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Measuring water surface topography using laser scanning

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ABSTRACT

Measuring the topography of water surfaces with conventional measurement methods is, particularly in the case of turbulent flow with strong vertical and longitudinal dynamics, a very demanding and challenging task. Channel confluences are important elements in river engineering, as they appear in natural and regulated river channels, torrents, as well as in numerous hydraulic structures. At confluences, especially in the case of incoming supercritical flow, turbulent three-dimensional flows occur, and a time-varying structure of waters surface. Laser scanning enables data capture with high spatial and temporal resolution, and this method is widely used nowadays. This article discusses laser scanning as a measurement method for acquiring the agitated shape of a water surface. The application of a commercial two-dimensional LIDAR device for free-water-surface acquisition is presented for two cases. In the first case the measurements were performed in a glass tank where it was possible to determine the precise reference water level. In the second case we used LIDAR with turbulent aerated flow for fluctuating free-water surface measurement. Measurements were taken in the model of supercritical confluence, where the development of standing waves leads to the phenomenon of self-aerated flow. The measurements presented in the paper were conducted for a selected discharge rates and the Froude numbers of the main and side flow channels. Measurement results are shown as surface profiles at several selected locations of confluence. This measurement method has proven to be very promising.

1. Introduction

1.1. Background

Beginnings of laser scanning date back to the 1960s, when use of this method was limited to military research projects. Because of the not yet sufficiently developed computer equipment of the time, which is necessary for the capture, storage, and especially the post-processing of large quantities of data, Light Detection and Ranging (LIDAR) technology was limited to research contexts until the 90s. With the development of technology to a level that made the production of commercial devices possible, and with the parallel development of hardware and software equipment for data storage and processing, the technology rapidly gained in validity and broad applicability.

Today, LIDAR technology is one of the most widely used and promising remote sensing technologies [1]. Its robustness and versatile use is reflected in a number of completely different fields of science and engineering. Because of its speed, accuracy, and efficiency, airborne and terrestrial LIDAR scanning is increasingly replacing traditional geodetic methods of measurement [1,2]; it facilitates the capture of data required for archaeological research [3,4] and detailed reconstruction of buildings [5–7], and with the classification of raw point clouds with enhanced algorithms the data can be used in forestry [8–10], geomorphology [11], etc. In LIDAR data acquisition of terrain topography, water bodies usually greatly affect the performance and accuracy of measurements.

LIDAR is a surveying method that measures distance to an object with a laser, based on the principle of time of flight measurement. In general, reflection from water may be of specular reflection or diffuse reflection type. In the event of specular reflection, the incident laser beam is reflected from the water surface in a single outgoing direction according to the law of reflection. For specular reflection, only light (Fig. 1, left) from perpendicular reflections reaches the LIDAR device to contribute to the measurements. In all other cases of specular reflections (Fig. 1, middle), the reflected beam does not reach the LIDAR. For the case of diffuse reflection (Fig. 1, right), reflected light always returns to LIDAR and distance can be measured provided that the intensity of reflected light is above the threshold, required by the LIDAR sensor. In aerated flows diffuse reflection also occurs in the presence of air bubbles close to the water's surface. If a bubble is located at some distance below the surface, the reflected light intensity is additionally attenuated by the light travelling through the water; attenuation should

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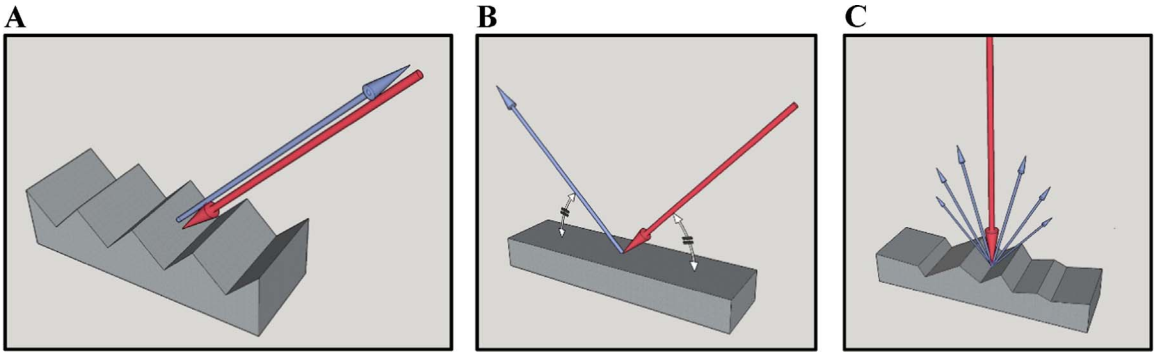

Fig. 1. Different types of reflection corresponding to object surface: a) reflection at perpendicular incident on a surface b), reflection on mirror surface at angle greater than 0 degrees c) diffuse reflection.

not be a problem in laboratory measurements. It may be worth noting that because of measurements of reflection from bubbles in the water or bottom, measured depths tend to be lower than the actual level.

Because of problems and errors in the measurements of the water bodies' topography (no reflection or possible reflection from suspended particles, bubbles, or the bottom), digital terrain model (DTM) (e.g. for river flow modelling) use a combination of filtered LIDAR data from the riparian terrain and bathymetry data set [12]. With the appropriate interpretation of the measurements results, the LIDAR technology can also be used to acquire free-water-surface profiles. Blenkinsopp et al. [13] used LIDAR to measure the time-varying free-surface profile across the swash zone. The water surface can foam in the swash zone's area, which increases the probability of diffuse reflections and hence measurements with LIDAR. The results show good agreement with measurements using ultrasonic sensors. Blenkinsopp and Allis have independently applied the method for laboratory profile measurements time-varying free-surface of propagating waves [14,15]. Both groups have taken measurements in wave flumes and have used water mixed with particulate matter to improve reflection, increasing the number of return signals in order to get valid measurements along the entire measurement window. In the literature available to us, we have not found any evidence that LIDAR technology has been used for laboratory measurements of clear water or for instances of turbulent aerated flow with complex free-water-surface. In such cases traditional laboratory measurement techniques do not provide comparable results.

The flow properties of the complex hydraulic phenomena (e.g. hydraulic jump, hydraulic structures, bifurcations, confluences, etc.) have been widely researched in the laboratory [16–21]. The measurements have been carried out with average hydraulic parameters, such as discharge, individual velocity components, and the water depth. While for velocity measurements non-intrusive measurement methods are currently most popular, especially image processing techniques like particle image velocimetry [22], bubble image velocimetry [23], optical flow [24], and computer-aided visualization method based on the advection-diffusion equation [25,26], conventional methods are still most commonly used for measuring of water levels, such as resistance-type probe, U-manometers, point gauges, ultrasonic sensors, etc. These methods give accurate results at suitable flow conditions. Resistance-type probes work on the principle of measuring the electric current between two parallel wires, which are immersed in water. The electric current that flows between the both wires is proportional to the immersed depth, at which it is possible to achieve a precision of less than ± 1 mm [17,27]. This measurement uncertainty is limited to bodies of water with smooth water surfaces. The performance of resistance-type probes is limited when two-phase flow occurs. Because the probe is positioned directly in the water flow, the problems also occur at high horizontal velocity of the flow transversally to the immersed wires, due to stagnation pressure. The same measurement uncertainty as with the resistance-type probes (± 1 mm) can also be achieved by U-manometers and point gauges. Both methods are still

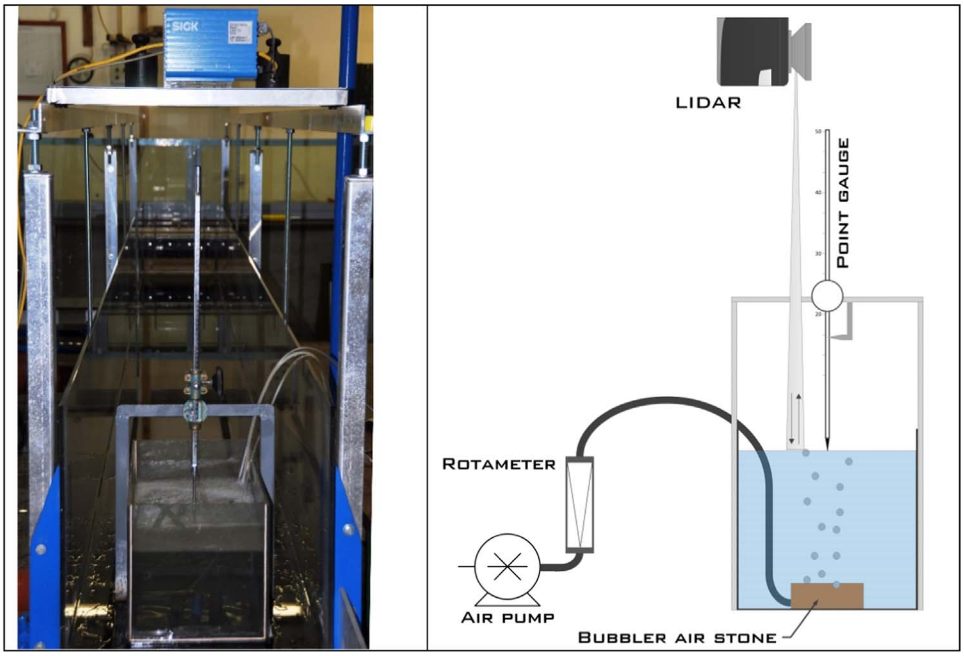

Fig. 2. The experiment setup of the first phase of verification: glass tank with point gauge, laser scanner, and additional equipment for injecting bubbles.