AIRBORNE HYDROMAPPING
AREA-WIDE SURVEYING OF SHALLOW WATER AREAS

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Earth Observation for a Changing World

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ABSTRACT:

Reservoir sedimentation and river degradation, water flow and water level dynamics, structure and zone variations of rivers and riparian areas – in order to measure, evaluate and study all these subjects, the continuous or at least repetitive monitoring of inshore waters is essential. The new European Water Framework Directive requires regular and repeated monitoring for surveillance, operation, investigation and reference. Hydrographic profile measurements are the basis for every close-to-reality study and task. Conventional methods like mechanical or sonic systems require major labor input and time. With the intention to provide area-wide surveying of shallow water areas (reservoir beds, river beds, lake beds) LIDAR (LIght Detection And Ranging) has been adopted and is further explored to extend its capabilities to shallow waters. The distance to an object is determined by measuring the time of flight of laser pulses from the sensor to the objects and back. To capture targets below the water surface, a green laser wavelength has to be selected matching the transmittance window of water. Supplementary information about intensity and waveform of the laser echo pulses are necessary to find a correct interpretation of the recorded signals.

KURZFASSUNG:

Luftgestütztes Laserscanning zur flächendeckenden Vermessung der Topographie hat sich in den vergangenen Jahren als äußerst leistungsfähiges Verfahren durchgesetzt. Die politischen Vorgaben (EU-Wasserrahmenrichtlinie) aber auch die weiter zunehmende Bedeutung des Gewässermonitorings (Hochwasserschutz, ökologische Fragestellungen, u.a.) begründen einen enormen Bedarf an Vermessungsarbeiten in Stauräumen, Flüssen und Bächen. Gewässersysteme sind einem ständigen Wandel unterworfen, ihr Sohlverlauf muss somit regelmäßig neu erfasst werden. Die luftgestützte Hydrographie beinhaltet das Potential den technischen, wissenschaftlichen und politischen Fragestellungen eine Lösung zu bieten.

1. MOTIVATION

The aim of the European Water Framework Directive is the sustainable and ecological utilization of water. It describes strategies which are to be used for realization of each EU member country. Among other things, a main part is the development and implementation of extensive river basin management plans as well as a comprehensive risk assessment of the different river basin units. The hydraulic morphology, i.e., the actual description of the shape of a water body (process, water body structure, water body ground substrate), represents the most important evaluation factor in this context.
A technical system for the fast and area-wide collection of the hydrographic shape of surface water bodies meets the demands of managing the interests of the European Water Framework Directive.
The possibility to capture shallow water areas in a similarly fast and economic procedure compared to topographic measurements, made available by the technology of airborne laser altimetry, contains great potentials for scientists and the economy. For hydrologic, hydrographic, hydrodynamic, morphologic, water quality-specific, economic, and political research of shallow water areas a full geometrical and realistic hydrographic mapping is required. Potential fields of interest are operation and management of inland water bodies and waterways, sustenance or preservation of close to nature water bodies.
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

The Unit of Hydraulic Engineering of the University of Innsbruck together with *RIEGL* Laser Measurement Systems investigate the potential performance of a world-wide first airborne laser scanning system, particularly designed for hydrographic surveying of shallow water areas. The concept of “Airborne Hydromapping” has the potential to meet the present and future requirements with respect to collecting up-to-date, high-quality, and high-resolution survey data in a fast and economic way (Figure 1).

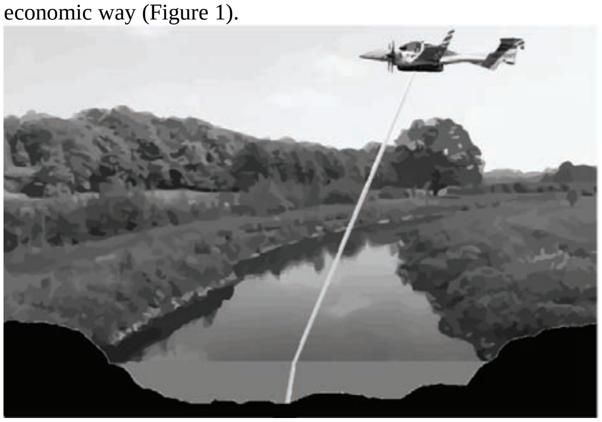

Figure 1. Airborne Hydromapping – shallow water hydrography in a fast and economic way

2. HYDROGRAPHIC AIRBORNE LASER SCANNING

Common laser scanning systems are used for the area-wide survey of topographic surfaces. Water-penetrating hydrographic laser scanner systems have been successfully used since more than 20 years for military purposes (submarine detection) and refined to collect terrain data of the sea bottom (offshore systems). The accuracy of systems designed for capturing the sea bottom (depths between 2 m – 50 m) is sufficient for certain application but there clearly are limitations in using such systems for the depth-range of shallow water areas (depths between 0 m – 10 m).

Low water depths, more unfavourable propagation characteristics, and the wish for a larger density of survey information ask for different technological approaches. An airborne laser scanning system dedicatedly designed for the survey of shallow water areas represents a technical innovation.

2.1 Hydrographic Laser Range Finding

The development of lasers delivering short laser pulses with high pulse energy at the favourable green wavelength (see below) has made a tremendous progress in the past few years. Employing such lasers makes possible to achieve the spatial resolution aimed at while at the same time allowing for reasonable measurement depths.

Hydrographic laser scanners carried by airplanes or helicopters make possible measuring of river and lake bed elevation or riparian areas with high resolution at a measurement rate not to be achieved with any other method. Such instruments typically make use of time-of-flight distance measurement of infrared and/or green laser pulses with pulse durations in the range of nanoseconds (Figure 2). Whereas the infrared signal is used for topographic measurements and also to determine the water surface, the green pulses have the ability to penetrate into the water and hit the bottom. An acceptable transparency of the water for the laser beam, a basic condition for capturing a water body, is given only a wavelength range between blue and green (400 nm – 600 nm).

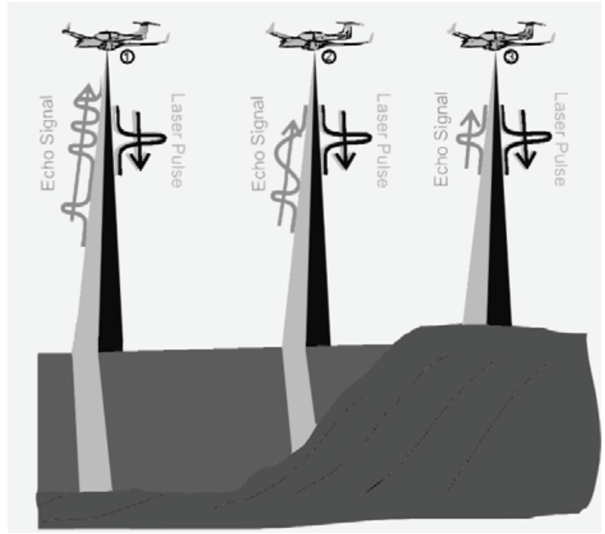

Figure 2. Schematic of the infrared (dark pulse in picture) and green (bright pulse in picture) laser pulses and their echo signal caused by the influences of terrain surface, water surface and the water bottom

Fast opto-mechanical beam scanning provides the coverage of a certain swath range along the platform’s flight path. The reflected signals from water surface and water bottom are captured by high-sensitive receivers. The received echo signals hold information about influences that affected the signal on its way (e.g. surface waves, turbidity, obstacles). In order to be able to interpret the resulting echo pulse shape and consequently also to discern targets very close to each other within each laser shot, it is mandatory to digitize the signals and apply full waveform analysis.

2.2 Airborne Hydromapping

Similar to existing laser scanning systems, a multiplicity of points is captured by determining the range and direction (covered by recording the scan mirror’s angular position) of targets identified within the recorded echo signals and is stored in the coordinate system of the sensor itself. For determining the dynamically changing orientation of the airborne system the trajectory data is required. By using Global Navigation Satellite Systems (GNSS, e.g. GPS) and an Inertial Measurement Unit (IMU) the data can be recorded and used to realize a strip adjustment (strip-wise scanning). The adjusted scans can be transformed into a superior, georeferenced coordinate system. After data acquisition and transformation the point cloud may be used to generate a digital surface model (DSM) trough triangulation. Even the point cloud itself can be regarded as a kind of basic model for measuring distances, angles or discern objects or shapes beneath the water. By applying filtering algorithms still to be developed, drifting groves, fish, sediment in motion, or water plants which are also captured may be removed. Extracting first and last echoes from the recorded echo signals alleviates the determination of the actual bed of the water body.

A research project, funded by the Austrian Research Promotion Agency (FFG), determines the authoritative factors for using the technology in mapping shallow water areas.

2.3 Series of experiments

Within more than two years the requirements of a laser scanning system capable of scanning shallow water areas has been investigated theoretically and by means of a breadboard system comprising a green laser and a corresponding receiver (Figure 3). The main focus was directed at identifying and eliminating factors which result in inaccuracy during an airborne hydrographic laser scan. The research concept included the factors:

- wavelength
- eye safety
- refraction
- reflection
- attenuation
- depth of water layer
- angle of incidence
- character, kind, and size of target
- orientation of target
- surface waves
- maximum and minimum measuring depth
- turbidity
- laser technology
- opto-mechanical sensor technology

Figure 3. Lifting platform with attached breadboard system, laser and sensor orientated down to basin

Preliminary tests contained the gathering of information about the effects on pulses on their way through water. The key components of the measuring unit were a pulsed laser with an emission at 532 nm (green wavelength), a highly sensitive receiver for the reception of the echo signals, a trans-impedance amplifier and a digital oscilloscope for signal recording. Further processing and analysis took place on a PC. The equipment was mounted on a lifting platform up to 25 m above a water basin (figure3, figure 4).

Figure 4. Different targets in water basin (assorted sizes of gravel, reflective materials), the basin offered a stepwise adaption of water depth and turbidity

Employing a water basin and a lifting platform made it possible to determine the characteristics of the laser and the opto-mechanical components. The water depth (up to 2 m), water properties (transmission), and the height of the laser platform (up to 25 m) were varied and the corresponding results were documented.

The intent of the research project is to design and develop an airborne hydrographic laser scanning breadboard, optimized for shallow water areas, optimized to be able to segregate the recorded signal even at a minimum water depth, which at the moment is estimated to be around 20 cm. The possibility to use the same laser source to capture water surface and bottom was investigated. Water waves lead to a different strength of the surface echo signals and could eventually cause it to even disappear completely. Further on, waves lead to variable impact angles. The refraction of the laser light consequently leads to a variation of propagation directions of the laser beam under water. In the experiments, this caused the laser footprint to roam around the bottom surface. This effect can be mitigated by using laser beams broad compared to the surface wave dimensions, and measuring only at comparatively still water conditions.

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 bottom) requires highly sophisticated analysis algorithms. Methods to separate different targets within one laser shot have to be employed.

The effects of turbidity can be mentioned as one of the main tasks of the project. The kind of turbidity has major influence on signal shape and amplitude. It was differentiated between turbidity caused by suspended particles or moving sediment (figure 5).

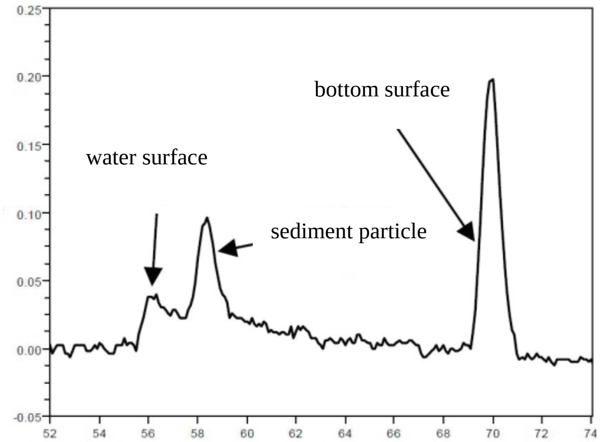

Figure 5. Recorded echo representing the different targets water surface, sediment particle and bottom surface

While echo waveforms resulting from reduced transmittance of a uniform suspension (organic or inorganic particles, organisms) are well understood and can be thoroughly interpreted, 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.

A hydraulic metering channel (figure 6) was used to gain more technical expertise on the maximum measuring depth, the way of propagation, and the characteristics of optical reflection of different materials compared to those in air. Measurements up to a maximum depth of 16 m were performed. The metering channel gave the possibility to investigate the effects on widening of the laser beam in water. Already a relevant enlargement is given in clear water and the effect grows with increasing turbidity. Turbidity is a factor which limits the system’s spatial resolution, i.e. the minimum size of objects to be differentiated from their surrounding terrain (footprint size).

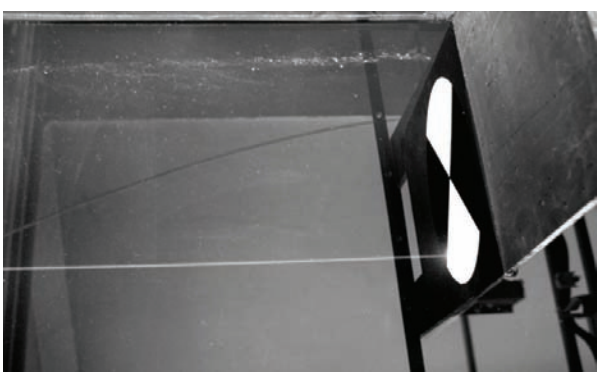
Figure 6. Hydraulic metering channel, green laser hits Secchi disk, maximum measuring depth of 16 m

To estimate the possibilities and future quality of surveys an easy way was need to determine the applicability of the system within water. For correlation of the measuring conditions a so-called Secchi disk was adopted.

The results of the first measurement series suggested an operation of the breadboard system at a natural river structure (figure 7). A cross section at the river Inn was selected, due to the possibility to mount the experimental setup on a bridge.

In addition, a modular cell concept was build to simulate a natural river. The 30 m x 2.5 m x 2.5 m basin is fitted with an artificial surface structure (made of Styrofoam cubes). The test field will be the basis for further research work during 2010 and the reference surface for calibration and validation of the system (figure 8).


Figure 7. Experimental setup of breadboard system at river Inn

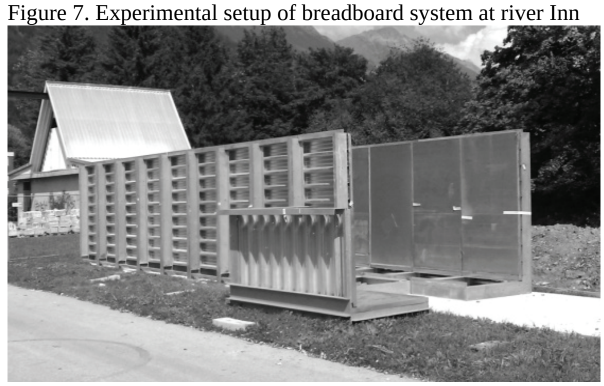
Figure 8. Modular cell concept, formed Styrofoam cubes build a natural river surface structure

3. CONCLUSION

Airborne laser scanning is unrivalled as the basic concept for fast and economic mapping of large or recurring areas and collecting up-to-date, high-quality, and high-resolution survey data.

Airborne Hydromapping has the potential to meets these requirements for shallow water areas. Provided sufficient transmittance, the accuracy of the measurement lies in the range of centimetres. The effective maximum range can be specified between a few centimetres (floodplains, riparian are-as) and several meters.

On the basis of the described series of experiments, a better understanding of the problematic areas of a hydrographic laser scanner for shallow-water scenarios could be developed. Turbidity is a main influencing factor. Signal shape and amplitude of echo pulses are highly influenced by water sediments. Measurement of the water bottom may eventually be impossible due to shielding effects of sediment or high suspension loads. The Secchi disk was determined to be a first evaluation criterion on survey effects caused by turbidity (“What can be seen can be measured.”). Further research investigates the Secchi depth of different Austrian and German water bodies on a regular basis. Seasonal and water body specific water characteristics will cause an optimum time slot of surveying (e.g. low tide, minimum of sediment transport, minimum of organic suspension). Otherwise, water quality is closely related to turbidity. The inter-relationship between the

influences on signal shape and amplitude could be used as indicator for water quality.
The roaming of the laser point on the bottom surface caused by waves, the widening effect (size of footprint) on the pulse's way through water or the drops of signals affects the optical, electrical, and mechanical setup of any system to be developed. To permit the desired spatial resolution (point density) a high laser pulse repetition rate and an adjusted scanning mechanism is required. The components of the next breadboard system will be installed in a compact unit (scanner unit approx. 360 x 230 x 279 mm, in addition 19-inch rack equipment) weighing approx. 40 kg in total. This enables the easy and economic mounting of the unit to an existing flight platform.

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