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Observation of surf zone wave transformation using LiDAR

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ABSTRACT

The use of LiDAR as an alternative to an array of in-situ instruments for water elevation measurement, specifically in the surf zone, is covered in detail. This paper outlines the advances in remote sensing of the coastal environment and provide both laboratory and field observations obtained through the application of LIDAR scanning devices. The results of this paper show a good correlation between LiDAR and pressure transducer measurements of water elevation in both a wave flume and within the surf zone (mean coefficient of determination of 0.76 and 0.89 respectively). The water surface reflectivity of the study area needs to be maximised in order for the LiDAR to provide suitable measurements, therefore a method of seeding in the wave flume is described. Points to consider for the setup of the LiDAR instrument in both the laboratory and the field are discussed, as well as the influence that wave parameters such as wave height and wave period have on the quality of results. Free surface elevation data across the spatial and temporal domain can be obtained with LiDAR and used for a wide range of wave analyses.

1. Introduction

The measurement of wave properties in the surf-zone is a research field that constantly innovates as technological capacity increases. Various instruments have been used to observe the many hydrodynamic processes intrinsic to the surf-zone. In-situ devices have been developed for the laboratory and the field to measure properties such as flow velocity, turbulence and surface elevation. In-situ devices are in physical contact with the water body and generally need to be placed as an array if more than one position is to be studied. Whether it is practical to place an array of instruments in-situ depends on the coverage required and the process to be observed. For example, pressure transducers are commonly deployed in the surf zone due to their relative ease of installation and their ability to estimate surface wave heights derived from linear wave theory [1].

Remote sensing techniques, of which there are many, allow instrumentation to be conveniently located near a water body with no direct interaction with the water body, resulting in measurements and observations that do not interfere with hydrodynamic processes. For example, water elevation measurements at a fixed position can be obtained using acoustic or LiDAR gauges. A time series of water elevation is measured by these instruments at a distance from the surface of the water, usually from directly above [2]. Innovative techniques have been devised to measure wave properties such as using light projection [3], 3-D PIV [4], colour block projection [5], and in the field, RADAR for breaking wave detection [6]. Preliminary research on shallow angle LiDAR indicated that sea surface elevations could be measured remotely and across the spatial domain [7][14]. Good agreement between surface measurements from a LiDAR and array of ultrasonic altimeters in the swash zone has shown that the technology can be utilized in the surf zone for cross-shore flow velocity measurements [8].

The total crest elevation, shape and transformation of waves in the surf zone can be difficult to measure due to the dynamic nature of the water surface. Problems also arise in the post-breaking phase of wave propagation where the presence of air bubbles can affect the accuracy of some measurement techniques. In addition, breakers in the field are more difficult to study as a number of measurement techniques used in wave flumes are impractical to install or operate in the surf zone. The present study outlines the use of LiDAR for free-surface measurements, including points to consider to maximise quality of results, as well as presenting both experimental data from wave flume tests and field data collected from the surf zone.

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2. LiDAR for water profile measurement

This paper will focus on the use of LiDAR for 2D profile measurements at a fixed point only due to practicality and the nature of the target surface; however as technology improves, inexpensive high frequency 3D scanners will no doubt become feasible. There are a number of commercially available LiDAR systems capable of providing detailed measurements of 2D profiles from manufacturers such as Leica, Riegl and Sick AG.

Scanning instrumentation either uses the time-of-flight principle or phase based optics to determine target distances. The instrument used in the experiments discussed in this paper uses time-of-flight in which the instrument emits a laser pulse towards the target object and subsequently detects the reflected light. The range of the object from the LiDAR system is determined by the time it takes for the transmitted pulse to travel to the object and reflect back to the sensor on the instrument. This will be recorded as a single point in space in relation to the point of origin at the LiDAR.

There are a number of factors that can influence the success of utilising LiDAR technology for dynamic free-surface profile measurements. These factors are inherent of the technology and therefore specific conditions need to be met in order to maximize the quality of results obtained from LiDAR instrumentation. These are, surface reflectivity which depends on the physical properties of the intended target, and lesser factors that include the angle of incidence, range and environmental conditions. Specular reflection is the direct reflection of light at an angle equal to the angle of incidence, whereas diffuse reflection is the scattering of light in many directions and at different intensities. LiDAR has the greatest chance of detecting diffuse reflections as the probability of a single, or multiple, return echo from the target direction is higher. Imperfections or roughness of the surface of the target object scatter the light and increase the chances of this occurring.

These airborne LiDAR systems use a combination of two different laser wavelengths to distinguish the water surface from the sea bed in order to determine the bathymetric elevation [9][15]. This can be achieved due to the difference in surface reflectivity of both bodies which is closely related to the physical properties of the materials (although not entirely due to this). The surface reflectivity in any individual study needs to be considered if LiDAR is to be used for free-surface water profile measurements, and this needs to be maintained otherwise there will be a loss of suitable data [10][17]. This applies to both experimental and field studies. However, the restrictions and advantages of the use of LiDAR in either situation are quite different. In a controlled experimental setup, say in a laboratory, the source of water would generally be from drinking water supplies or recycled water. Clarity of the water prevents a strong surface reflection signal and the laser pulse will more than likely pass through and reflect from the surface of the water body container. To overcome this problem various techniques can be used to change the optical properties of the water such as spreading a buoyant material across the surface or adding particulate matter to the water body [11]. In the surf zone phenomena such as biological matter, surface ripples, foam and bubbles all contribute to an increase in surface reflectivity compared to calmer water bodies and to experimental setups [12] [16].

The output of LiDAR systems are generally comprised of a point cloud or a matrix of data points, with 3D coordinates and time being the primary parameters. The point cloud can be validated against known reference points such as fixed objects within the instruments line-of-sight, or specifically for this study, data obtained from independent surface tracking instruments. If validation of the point cloud data is not performed then a seemingly complete data set assumed to be representative of measured water surface may not be accurate. If a laser pulse penetrates the water surface and reaches another target past this point (such as the beach slope in a wave flume) a reflection is possible and will be detected by the LiDAR system as a valid data point. The laser pulse will undergo refraction as it passes from one medium to another that will in turn lengthen the travel time for that pulse resulting in a longer calculated range than if the water body was not there. This does assist in the identification of data points that are not of the water surface as there will be a noticeable difference between these points and the expected surface position. However if the data set is not checked adequately these points may go unnoticed. For this study each of these issues were addressed through control of the experiments or post processing of the collected data.

3. Methodology

For both the flume and the field studies the LiDAR used was a LMS511-20100 PRO Laser Measurement Sensor produced by SICK. The instrument uses a Class 1 laser with a wavelength of 895–915 nm. The instrument has a maximum field of view of 190° with an angular resolution and scanning frequency that are dependent on each other. The minimum angular relocation of the instrument is 0.1667° and the maximum scanning frequency is 100 Hz. A balance between resolution and frequency was preferred with the LiDAR operating at 0.25°@35 Hz. The instrument has a scanning range of up to 80 m and can filter data points using up to 5 echoes from a single laser pulse. Output from the scanner is in the form of scan angle and the corresponding distance to the reflection of the laser pulse determined by the time-of-flight principle.

3.1. Flume measurements

A laboratory experiment was conducted using a LiDAR and array of pressure transducers (PT) in a 2D glass-walled wave flume at the Griffith School of Engineering, Griffith University, Gold Coast. The setup is illustrated in Fig. 1 and includes a summary of simulated surf conditions. The effective test section dimensions from the end of the beach slope up to the wave paddle are 12 m long, 0.45 m wide and 0.8 m deep. A HR Wallingford piston-type Wave Generation System was used to generate waves in the flume. The beach slope was constructed

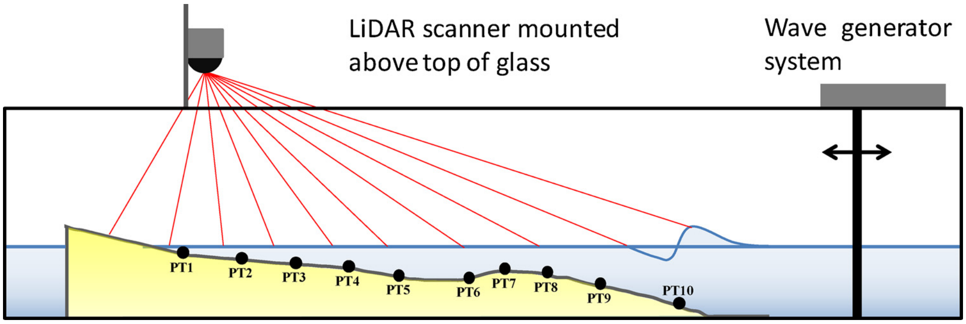

Fig. 1. Wave flume setup diagram.