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A Novel Approach to Laser-Based Hydrographic Data Acquisition

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In order to continuously monitor, evaluate, and study reservoir sedimentation, river degradation, water flow and water level dynamics, structure and zone variations of rivers and riparian areas as requested by the European Water Framework Directive, the repetitive surveying of inshore waters is essential. This can be achieved in an effective way by employing hydrographic airborne laser scanning. Conventional airborne laser scanning systems dedicated for acquisition of hydrographical data rely on laser pulses with exceptionally high pulse energy and large beam diameter and divergence with the purpose to penetrate as far as possible beneath the water surface and to largely eliminate the influence of surface waves, respectively. In a joint research project, the Unit of Hydraulic Engineering at the University of Innsbruck together with *RIEGL* Laser Measurement Systems investigate the potential of a novel approach towards the acquisition of reliable, high-resolution hydrographical data dedicated for surveying inland waters and shallow coastal zones. Measurement results obtained with a compact airborne laser scanning system employing a narrow laser beam at 532 nm, operating at a net measurement rate of up to 200 kHz are presented and the field of applications is assessed.

Introduction

There is a tremendous interest in hydrographic laser scanning for coastal zone and inland water mapping, nursed by the requirements arising from the European Water Framework Directive and also by increasing problems caused by extreme weather phenomena in the recent years.

The possibility to capture shallow water areas in a fast and economic procedure, comparably to conventional topographic airborne laser scanning, bears great potential for hydrologic, hydrographic, hydrodynamic, morphologic, and water quality-specific analysis of shallow water areas. Potential fields of interest are operation and management of inland water bodies and waterways, sustenance or preservation of close-to-nature water bodies, and monitoring of shallow water coastal zones.

In addition to the use of the data for different kinds of numerical models and their calibration (hydrodynamic models, water quality models, sediment transport models, groundwater models, climate change models) a large field of application is conceivable:

- riverbed changes due to sediment transport
- continuous and close to reality modeling of river structures and riparian areas
- water body management and habitat mapping
- documentation of renaturation and technical measures on water bodies
- data basis for civil authorities
- flood management and planning

Hydrographic airborne laser scanning systems with the main objective to reach maximum water depths and hence cover maximum surveyable area in coastal zones have been available for many years now. It is our aim to develop a system dedicated for high resolution hydrographic surveying. To this end, *RIEGL* Laser Measurement System teamed up with the Unit of Hydraulic Engineering of the University of Innsbruck in a joint research project to assess the applicability of a system with high spatial resolution but limited penetration, mainly for inland-water applications. After a series of preliminary investigations and experiments, a technology demonstrator was developed and manufactured. Preliminary tests on ground have already been performed and will be followed by flight tests.

In this paper we give a brief review of the results achieved so far and the envisaged goals of the present activities.

Laser Scanner Concept

The green laser wavelength employed for laser scanners dedicated to be able to measure beneath the water surface is exceptionally critical with respect to eye-safety. Therefore, in order to be allowed to operate a hydrographic airborne laser scanner over populated areas, the NOHD of the instrument must not exceed the expected minimum flight altitudes. In other words, the laser power density on the ground is limited to values determined by the laser safety standard. Thus, when designing a hydrographic laser scanner, one has two choices. If the target is to reach maximum depths, one has to employ laser pulses with exceptionally high energy which in turn requires a large beam diameter and leads to limited spatial resolution on ground. If, on the other hand, high spatial resolution is required, a small beam diameter has to be used and consequently only medium pulse energy may be employed.

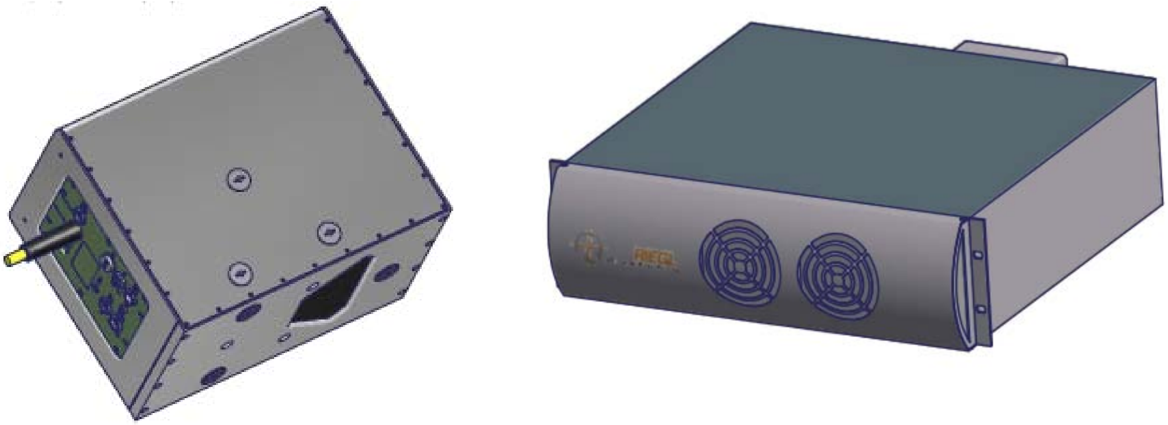

Figure 1: Scanning head (left) and laser module (right) of the *RIEGL* hydrographic airborne laser scanning demonstrator.

In order to provide a flexible instrument with attractive size, weight, and power consumption, we chose the second option. Aiming at high resolution, the laser scanner emits a narrow beam of about 1 cm diameter with a beam divergence in the range of 1 mrad. Therefore, at the nominal flight altitude of 500 m, the spatial resolution as defined by the laser beam geometry is in the range of 50 cm. High spatial resolution is also supported by an exceptionally high net measurement rate of 110,000 measurements per second. The *RIEGL* hydrographic airborne laser scanning demonstrator consist of a very compact and lightweight scan head including the scanning mechanism, the laser transmitter optics, the optical receiver and the waveform processing electronics. The powerful laser source is housed in a

19” case, connected to the scan head via an armored glass fiber cable and electrical cables (cf. Figure 1). The dimensions of the scanning head and the laser unit are 360 x 232 x 277 mm^3 and 520 x 482.6 x 132.6 mm^3, respectively. The total weight is 36 kg, the power consumption is 250 W.

The incoming echoes are digitized at a sampling rate matched to the pulse width. The instrument is equipped with optional online waveform processing of topographical data. Full waveform data is stored for postprocessing of hydrographical data.

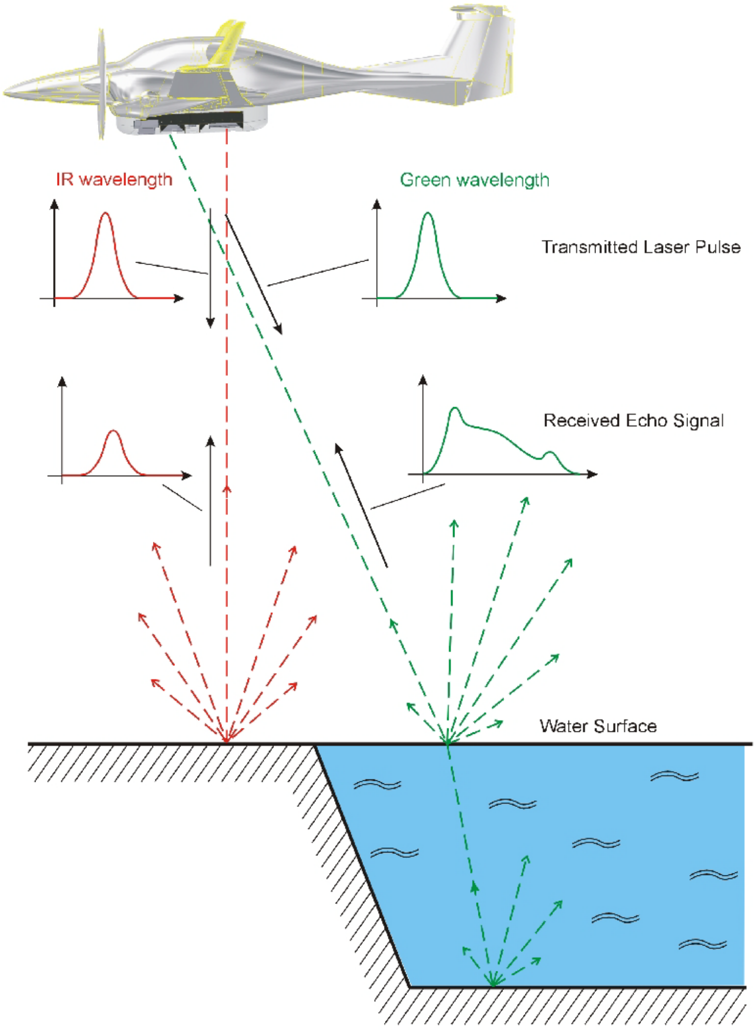

Figure 2: Combination of topographic laser scanner LMS-Q680i (near IR-wavelength) and hydrographic laser scanner (green wavelength).

While the hydrographic laser scanner may be used separately from any suitable airborne platform, a first integration into a belly pod of a Diamond Aircraft DA42 MPP twin engine surveying aircraft together with the topographic laser scanner *RIEGL* LMS-Q680i, as shown in Figure 2 and Figure 3, is foreseen. In this configuration, the two laser scanners at different wavelengths complement each other by delivering topographic data at two wavelengths as well as hydrographic data. In addition the infrared laser will serve to improve the determination of the exact position and inclination of the water surface.

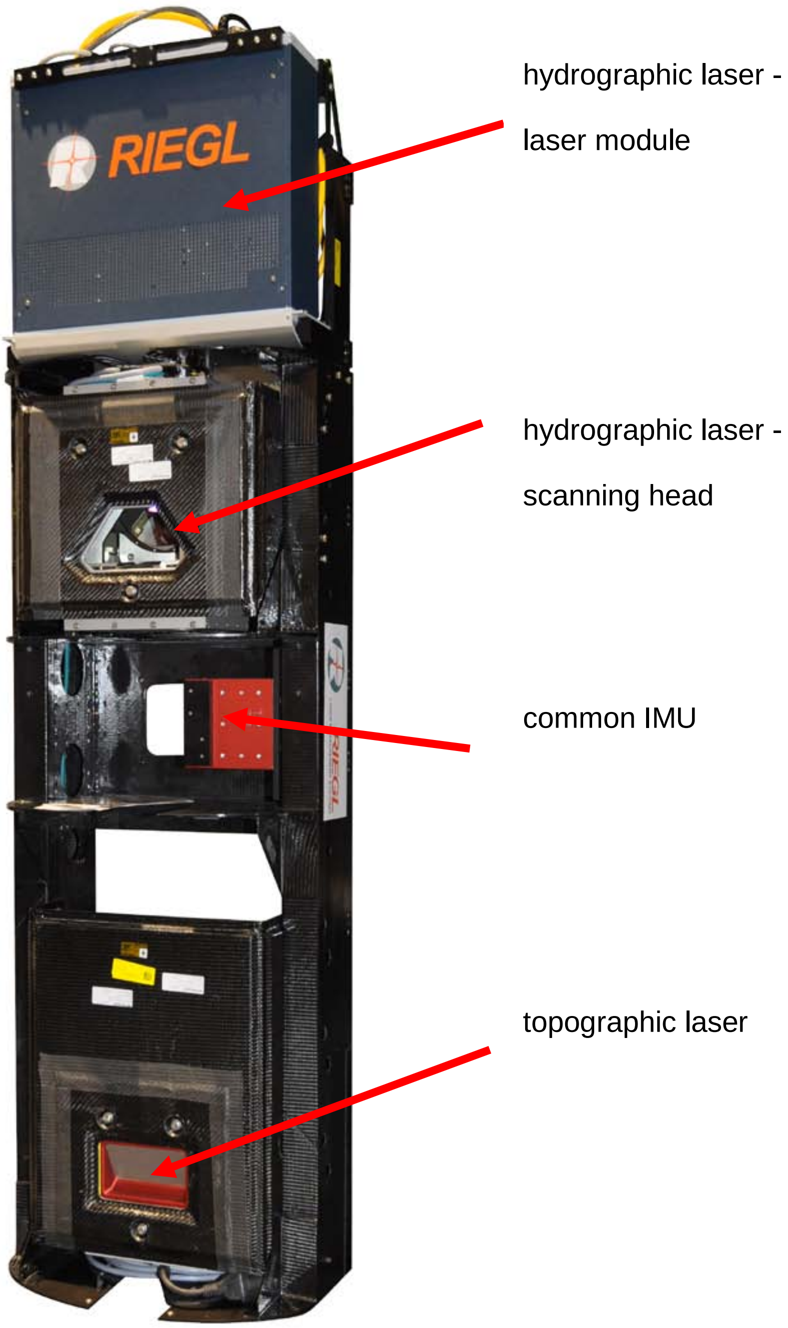

Figure 3: Hydrographic and topographic laser scanner integrated in belly pod for a DA42 MPP aircraft.

The scan mechanism is based on a rotating multi-facet mirror. As indicated in Figure 2, the scan axis of the hydrographic laser scanner is tilted by about 20° with respect to the nominal flight direction. This results in an arc-like scan pattern on ground and has the advantage that the angle of incidence of the laser beam to the water surface varies only by about 1° over the entire scan range of up to 60° (the full performance is obtained within 42° scan range). The scan rate can be varied from 10 to 200 lines per second.

Figure 3 shows a photograph of the two modules of the hydrographic laser scanner integrated in the belly pod (cleavage removed) of the DA42 MPP aircraft together with the topographic laser scanner *RIEGL* LMS-Q680i and an IMU.

Experiments

In order to have the possibility to test the performance of the new system under controlled conditions, a test site was set up at the University of Innsbruck. The basin as shown in Figure 4 is 17 m long, 3 m wide and 2.5 m deep. An artificial riverbed with typical characteristic with respect to shape and surface structure has been inserted. Water can easily be pumped into and out of the basin, surface waves and drift can be generated by a large pump circulating the water inside the basin. Turbidity was simulated by adding sediment material. In the future it is planned to extent the experiments by modifying the surface properties and adding mud, plants, and other obstacles.

Figure 4: Test site: Empty basin with artificial riverbed (left) and flooded basin with turbid water (right). Basin size 17m x 3m x 2.5m.

The experimental setup was such that the laser scanner was put on a boom lift and positioned over the basin. Flight over the basin was simulated by moving the platform of the boom lift alongside the basin. The operator inside the cabin of the boom lift not only controlled the laser scanner but also the motions of the lift. Figure 5 shows a photograph taken from the cabin of the boom lift. The arced scan pattern is clearly visible on the ground.

Figure 5: View from the cabin of the boom lift down to the empty basin. The scan line of the laser scanner is visible on the ground.

Results of the experiments carried out in June 2010 are presented in Figure 6 and Figure 7. A typical echo waveform is presented in Figure 6**.** The water's surface results in a first echo of high amplitude, followed by the distributed reflection from turbid water. The turbidity can be estimated from the slope of the trailing edge of the water echo. For the presented measurement there is no additional echo but the water bottom, represented by the second peak in the echo waveform. Figure 7 shows a cross section of the half-empty basin resulting from a 3-D point cloud obtained by moving the laser scanner over the basin. During the corresponding measurements the water was clear with small surface waves. The color of the points indicates the echo amplitude. The echoes from the built-in structure become weaker with increasing water depth. The water's surface delivers a separate target as long as a minimum water depth of less than 25 cm is exceeded.

The acquired data confirms the necessity of specific signal processing techniques to handle recorded echo signals. The complex measuring situation of hydrographic scans with its different targets on the pulse's way through water (water surface, floating matter, sediment, fish or vegetation) requires highly sophisticated analysis algorithms. Methods to separate different targets within one laser shot have to be employed as well as methods to determine waterbody-specific factors by full-waveform analysis.

Turbidity has major influence on signal shape and amplitude. We were able to differentiate between turbidity caused by suspended particles or caused by moving sediment. While echo waveforms resulting from reduced transmittance of a uniform suspension (organic or inorganic particles, organisms) are well understood and can be thoroughly interpreted (the echo waveform presented in Figure 6 corresponds to such form of turbidity), echo waveforms resulting from moving sediments are far more complex. Coincidental, strong, and discrete echoes of a sediment particle may be not definitely separated from the bottom echo or misinterpreted as bottom echo. Besides, if sediment transport forms a kind of solid interlayer measurement of the actual ground is not possible.

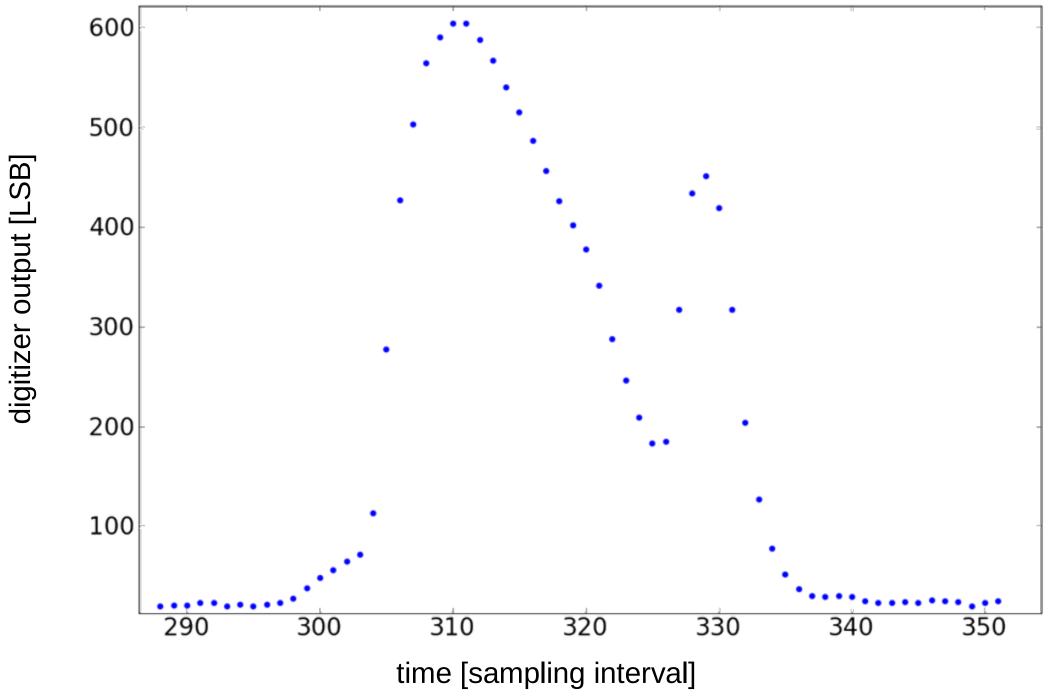

Figure 6: Digitized echo signal from water surface and ground. Distributed reflection from the water body results in a slow decline on the trailing edge of the surface echo pulse.

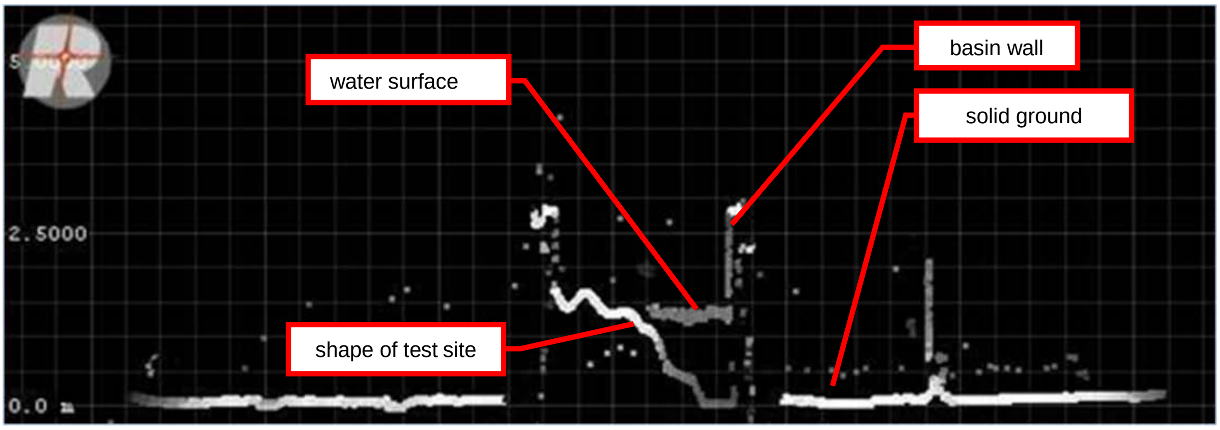

Figure 7: Cross section of test site measured with hydrographic laser scanner. The basin was half-empty. Basin wall, ground, water surface and shape of the built-in structure are highlighted. The grid width is 0.5 m.

Conclusion and Outlook

A new airborne laser scanner, dedicated for hydrographic applications has been developed and tested on ground. First results are encouraging with respect to the achieved spatial resolution and discrimination of water surface from ground targets. The system is expected to be able to measure 1 Secci depth from an airborne platform.

The next planned step is to perform measurements from an airborne platform (fixed-wing or helicopter) in order to prove the system's capabilities under real-life conditions. These tests will be complemented by continued experiments at the test site in Innsbruck under different conditions to improve the hydrographic and hydromorphologic interpretation of the echo data to be able to make optimum use of the experimental data from real water bodies.

References

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