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# Application of SfM photogrammetry for morphological changes on gravel beaches: Dugi Rat case study (Croatia)

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**Abstract:**
Glavica (natural) and Dugi Rat (artificial) gravel beaches in Croatia were monitored using ground-based photography and structure-from-motion (SfM) photogrammetry, in order to assess morphological changes after storm events. In contrast to stormy waves caused by Bora winds (NE), Sirocco winds (SE) induced waves which initiated morphological changes on both beaches. Beach orientation with respect to the prevailing wind directions is the governing factor determining direction and quantity of sediment transport. We demonstrate that the SfM approach using Agisoft PhotoScan Pro and high accuracy dGPS measurement can give DEMs with error on control points generally <2cm and thus are suitable for assessing morphological changes that exceed ~5 cm.

**Keywords:** Adriatic Sea, Beach morphology, Gravel beach, Storm events.

## 1. Introduction

Digital elevation models (DEMs) obtained by Structure-from-Motion (SfM) photogrammetry combined with Multi-View Stereo (MVS) have been recently used and evaluated for various purposes in geosciences construction (JAMES & ROBSON, 2012; WESTOBY *et al.*, 2012; RUŽIĆ *et al.*, 2014). In contrast to classic photogrammetry, the method does not require pre-calibrated camera and orientation and scene geometry are automatically and simultaneously built using overlapping photos taken from different angles. The result is an unscaled 3D point cloud in an arbitrary coordinate system, which can be precisely and accurately referenced to a real-world coordinate system for the purposes of regular monitoring and further analysis. To do so, dGPS measured ground control points (GCPs) of high accuracy are usually introduced and identified in images. DEMs with centimetric precision (both vertical and horizontal), high resolution and accuracy can be obtained by SfM-MVS and are comparable with those obtained by laser scanning (JAMES & ROBSON, 2012).

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Gravel beaches, unlike their sandy counterparts, are rarely studied (BUSCOMBE & MASSELINK, 2006). It is well known that gravel beaches are very effective in dissipating wave energy (PEDROZO-ACUÑA *et al.*, 2007) and they are very important part of tourist attractions, in particular in Croatia. The evolution of the mostly carbonate Croatian rocky coast has resulted in dispersed small gravel beaches (PIKELJ & JURAČIĆ, 2013), and there is a recent tendency to enlarge these beaches and build artificial ones. Both natural and artificial beaches lose sediment during winter months and they need to be regularly replenished due to the lack of natural sediment supply. However, there is a little understanding of how these beaches behave during a range of environmental conditions. For this purposes SfM-MVS approach has been applied. Here we focus on monitoring two beaches situated in Dugi Rat village (Middle Dalmatia, Fig. 1). Glavica is a 170 m long natural beach oriented S-SW to N-NE on a predominantly NW-SE (Dinaric) coastline and thus directly exposed to *Sirocco* waves. Dugi Rat is an 80 m long embayed artificial beach oriented W-NW to E-SE, bordered by stone groins and divided in half by a concrete groin-pier. We present morphological changes on those two beaches after two storm events (*Bora* and *Sirocco* winds) during February 2015.

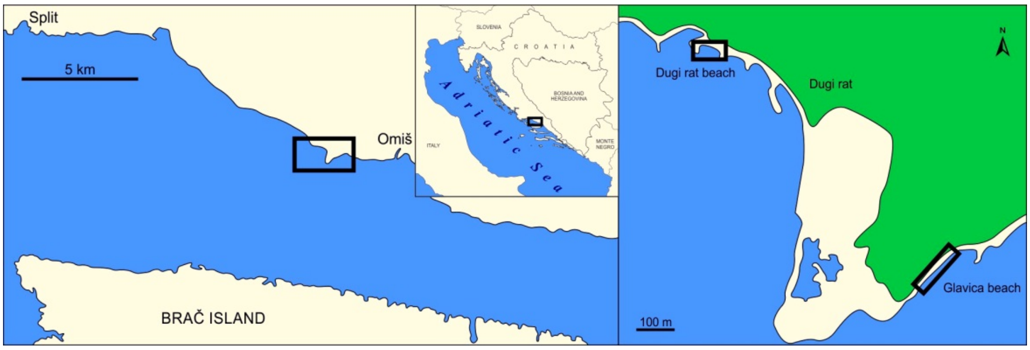


*Figure 1. Location of the study site (left) and the orientation of beaches (right).*

## 2. Materials and methods

Up to 400 and 700 photographs were collected each time on Dugi Rat and Glavica beach respectively, using a Canon EOS 450 D digital camera (with a zoom lens fixed to 18 mm focal length and autofocus), held at eye level and overhead mounted on a pole. “Walk-around” survey scheme was applied to collect photographs covering the study area, following general recommendations given by JAMES & ROBSON (2012) and BEMIS *et al.* (2014) (*e.g.* carried out under diffuse lighting conditions with >60% overlapping between adjacent photos and using convergent imaging directions). The GPCs needed for georeferencing were obtained by virtual reference station real-time kinematic (VRS RTK) positioning method, using Trimble R8 GNSS receiver and CROPOS VPPS service. Horizontal and vertical accuracies were within 2 and 4 cm respectively. Photo processing and DEM generation were carried out with Agisoft

PhotoScan Pro software. The achieved accuracy of DEMs obtained was mostly within the magnitude of dGPS accuracy and thus, the quality of the GPS equipment should be one of priorities for SfM model reconstruction. After being exported from PhotoScan, DEMs have been further analysed for beach volume and topography changes with Golden Software Surfer.

**3. Results and discussion**

In the PhotoScan processing, control point information are included within the bundle adjustment, in contrast to the approach used by JAMES *et al*. (2013) for a similar pocket beach at Uboka cove (Istria, Croatia). As a result, point clouds obtained in this study are of higher precision, having overall root mean square error (RMSE) on the control points ranging between 1.3 cm and 5.7cm, mostly < 2cm, which is within the limits of dGPS accuracy.

Similar to most Croatian beaches, Glavica and Dugi Rat are sufficiently small (10s m to ~100 m in length) and sufficiently textured (since being composed of gravel), to allow a ground-based SfM application to produce satisfactory results. Special care was taken to acquire images during favourable lighting conditions and avoid shadows, as recommended by JAMES & ROBSON (2012). However, only the dry part of the beach could be assessed with this method, and additional methods will have to be used to assess the elevation changes below the sea surface. Nevertheless, significant changes were detected in DEMs of both beaches following stormy events.

The *Bora* event caused generally gentle erosion along the most of the Glavica beach, visible as a narrow strip of sediment loss (up to -25 cm) along the lower beach face. Only most south-western part showed sediment accumulation (up to +20 cm) and a small net gain of sediment (~2 $m^3$) to the small rocky headland preventing further long-shore transport. Such sediment displacement indicates prevailing longshore current from NE to SW.

At the same time, no significant changes in beach elevation were observed along the Dugi Rat beach, except mild sediment loss in its western part. Only the lowest part of the beach was affected due to the reduced water level resulting from higher pressure and onshore wind direction.

In contrast to the *Bora* event, both beaches underwent more significant changes during stormy *Sirocco*. Glavica beach lost ~ 25$m^3$ with the most visible lowering (up to -35cm) occurring in the southwest part and in the middle of the beach. The low air pressure accompanied with *Sirocco* pulls up the sea surface, moving the wave breaking zone onshore. Due to the more powerful waves generated, wave run-up reached the upper part of the beach. This was observed during the storm and evident from a steepening in the beach slope. Analysis of the DEM created after *Sirocco* showed accretion up to +40 cm just of the toe of the beach, in form of several small berms created by swash zone processes of gentle post-storm waves.

Both sections of Dugi Rat beach have shown erosion on the eastern sides, while sediment accumulated on their western sides. This sediment relocation indicates the direction of the longshore sediment transport from east to west caused by *Sirocco* waves. The beach section from the pier to the east has net loss of the sediment, while the section from the pier to the west showed net sediment gain. Since negligible sediment transport was observed over the pier, it is assumed that some sediment was transported toward west around the pier in the nearshore zone.

## 4. Conclusions

The results presented here have shown that SfM-MVS photogrammetry can be successfully applied for frequent beach surveys in order to determine short term changes. No significant elevation changes were observed in the Dugi Rat beach after *Bora* storm. Only minor changes were observed at narrow strip of the lower beach face on the Glavica beach, with net change being accumulation. In contrast, waves induced by *Sirocco* initiated notable longshore and cross-shore sediment transport on both beaches. Due to its direct exposure, wave run-up caused by *Sirocco* event may reach the top of the Glavica beach causing larger sediment movement. Hence, the beach orientation in respect to prevailing wind condition plays an important role for sediment transport direction as well as the volume of sediment relocated.

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