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UAS-SfM as a cost-effective tool for coastal monitoring and management

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Abstract

Coastal zone monitoring is essential in order to understand their evolution and incorporate sustainable coastal management practices. Frequent data collection is essential but often surveys can be costly and time-consuming. Several costly and time-consuming tools and techniques have been developed during the last few years for change detection and monitoring, allowing for both qualitative and quantitative analysis. In this study we present the ability of an off-the-shelf Unmanned Aerial Systems (UAS) coupled with Structure-from-Motion (SfM) photogrammetry to map and measure coastal features (e.g. shorelines). The UAS surveys taken place over three campaigns during Autumn 2017 (November), Spring 2018 (March) and Autumn 2018 (October) in Pinios river deltaic coast. The demonstrated UAS-SfM methodology produced remote sensing data with great spatial resolution which could be used to visually identify important parameters for coastal research and management at a fraction of the cost of other available techniques and. Even an off-the-shelf UAS is suitable for repeat surveys to assess spatial and temporal changes at small spatial extents and to better comprehend how these may be related with site-specific natural processes along the coast.

Keywords Coastal area Monitoring Management Remote sensing Structure from motion.

1 INTRODUCTION

Coastal zone monitoring of dynamic morphodynamical environments such as river deltas is essential in order to understand their evolution and incorporate sustainable coastal management practices. Frequent data collection is essential but often surveys can be costly and time-consuming. This often leads to increase the time lag between successive monitoring campaigns to reduce survey costs, with the consequence of fragmenting the data available for coastal zone management. In this study we present the ability of off-the-shelf Unmanned Aerial Systems (UAS) coupled with Structure-from-Motion (SfM) photogrammetry to map and measure coastal features (e.g. shorelines).

2 MATERIALS AND METHODS

2.1 Study Area

The study area is in Thessaly, an administrative region of Greece, on the western shore of the northwest Aegean Sea in the eastern Mediterranean Sea and the receiving basin is Thermaikos Gulf which extends from Thessaloniki bay to 200 m isobath (Figure 1). Annually, the deltaic coastline is mainly exposed to winds blowing from the north, northeast and east with a frequency of about 17%, 13% and 15% respectively. Additionally, waves have heights of <1 m and of >2 m with a frequency of 83.2 % and 4.82 % respectively (Athanasoulis and Skarsoulis 1992). From the dominant north direction, the fetch is about 105 km and the mean wave height is 0.6 m. Waves from the east have a fetch of 125 km and mean wave height of 0.9 m whereas, waves from the northeast have a reduced fetch of about 60 km and mean wave height of 0.8 m. The longest fetch is from southwest (275 km) but the waves originating from this direction are much less frequent (2.6 %). Hence, the Pinios delta is exposed to long fetches available from N, NE, E and SW (Foutrakis et al. 2007) subjecting the deltaic coastline to a relatively monthly high wave attack of 70-1454 w/m^2 (Poulos et al., 2000). Surface currents are generally weak (<10 cm s^{-1}) (Karageorgis and Anagnostou 2001) and the mean tidal range is 19 cm (Tsimplis 1994). The socio-economic development in the deltaic plain is based on agriculture and tourism. Hence, the cultivated and urban areas have increased significantly over the recent decades and the main land use along the coastline is buildings (e.g. hotels, vacation residences). For the purposes of the study three segments of the deltaic coast were selected; Stomio, Alexandrini and Nea Mesagkala.

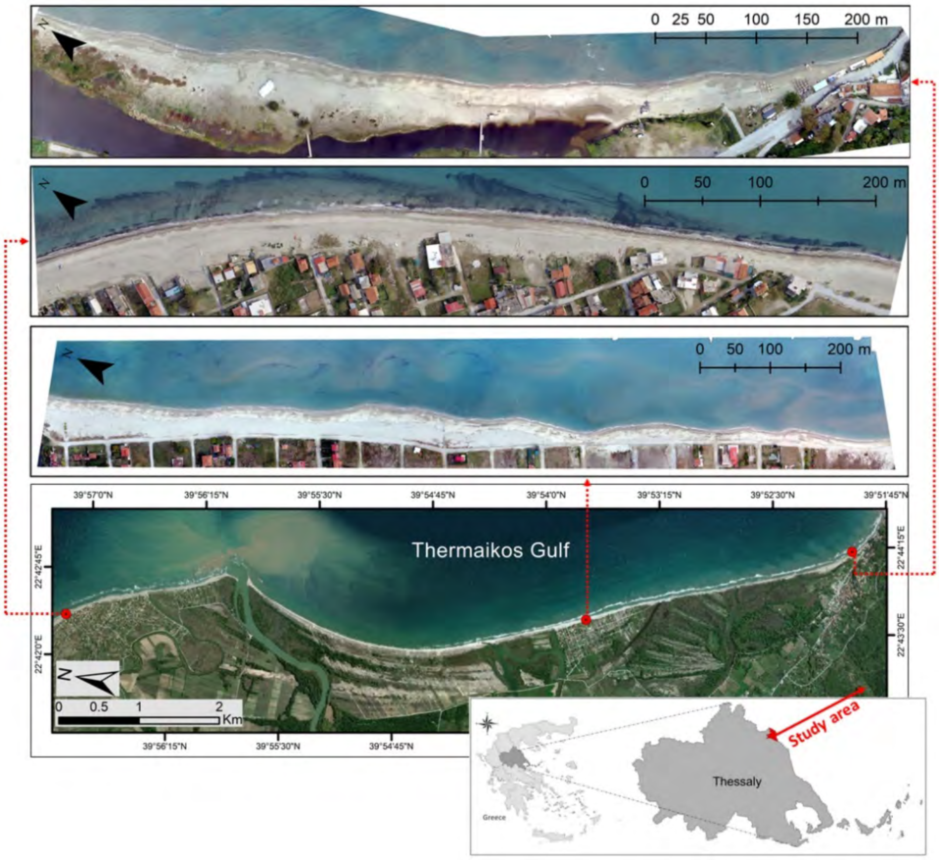

Figure 1 From bottom to top: Study area and UAS surveys in Alexandrini, Nea Mesagkala, and Stomio.

2.2 Methodology

2.2.1 UAS platform and field data collection

We deployed a Phantom 4 (P4) manufactured by DJI Inc. (Shenzhen, China); a popular quadcopter which has many features of interest for scientific applications. The integrated camera can acquire 12-megapixel still imagery and uses a wide-angle rectilinear lens and thus avoid the heavy distortions common with the fish-eye lenses employed in several older drone and camera models. For navigation and flight stabilization, the internal consumer-grade positioning system uses both the GPS and GLONASS systems, increasing the number of satellites used in the position determination. DJI's specifications report a positioning accuracy of ≈2.5 m; adequate especially for the horizontal axis the measurements of which are also used for the alignment of the images captured during the survey. These positions are automatically exported to the EXIF metadata for each image in WGS84 latitude and longitude thus providing a location stamp (geotag) for each image.

The high resolution natural colour aerial images of the three coastal areas were collected over three campaigns in Autumn 2017 (24/11/17), Spring 2018 (11/03/18) and Autumn 2018 (02/10/18). Skies were cloud free and wind speeds never exceeded P4's maximum wind speed resistance (10 m/s). Each fully automated survey was planned and executed with the freeware "Dronedeploy" mobile application which allows the user to define and check effortlessly on site a variety of flight and camera capturing parameters (e.g. flight altitude and resolution, battery usage, front and side overlap etc.) before the image acquisition.

2.2.2 Structure-from-Motion
Visual-topographic point clouds and an orthomosaic were produced using SfM algorithms in Agisoft Metashape Professional software (Agisoft 2019). The SfM workflow to generate a point cloud includes photo alignment and tie point generation, camera optimization, and finally dense point cloud construction. Since fine topographic details were available, the workflow continued with meshing the original images. Texturing was also applied to the resulted mesh in a future step and a high quality orthophoto was generated (Figure 1).

2.2.3 Shoreline change monitoring
The most critical part of the methodology, in terms of shoreline change monitoring, is to identify with high accuracy the separation points between the waterbody and the land. To this purpose, the high quality orthophoto of each period was used (Figure 1). Due to very high density of pixels, the wet and dry areas were detected readily in the image, making the shoreline digitizing procedure an effortless task with very accurate results. Afterwards, the Digital Shoreline Analysis System v.4.3 (DSAS) was employed to estimate the seasonal shoreline changes. It is an extension of the ESRI ArcGIS v.10 software that computes rate-of-change statistics for a time series of shoreline vector data using a measurement baseline method. According to this method, the baseline is constructed by the user and serves as the starting point for all transects cast by the DSAS application. The measurement transects intersect each shoreline at the measurement points used to calculate rates of changes. The distances from the baseline to each intersection point along a transect are used to compute the selected statistics. For the purpose of this study an onshore baseline was constructed roughly parallel to the general trend of the coastline and transects were spaced at 5 m intervals. Although there are several methods for calculating the rate-of-change by DSAS, Net Shoreline Movement (NSM) method was chosen to analyze the shoreline changes. It is associated with the dates of only two shorelines and reports not a rate but the distance between the oldest and youngest shorelines for each transect (Thieler et al. 2009).

3 RESULTS AND DISCUSION

3.1 Nea Mesagkala
This segment is located north of Pinios river mouth and is characterized by the expanding residential use of the beachfront over the past 30 years not within a coastal management framework. Also, during the summer season the beach is modified to create more space for recreational use. SCE analysis showed that the lowest maximum total change in shoreline movement is observed at Nea Mesagkala (13 m) among the three studied areas. In terms of NSM analysis, 78% of the shoreline has propagated from 11/2017 to 03/2018 (winter period) and 69% retreated from 03/2018 to 10/2018 (winter-summer) (Figure 2a and 2b). The same analysis for the period 11/2017-10/2018 reports that 77% of the shoreline has propagated (Figure 2c). Although SCE and NSM analysis reported insignificant net retreat during the monitoring period, this part of deltaic coast is the most vulnerable and susceptible to increases in wave runup, storms and inundation because of its physical attributes (e.g. gentle slope, small width, absence of dune system). As shown in Figure 3a at some parts of the stretch coastal buildings are affected by storms originating from the less frequent east and southeast waves during the year.

3.2 Alexandrini
This segment is located between the river mouth and Stomio and together with Nea Mesagkala is highly anthropized with many fixed structures along the beachfront. However, Alexandrini represents a more natural beach system than the Nea Mesagkala. DSAS analysis reported that maximum total change in shoreline movement in this part of deltaic coast is 19.3 m while the 67% and 62% of the shoreline retreated the periods 11/2017-03/2018 and 03/2018-10/2018 respectively. Even though, the above statistics suggest a risky and hazardous setting for coastal structures along the stretch, the undisrupted, in most cases, dune system, provide a buffer against extensive shoreline retreat and wave overtopping during storm events and provide a source of sand to replenish the beach during periods of

erosion a buffer against sea erosion and wave overtopping during storm events (Figure 3c).

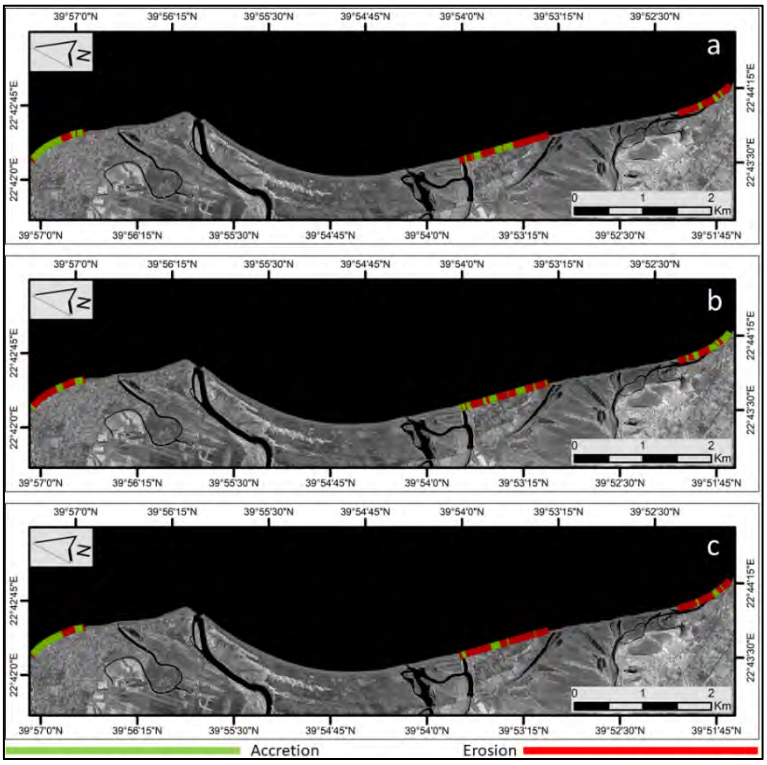

Figure 2 Results of NSM analysis during three periods: a) 11/2017 –03/2018, b) 03/2018 – 10/2018 and c) 11/2017-10/2018.

3.3 Stomio

Stomio, positioned at the south edge of the deltaic coast, is not characterized by urbanization like the other two segments and can be considered as natural dynamic system controlled mainly by physical processes. It has the widest beach in the entire study area and hosts the mouth of an abandoned channel of Pinios river. Usually, during wet period the mouth is opened dividing the beach into two segments.

Figure 3 The potential of UAS surveys in coastal monitoring: a)old/contemporary wave runup level and disrupted dune at a part of Nea Mesagkala beach characterized by shoreline retreat during whole monitoring period, b) vegetated dunes and wave runup in Nea Mesagkala, c) beach cusps and eroded dune in Alexandrini

and d) beach cusps and winter vegetation in Stomio.

and providing additional sediment input. During the dry period the mouth is closed, and the beach is used for recreational and touristic purposes. Among the three studied segments, SCE analysis presented that the greatest maximum total change in shoreline movement for all available shoreline positions is observed at Stomio (34 m). However, the big beach width dissipates wave energy and consequently decreases the impact of storms. Like Alexandrini, exhibits almost identical trend through the monitoring period in terms of shoreline movement; 80%, 43% and 83% of the shoreline has retreated during the periods 11/2017-03/2018, 03/2018-10/2018 and 11/2017-10/2018 respectively.
It is worth noting that during the period 11/2017-03/2018 while in Nea Mesagkala most of the shoreline (78 %) has propagated in Alexandrini and Stomio most of the shoreline has retreated. Probably this difference was caused by flood incident occurred 15 days before the UAS survey. Nea Mesagkala beach being very close to the Pinios river mouth affected by the plume dispersion in a greater degree than the other two sites.
Finally, beach cusps, dunes and vegetated areas were detected and recorded easily at different sites and dates; their size and position could potentially provide valuable information about the state of the beach (accretion/erosion) and the related wave regime.

4 CONLUCIONS

The use of UAS-SfM has enhanced the ability of monitoring coastal features. Thus, the extraction of the shoreline position was very precise (e.g. clearly visible berm, swash zone, beach step) and the resulted statistics characterized by very low uncertainty. UAS-SfM produces remote sensing data of great spatial resolution which could be used to visually identify important parameters for coastal research and management at a fraction of the cost of other available techniques and means (e.g. topographic surveys, airborne lidar and high-resolution satellite images). This method can serve as an important tool for coastal management because it is suitable for repeat surveys to assess spatial and temporal changes at small spatial extents and to better comprehend how these may be related with site-specific natural processes along the coast.

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