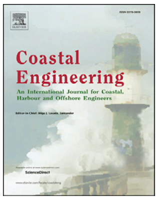
Coastal Engineering 130 (2017) 46–51

Contents lists available at ScienceDirect

Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng



Wave runup video motion detection using the Radon Transform

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ARTICLE INFO

Keywords:
Nearshore
Image processing
Radon Transform
LiDAR
Swash zone
Shoreline
Flow motion
Groundwater seepage

ABSTRACT

A new method of runup detection from video imagery is introduced and validated at an energetic dissipative beach. The instantaneous waterline is detected from uprush and backwash by using the Radon Transform (RT). The method is compared to conventional color contrast method from RGB images and LiDAR measurements. In our observations, the RT shows better detection skill even for adverse conditions, such as those present on flat dissipative swash zones where contrast is reduced. Because the RT is a proxy of deeper waterline (~0.1 m) it is less sensitive to lack of contrast due to sand saturation. Moreover, since it is based on motion detection, it is less sensitive to changes in lighting conditions. Overall, the RT offers an attractive alternative for long term automated detection of the runup.

1. Introduction

Swash zone processes are a fundamental component of the beach system dynamics (Holman and Sallenger, 1985; Masselink and Hughes, 1998; Puleo et al., 2001). The swash zone links the terrestrial and marine environments and is an important source of sediment exchange between the surf zone and the subaerial beach (Masselink and Puleo, 2006). Given this relevance for nearshore hydrodynamics and morphodynamics, it is essential to have a monitoring system capable of capturing its large variability in space and time.

Remote sensing techniques, such as video imagery, are becoming more common in coastal studies and techniques have advanced greatly in recent years (Holman and Stanley, 2007; Holman and Haller, 2013). This type of remote sensing technique allows the automatic collection of a dense array of data, over a large range of temporal domains, ranging from wave-by-wave (seconds) to long term (years).

Video pixel array are usually sampled over time along cross-shore lines, allowing the creation of space-time maps of optical pixel intensity (usually termed timestacks) from which the swash can be identified (Aagaard and Holm, 1989; Guedes et al., 2013). Most existing methods of runup detection from video timestacks are based on pioneering studies of Holland and Holman (1993) and Holland et al. (1995, 2001) where the instantaneous waterline is defined as the interface between water and beach, and it is derived from optical information by the sharp Contrast in Color band (CC). These methods are based on color contrast and not on hydrodynamical aspects. Thus, they can be sensitive to any changes in lighting conditions, sand and water color which may reduce the contrast, or induce false detection. Alas, they generally necessitate a time (to allow for changing lighting conditions throughout the daylight hours) and site specific calibration (Vousdoukas et al., 2014). For instance, the presence of wet sand creates a stark contrast with dry sand, and it is this boundary that can be erroneously identified as the shoreline. This is more frequent at dissipative beaches, and it often requires a manual correction of runup detection (Senechal et al., 2011; Guedes et al., 2013).

As an alternative to methods based on CC, the waterline can be defined from its motion, using the Radon Transform (Radon, 1917), by taking advantage of the spatio-temporal format from video timestacks, which is perfectly suited for this type of angle separation. The RT has recently been successfully applied to ocean waves, in particular for the

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https://doi.org/10.1016/j.coastaleng.2017.09.015
Received 11 April 2017; Received in revised form 8 August 2017; Accepted 26 September 2017

detection of ship wave (Copeland et al., 1995) and more recently to nearshore wave dynamics (Yoo et al., 2011; Almar et al., 2014), alongshore current (Almar et al., 2016) and swash motion (Zhang et al., 2009) but no attempt as conducted to estimate runup, despite the high potential of its use.

This paper introduces an alternative method for runup detection based on the RT and provides a quantitative validation through a comparison with LiDAR measurements conducted at a dissipative beach.

2. Runup detection principle using the Radon Transform

The RT *R* (ρ,θ) of a bidimensional field $\eta(x,y)$ (Radon, 1917; Deans, 1983; Duda and Hart, 1972) corresponds to a polar projection and can be defined as:

$$R(\rho,\theta)=\oiint \eta(x,y)\delta(x\cos\theta+y\sin\theta-\rho)\mathrm{d}x\mathrm{d}y \tag{1}$$

where δ is the Dirac delta function, θ and ρ are the angle and distance from origin of the integration line defined as $\rho = x\cos\theta + y\sin\theta$. The origin is the center of the two-dimension field. The Radon transform $R(\rho,\theta)$ is defined for all possible values of θ from [0 to 180°] and ρ from 0 to the diagonal length. The original field η(x,y) can be back projected using the Inverse Radon Transform at selected range of θ values:

$$\eta(x,y)=\oiint R(\rho,\theta)\mathrm{d}\theta\mathrm{d}\rho \tag{2}$$

As an illustration, Fig. 1 shows the application of the RT to a realistic cross-shore video timestack in the swash zone. The uprush and downrush motions are clearly visible in Fig. 1a from the optical textured surface of turbulent swash flow. In the Radon space (Fig. 1b), these motions with opposite direction show peaks at different values of θ, and alternate as the swash flow reverses; here negative and positive θ values respectively for uprush and donwrush. The incoming and outgoing motions are separated (see Fig. 1a, red and blue features) by back projecting the original signal at negative and positive angles, respectively. In video timestack images, the runup is generally visible as a rapidly moving edge. Based on the RT, the runup can be then defined as the location of the maximum variance of the incoming (periods of uprush) and outgoing (periods of backwash) components. Our algorithm is implemented in Matlab, using on the Image Processing Toolbox, and is available from the authors upon request.

3. Field data

Data used in this paper were collected at Mataquito, Chile, on December 9th, 2012 (Fig. 2 a, Cienfuegos et al., 2014). Mataquito is located in the Central coast of Chile. It is a black-colored, medium grain-size ($D_{50} = 0.2$ mm), intermediate to dissipative, micro-tidal beach, exposed to energetic waves. During the measurements, waves were moderate (H_s = 1.5 m, T_p = 14 s), the tide was low (−0.23 m) and the swash zone was located on the flat section of the lower intertidal profile (slope ~0.04, Fig. 2b).

A 2D scanning LiDAR (SICK LMS511-10,100 Laser Measurement System) was deployed on a scaffolding tower, at an elevation 7.3 m above the beach in the upper swash to measure swash hydro- and morphodynamics (Blenkinsopp et al., 2010; Almeida et al., 2015; Vousdoukas et al., 2014; Brodie et al., 2015). Video swash monitoring was undertaken at 30 Hz using a SONY HDR-CX190 full HD 1920 × 1080 camcorder installed on a tripod. Timeseries of video pixel intensity were sampled along a cross-shore line, separated 3 m alongshore from LiDAR transect, and instrumented with metallic poles (Ibaceta et al., 2014). Rectification from image pixels into real world coordinates was accomplished through a direct linear transformation using DGPS ground control points (Holland et al., 2013) at the pole locations (Fig. 2). The horizontal resolution obtained from the video data varied from less than 0.01–0.06 m along the cross-shore transect.

The ability of the RT method to detect runup is tested against concurrent LiDAR measurements over a 20-min period obtained during the Mataquito experiment. The raw LIDAR measurements represent reflection of the laser beams from the beach topography as well as the water surface, without any distinction between the two. Water level is computed as water surface elevation above the bed, computed as the minimum level measured over the 20-min period. The runup edge is detected using a water level threshold, typically around 0.05–0.08 m (Blenkinsopp et al., 2016; Vousdoukas et al., 2014; Almeida et al., 2015), to cope with noise inherent to LiDAR measurements. Here, a 0.08 m threshold for LiDAR data for bed and water limit is used and is further

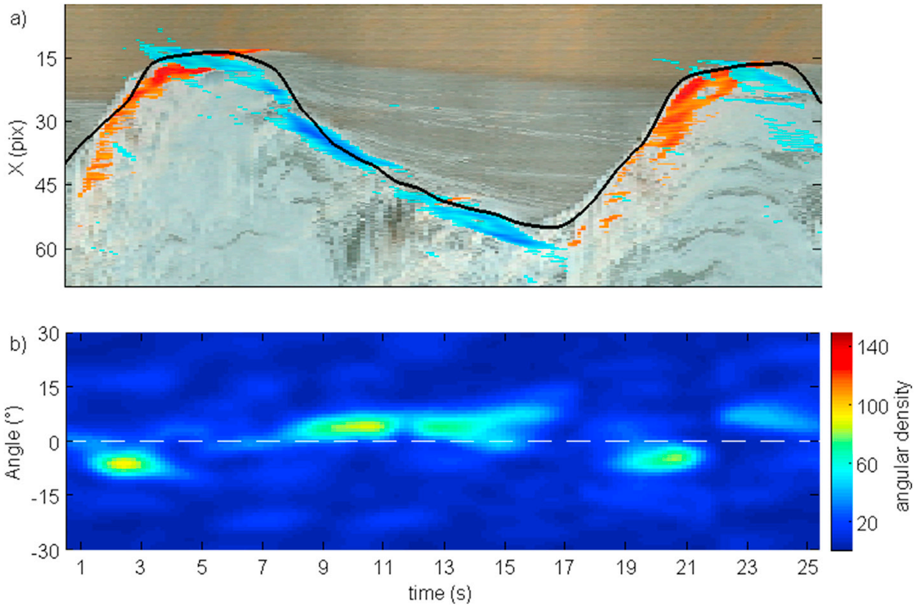

Fig. 1. a) Aerial view of Mataquito beach, Chile with studied cross-shore transect (dashed line) and b) surveyed bathymetric profile, solid and dashed blue lines stand for mean sea level, max and min spring tidal elevations, respectively. The local slopes on the upper and lower intertidal parts of the beach profile were 0.06 and 0.03 respectively. In c) and d) the deployment of the LiDAR and concurrent video camera and swash poles are shown. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)