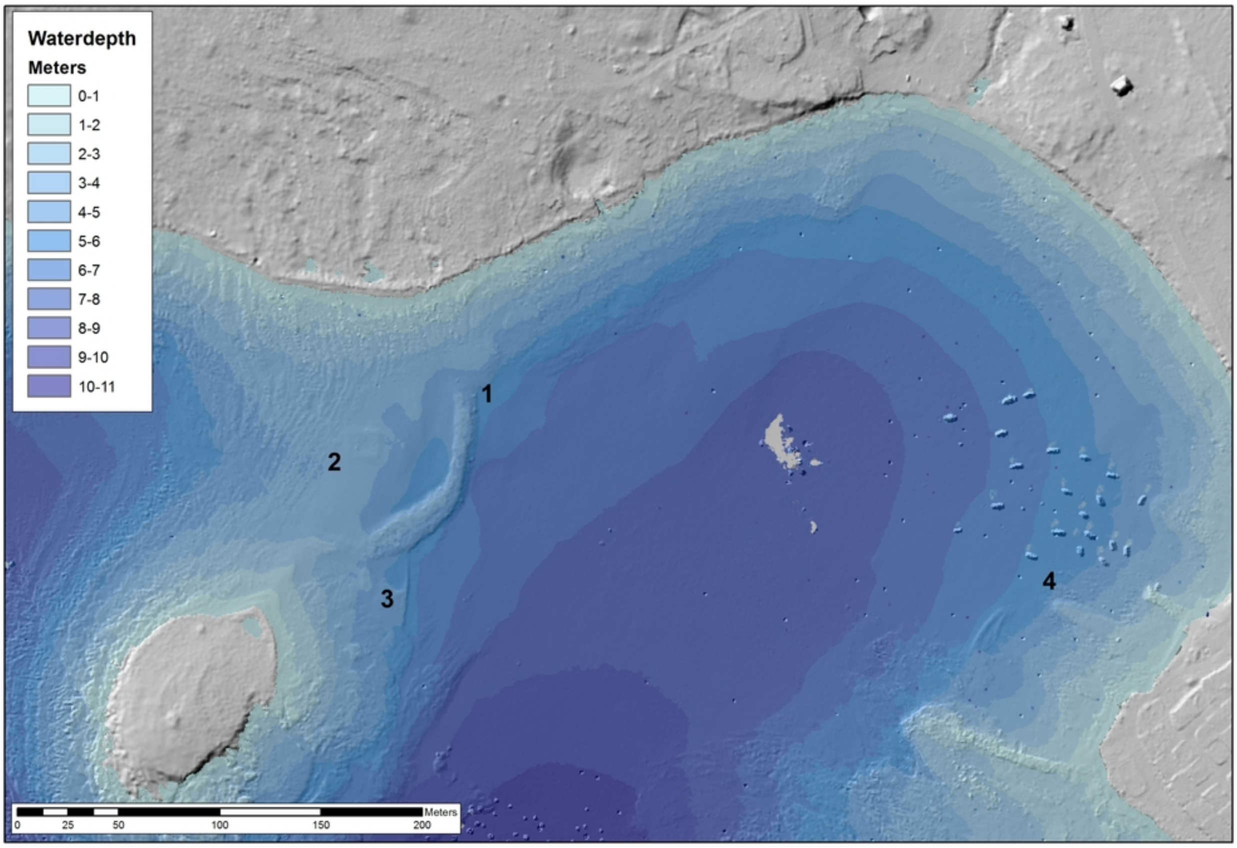

Figure 3: *Shaded filtered DTM generated from an ALB data acquisition campaign over the Roman harbour site of Kolone, Croatia. The shaded DTM combines land surface and underwater topography. Furthermore, a color-coded map of the water depth is superimposed. The following archaeological features can be recognized: (1) presumably Roman embankment connecting the small island with the main land (2) previously unknown, undated square structure, 15 m by 15 m with 0.5 m high walls, (3) wall with unknown function, and (4) Roman mole.*

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