USE OF RPAS TO MONITOR COASTAL DUNE SYSTEMS AND BEACH EROSION IN GUARDAMAR DEL SEGURA, SPAIN

José Ignacio Pagán[1], Luis Bañón[2], Pablo Ortíz[2], Luis Aragonés[2], Isabel López[2]

[1]University of Alicante, Department of Civil Engineering, Carretera San Vicente del Raspeig s/n - 03690 San Vicente del Raspeig, Alicante (Spain), phone +34 965902379, e-mail: jipagan@ua.es

[2]University of Alicante, Department of Civil Engineering.

Abstract – Coastal dune ecosystems had a crucial role in coastal dynamics, so it is essential to measure their movements precisely and monitor their changes over time. The natural interactions can be altered by anthropic pressure, modifying the coastal dynamics, causing alterations in beaches and dunes and affecting their stability. In recent years, the appearance of affordable low take-off weight Remotely Piloted Aircraft Systems (RPAS), together with the development of image-based computing techniques such as Structure-from-Motion (SfM), has increased the use of RPAS-based photogrammetry to produce high-resolution digital elevation models (DEMs) for the study of different surface processes, and specifically, for surveying dune ecosystems. This study aims to evaluate the applicability of RPAS to conduct periodic accurate studies at an affordable cost, to monitor the evolution of the coastal system of beaches and dunes, as well as the erosion caused by coastal regression. The study is focused on Guardamar del Segura, Alicante (Spain), an area strongly affected by anthropogenic pressure and coastal erosion. The methodology applied used a DJI Phantom 4 quadcopter, a device with a high ratio of sensor quality and performance at a very reasonable cost. The flights were planned so that the study area, with a length of 3.2 km long and 150 m wide (0.51km^2), was covered in 4 passes. A series of targets distributed throughout the study area were used as ground control points (GCP) for the photogrammetric georeferencing process. Its coordinates were surveyed by a Leica Zeno FLX100 GNSS, which provides an accuracy of its measurements of 2 cm horizontal and 3 cm vertical. The SfM algorithm enables the reconstruction of a 3D scene by resolving the geometry of the images, the camera positions and their orientation simultaneously using Agisoft Methashape software. The Digital Surface Models (DSM) obtained from the RPAS with the SfM-MVS algorithm have a high density (450 pts/m^2) and high accuracy, with RMSE in both the GCPS and check points < 3 cm in horizontal and < 1 cm in vertical measurements. The orthophotos and DSM generated have a spatial resolution of 2.5 cm/pixel. This very high resolution enables to accurately detect the shoreline, the dune limits and anthropogenic actions, as well as the shape of the dune and beach. Also, to monitor changes and the effects of storms precisely. Significant erosion has been detected along the entire length of the coastal area, as well as a movement towards the interior of the dune ridge was detected. In conclusion, the complex dune ecosystem and beaches of Guardamar del Segura has proven to be an excellent test site for monitoring coastal processes using a small, lightweight, easily deployable and affordable commercial RPAS. The possibility of quickly obtaining orthophotos and Digital Surface Models of very high resolution, covering large extensions at a low cost, enables us to model and monitor these rapid-changing environments with regularity and accuracy.

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Introduction

Coastal dune ecosystems had a crucial role in coastal dynamics, so it is essential to measure their movements precisely and monitor their changes over time. In addition, anthropic actions, modifying the coastal dynamics may cause alterations in beaches and dunes and affect their stability [8]. Dunes in coastal environments are challenging landforms to analyse, due to the complex interaction among topography, vegetation, aeolian and marine processes that affect them [14]. Traditional surveying methods frequently require a large amount of time and labour for obtaining accurate data, even using technologies such as global navigation satellite system (GNSS) using real-time kinematic (RTK) for surveying [7]. Although the use of transects might be adequate for modelling a beach, in a dune area the likelihood of correctly representing the behaviour of a wider zone using transects decreases [1]. Additionally, the reduced resolution of the field data often makes it difficult to obtain precise volumetric measurements of the dune system and thus to accurately monitor the changes.

In recent years, the appearance of affordable low take-off weight Remotely Piloted Aircraft System (RPAS), together with the development of image-based computing techniques such as Structure-from-Motion (SfM), has increased the use of RPAS-based photogrammetry to produce high-resolution digital elevation models (DEMs) for the study of different surface processes [6], and particularly, for surveying dune ecosystems [3]. It enables the study of the coastal strip with fast and high-performance surveys, at the desired sample frequency and with accurate results [13].

This study is focused on Guardamar del Segura, Alicante (Spain), an area strongly affected by anthropogenic pressure and coastal erosion [11]. The aim is to evaluate the applicability of RPAS to conduct periodic accurate studies at an affordable cost, to monitor the evolution of the coastal system of beaches and dunes, as well as the erosion caused by coastal regression.

Materials and Methods

The area of study encompasses the coastal area that extends from the north of the town of Guardamar del Segura, Alicante, located on the southeast Mediterranean coast of Spain. It covers two beaches, one southward of the mouth of the Segura River, Los Viveros Beach, and the other one to the north, Los Tusales beach (Figure 1). Its main characteristics are described in Table 1. Both are open sandy beaches in the natural coastal dune park named Dunes and Pine Forest of Guardamar del Segura, declared a Site of Community Interest (SCI) due to their unique landscape and ecosystems. The breakwaters located at the mouth of the Segura River had affected these nearby beaches, causing the North-to-South longitudinal transport to be cut and thus an erosive process in Los Viveros Beach [2].

The total surface area covered in this research was 0.51 km^2, forming a rectangular region with a length of 3.2 km and a width of 150 m (Figure 1c). The predominant wind directions are ENE and NE, both with a frequency of 15 % with maximum speeds not exceeding 10 m/s. The tidal range is only influenced by weather conditions, giving values of approximately 0.30 m [4]. The study area is subject to tremendous anthropogenic stress. A marina was built in 1998 and restoration to recover the foredune from the different aggressions it was suffering was planned in 2002 and finally completed in 2011 [11].

Table 1 – Main characteristics of the beaches studied.

	Los Viveros beach	Los Tusales beach
Length (m)	1620	1780
Average width (m)	14	25
Sediment type	Fine golden sand	Fine golden sand
D_{50} (mm)	0.228	0.220
Urban development	No	No
Dune ridge	Yes	Yes

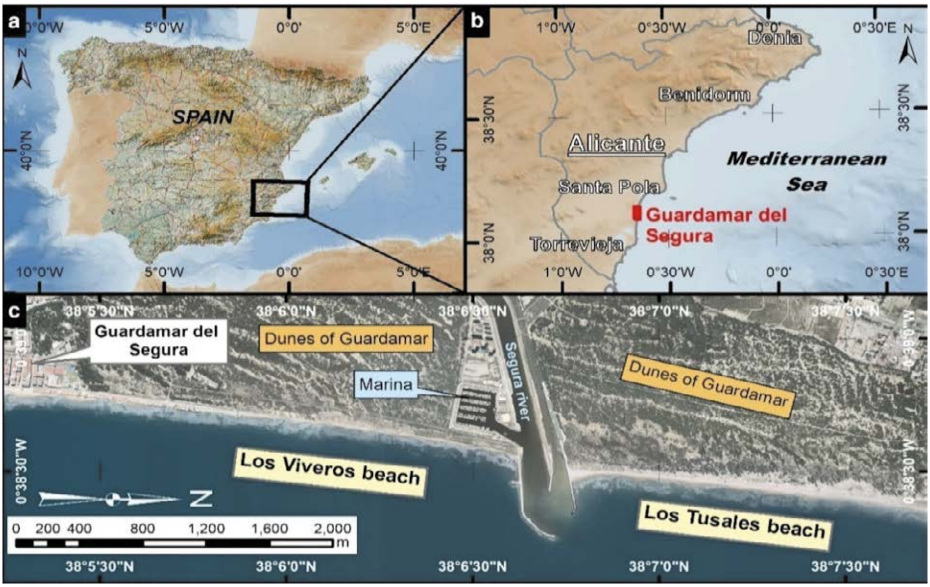

Figure 1 – Area of study located on the Mediterranean coast of Spain (a), in the south of the province of Alicante (b) northward of the town of Guardamar del Segura (c).

The RPAS used was a DJI Phantom 4 quadcopter, a device with a high ratio of sensor quality and performance at a very affordable cost (valued at 1500€). It was equipped with an FC330 built-in camera and a 1/2.3” CMOS sensor with a resolution of 12.4 Mpix. A Leica Zeno FLX100 GNSS antenna was used for surveying, enabling professional data capture in an ultra-portable housing at a very reasonable cost (3500€). The accuracy obtained using RTK with the NTRIP-based network solution linked to the GNSS ERVA reference station network via GPRS/3G connection was 2 cm horizontal and 3 cm vertical. Data processing was carried out using a Dell WorkStation with an Intel Xeon W2123 at 3.6 GHz, 16GB of RAM and a GPU Nvidia Quadro P2000. The general workflow followed is shown in Figure 2.

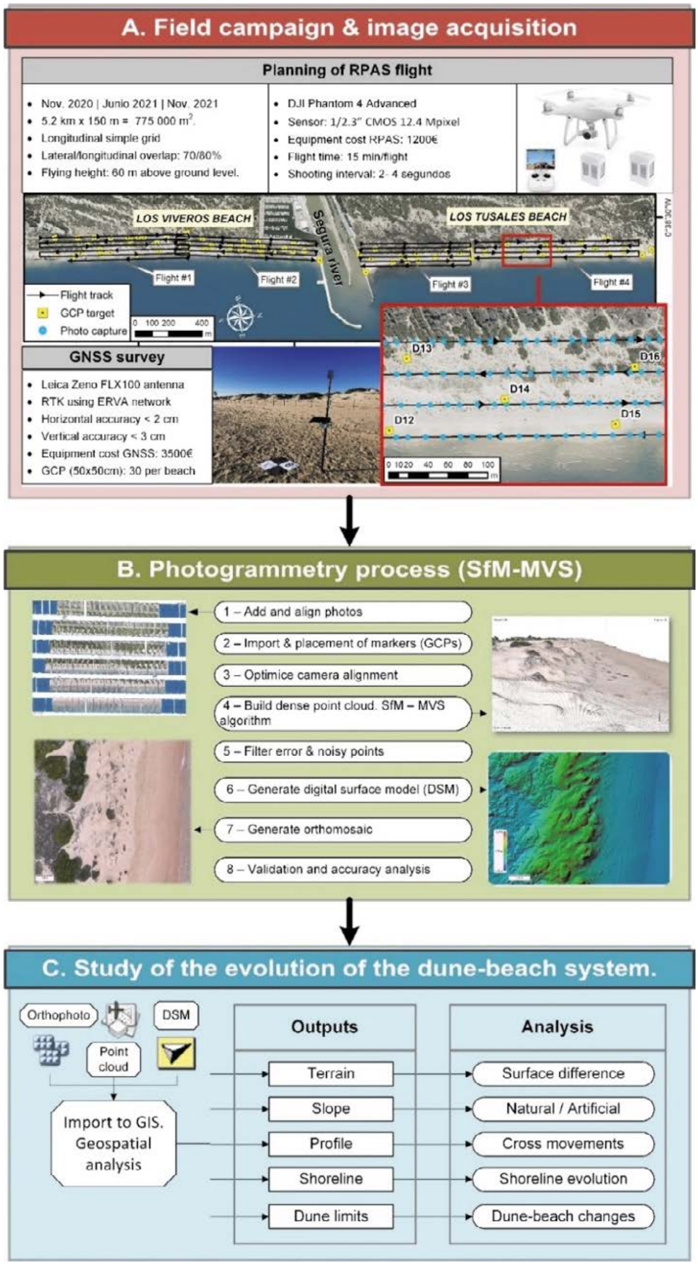

Figure 2 – General workflow followed, (A) field campaign and image acquisition, (B) the photogrammetry process using SfM-MVS algorithm and (C) study of the evolution of the dune-beach system using geospatial GIS techniques.

Three flight campaigns were carried out in November 2020, May 2021 and November 2021. The flight altitude was set at 60 m above ground level, taking a picture every 2–4 s. The latitudinal overlap was set to 70 %, and the longitudinal overlap was fixed to 80 %. The flights were planned so that each beach was covered in 2 passes, with approximately 600 images per campaign captured. At the same time, a series of 50x50 cm targets distributed throughout the study area (30 per beach) were used as Ground Control Points (GCP) for the photogrammetric georeferencing process.

The photogrammetry process using the Structure-from-Motion MultiView Stereo algorithm enables the reconstruction of a 3D scene by resolving the geometry of the images, the camera positions and their orientation simultaneously using Agisoft Methashape software (Figure 2B). The GCP surveyed by GNSS improves the model reconstruction results. Once the accuracy is satisfactory, a reconstruction processing algorithm is applied to generate the dense point cloud with RGB colours (Figure 3C). Through the calculus of the confidence parameter, the noisy areas of the dense cloud (e.g. the sea) can be deleted prior to generating a full Digital Surface Model (DSM) (Figure 3B). This DSM was used to create an orthomosaic of the entire monitored area (Figure 3A).

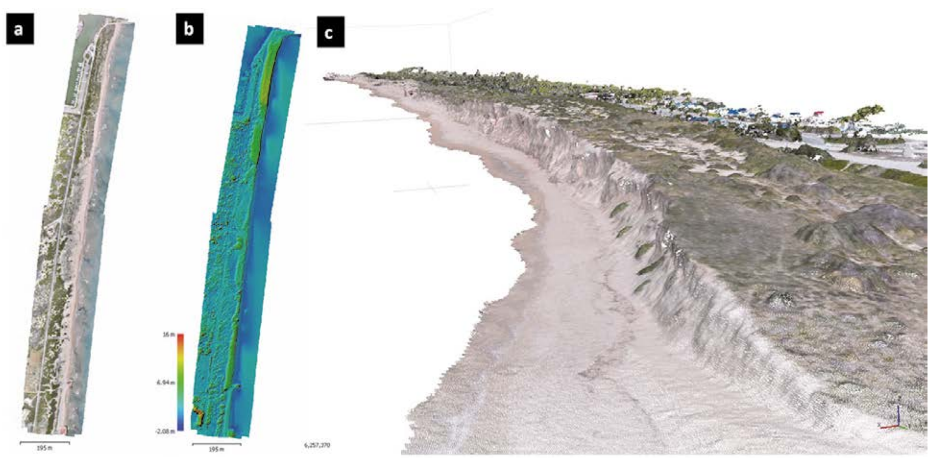

Figure 3 – Orthomosaic (a) DSM (b) and detail of the dense point cloud in Los Viveros beach.

The last phase was the study of the evolution of the dune-beach system (Figure 2C). The datasets created for each surveyed period (orthomosaics, cloud points and DSM) were imported into a GIS environment to perform geospatial analysis. A terrain dataset is a multi-resolution TIN-based surface created from measurements stored as entities in a geodatabase. The slope of the surface is generated from the DSM, enabling the analysis of the stability of the dune slopes and whether they correspond to a natural slope (when the value is below the friction angle of sand, 35°) or if is higher and may represent an artificial material or instability risk. An advantage of using DSMs is that it is possible to interactively generate cross-shore transects anywhere in the study area for each date studied. The position of the shoreline and the dune foot is also identified. The shoreline for the RPAS survey had been manually delineated using the orthophoto generated. The criteria to identify the shoreline were marking the high-water mark on the beach [9]. Also, for the dune foot, the line was delineated by the combination of visual identification on orthoimages and changes in the slope of the DSM. Finally, changes were detected between the available periods (25 November 2020 – 31 May 2021, 31 May 2021 – 30 November 2021) as well as within the total study period (25 November 2020 – 30 November 2021) to see interannual changes.

Results

The DSMs obtained from the RPAS with the SfM-MVS algorithm have a high density (450 pts/m^2) and high accuracy, with RMSE in both the GCPS and check points < 3 cm in horizontal and < 1 cm in vertical measurements. The orthophotos and DSM generated have a spatial resolution of 2.5 cm/pixel. This very high resolution enables to accurately detect the shoreline, the dune limits and anthropogenic actions, as well as the shape of the dune and beach. Also, to monitor changes and the effects of storms precisely (Figure 4).

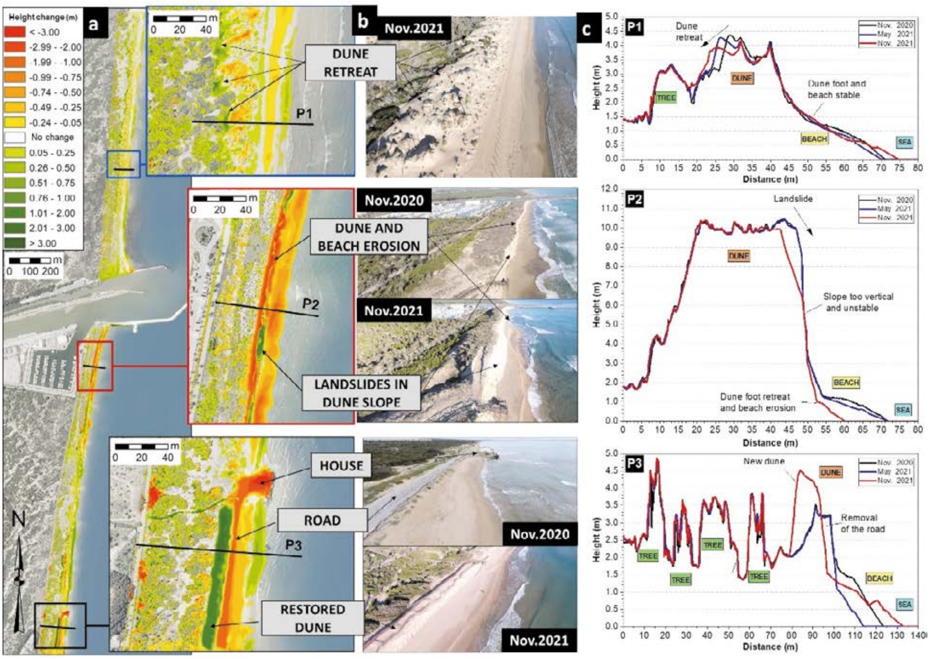

Figure 4 – Height changes obtained from DSM difference between November 2020-November 2021, with areas of interest showing changes in dune and beach (a). Aerial views obtained from videos recorded during the RPAS surveys (b) and cross-shore profiles with changes marked (c).

At Los Tusales beach, stability in the sedimentary budget is observed, although there is a movement towards the interior of the dune ridge. Shoreline also remains stable. However, in Los Viveros beach, southern of the breakwaters of the mouth of the Segura River, significant erosion has been detected along its entire length. The shoreline has retreated up to 10 m whereas the dune foot recedes 3 m. The dune slope in this strip of the coast is almost vertical (>75º) due to the erosion of the storms that hit this beach during the year studied. A volume of 11 520 m^3 of sand has been lost in one year.

Restoration actions were also detected and monitored in the south part of Los Viveros beach, an area extremely affected by erosion at the point that the existing road and houses had to be demolished. 150 m of new dune at a height of +4.5 m.a.s.l. were created and beach width was recovered.

Discussion

This study validates the use of aerial photogrammetry techniques using low take-off weight RPAS and their subsequent treatment with SfM-MVS algorithms for the generation of low-cost and high-quality DSMs. The outcomes in terms of accuracy are comparable to those obtained by diverse researchers [5, 12] and improve the first attempt made by the authors in 2017 [10]. Overall processing time using a new workstation (less than 3 hours for the whole photogrammetry workflow) has led to an enhancement in the spatial resolution of the outputs, obtaining points cloud with more than 265 million points that enable to modelling of the dune-beach system very accurately. The surveying time is also dramatically reduced from classic topography survey methods, covering the two beaches with only 4 flights of 15 minutes each, permitting to cover an area of 0.51 km^2 in one morning. That is an important factor, especially for extensive and inaccessible zones such as beaches or dune fields [3].

However, there are some drawbacks to this approach. Firstly, flight regulations can be restrictive on the areas to survey, especially near populated areas [10]. Secondly, the SfM-MVS technique generates a dense point cloud of the surface that can be converted in a DSM, but height can come from the top of buildings, tree canopy, powerlines and other features, so it is necessary post-processing to mask the areas with this undesired data [12].

The results obtained in the period of study show that the erosive trend detected in previous research in Los Viveros beach [2, 10] has continued, whereas Los Tusales Beach is stable. The lack of enough backshore width could have led to the increase in the erosion detected in the last period. Wave attack may also create a notch at the dune foot leading to mass failure: the collapse of a dune slab. That could also explain the steeper slope observed on the seaward side of the coastal dune on the north strip of this beach. Apart from the erosive coastal dynamics mentioned above, the effect of anthropogenic actions must be added. For instance, the continuous process of regrading the seaside slope of the dune, detected during the monitoring, increases the retreat of the foot dune.

The novelty of this research is the extensive field survey conducted using RPAS, outlining the significant reduction in time and costs instead of classical surveys, providing regular and detailed analysis of the evolution of these rapidly changing systems based on quality data and enabling coastal managers to adopt appropriate maintenance decisions.

Conclusion

The complex dune ecosystem and beaches of Guardamar del Segura has proven to be an excellent test site for monitoring coastal processes using a small, lightweight, easily deployable and affordable commercial RPAS. Despite the existing minor drawbacks, the advantages of RPAS surveys combined with SfM-MVS methodology make this method suitable for coastal dunes and beach surveys. The possibility of quickly obtaining orthophotos and Digital Surface Models of very high resolution, covering large extensions at a low cost, enables to model and monitor these rapid-changing environments with regularity and accuracy.

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