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Research Note

Investigating the Use of UAV Systems for Photogrammetric Applications: A Case Study of Ramla Bay (Gozo, Malta)

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Abstract. In this study, we present the 3D digital model of Ramla Bay (Gozo) obtained by using photograms taken from drones. The high-resolution 3D model of Ramla Bay allowed the construction of a detailed Digital Elevation Model (DEM). Comparison of an earlier LIDAR data derived DEM (ERDF 156 Data, 2013) and the photogrammetric DEM developed in this study allowed to make preliminary observations regarding the potential evolution of the coastal area over the last 5 years. This study serves as a proof of concept to demonstrate that coastal evolution can be quantitatively analysed in terms of changes of the sand dune systems. Furthermore, the technique used in this paper represents a good compromise in terms of cost effectiveness and a valid substitute for laser scanner survey. It is also useful for monitoring the dynamics of the beach-dune system and the characterization of the coast for the mitigation of coastal erosion.

Keywords: Photogrammetry, Ramla Bay, DEM, Drone, UAV, 3D Digital Model

1 Introduction

In recent years, approaches, technologies, and software for creating digital models of reality have undergone significant advancement. Acquisition time, post-processing tools and cost have also improved considerably. Digitization now allows reliable coverage of artefacts, ranging from small gauge (e.g. an archaeological prehistoric stone tool Crupi et al., 2016; D'Amico et al., 2017) to larger scales (e.g. building, urban segments or habitat areas Crupi et al., 2017). One of the 3D digitization and reconstruction techniques is known as photogrammetry. While no universally accepted definition of photogrammetry is available, it can be described as a science to obtain reliable information about the spatial properties of land surfaces and objects, without physical contact (Schenk, 2005). Photogrammetry provides methods to obtain quantitative information and is often defined as the "science of measurement through aerial photography". However, it is traditionally part of geodesy sciences, belonging to the field of remote sensing (RS). Through its application, it is possible to determine distance, area and other geographical information, provided that reference terrain coordinates are available; from this one can then calculate geometric data or create detailed cartography.

The fundamental principle used in photogrammetry is triangulation (Figure 1). By taking photographs from at least two different locations, so-called "lines of sight" can be developed from each camera to points on the object. These lines of sight are mathematically intersected to produce the three-dimensional coordinates of the points of interest (Nisha, 2013). While from a single photo (with a two-dimensional plane) one can only obtain two-dimensional coordinates, stereoscopic viewing may be employed to obtain three-dimensional information. Essentially, if there are two (or more) photos of the same object but taken from different positions, one may easily calculate the three-dimensional coordinates of any point which is represented in both photos. Therefore, through the use of photogrammetry, it is possible to calculate the three-dimensional object coordinates for any object point represented in at least two photos. If this task is completed by using several images, it is possible to digitize points, lines and areas for map production or calculate distances, areas, volumes, slopes and much more. In addition, photogrammetry also enables one to

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measure fast moving objects. This can include running or flying animals or even waves. In industry, high-speed cameras with simultaneous activation are used to obtain data about deformation processes (such as those observed in car crash-tests). A further advantage of photogrammetric matching techniques is the fact that they are relatively fast and cheap in respect to the traditional laser scanner techniques (Nuikka et al., 2008), which are nowadays widely used in terrain models generating large amounts of 3D point data.

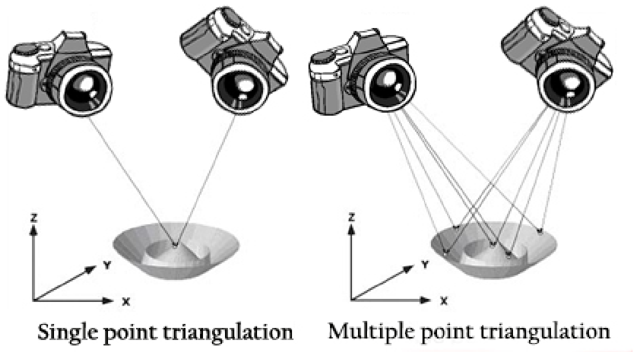

Figure 1: Schematic triangulation processes for photogrammetry.

Protection and proper management of archaeological sites are essential for studying and interpreting old cultures by preserving any artefact for the benefit of present and future generations. Photogrammetry can represent a key factor and in recent years it has been applied to planning, recording, reconstruction, and revitalization of world heritage sites (Al-Ruzouq, Al-Rawashdeh, Tommalieh & Ammar, 2012). It can also be used for supporting open-pit mine excavation stages and to plan rehabilitation strategies (Esposito, Mastrorocco, Salvini, Oliveti & Starita, 2017) as well as for forestry and management planning (Mafanya et al., 2017) and disaster management (Vetrivel, Gerke, Kerle, Nex & Vosselman, 2016; Gómez, White & Wulder, 2016). In fact, oblique aerial images offer views of both building roofs and façades and thus have been recognized as a potential source to detect severe building damages caused by destructive disaster events such as earthquakes. They, therefore, represent an important source of information for first responders or other stakeholders involved in the post-disaster response (Vetrivel et al., 2016).

1.1 Test Site

The test site, Ramla Bay (*Malt. Ir-Ramla*), is located on the northern coast of the island of Gozo (Figure 2). The area is characterized by the typical 'cake-layer' Maltese stratigraphic sequence, comprising, in the case of the study site, Miocene rocks. The islands are composed of a five-layer sequence of Oligocene–Miocene limestones and clays, with the compact Lower Coralline Limestone (LCL) being the oldest exposed layer, and forming steep-sided cliffs along the southern coast of Gozo. In order of decreasing age, the next four layers are the Globigerina Limestone, a fine-grained foraminiferal limestone; the Blue Clay (BC) formation, a series of carbonate-poor clays and marls that is highly erodible and plastic when wet; the Greensand, a thickly bedded, coarse, glauconitic, bioclastic limestone, which forms sharp contact with Blue Clay and a more transitional contact with the younger stratum above it; and, the Upper Coralline Limestone (UCL), a patch reef, cross-bedded oolitic biocalstic limestone that is similar to the LCL and forms a well-developed karst landscape (Pedley, House & Waugh, 1978, 2002, and references therein). Deposits of Quaternary age can be observed within the area in question in the form of consolidated hill-slope material and sheen deposits.

Ir-Ramla is a typical pocket embayment, nestled between two promontories, plateau extensions of the villages of Xagħra to the west and Nadur to the east. The promontories are bisected by broad valley slopes, the bed of which commences as Wied il-Ħannaq at the system's headwaters at Ta' Hida in Nadur, snaking its way towards the coast through Blue Clay slopes and resting on Globigerina Limestone geology (Scerri, 2003). At its mouth, the bay supports a fine sand beach and Elytrigia foredunes comprising Quaternary blown material as a result of weathering processes and splash erosion of Għajn Melel Member rocks (the basal unit of the UCL, which lies atop the Greensand stratum), (Micallef, Lanfranco & Schembri, 1994; Cassar & Stevens, 2002). Mass movement on the upper Ta' Venuta slopes (including slope failure and slippage around the base of the escarpment) is the process responsible for these scarp line fragments to accumulate nearer the shoreline, often forming boulder fields in relatively shallow waters of the bay (Scerri, 2003). A considerable amount of sand at ir-Ramla also originates from Wied il-Pergla to the west, as sediment is transported via run-off waters during the wet season (Cassar & Stevens, 2002).

2 Methodology

2.1 Data Collection

To build a 3D model using photogrammetry, many types of images can be used such as satellite, airborne, balloon, UAVs (Unmanned Aerial Vehicle), terrestrial and even underwater images. It is, however, necessary to have at least 2 overlapping images of the same scene in order to derive 3D information. In recent years, UAV photogrammetry imaging applications have increased rapidly due to the lower costs of a UAV for aerial surveying associated with the relative simplicity in operating such systems. With GPS equipped drones, digital cameras

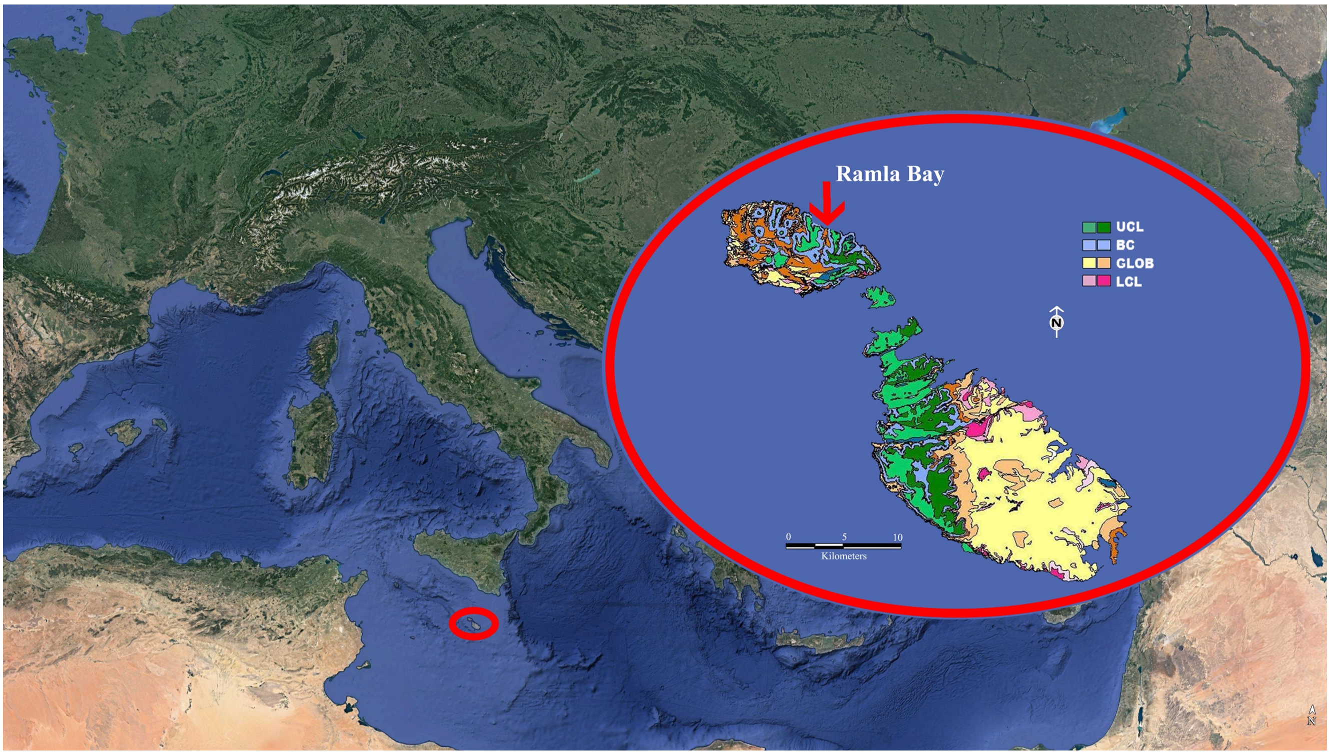

Figure 2: Geographic location of Maltese Islands and simplified geology map; modified from Oil Exploration Directorate (1993). Arrow indicates the location of the study area.

and powerful computers, surveys with an accuracy of 1 to 2 cm are possible (Corrigan, 2017).

In this study, a survey was carried out using a light drone (DJI Phantom 4) equipped with a camera. The main features of the system are reported in Table 1. The flight was performed in manual mode at a height of 50 m above sea level (Figure 3). Throughout the area of interest 10 markers were placed on the ground and the relative spatial coordinates were taken through the use of a GPS. This was done to ensure correct and precise georeferencing of the area in order to properly export the final 3D to scale. Approximately 150 images were acquired during two separate surveys. The images were acquired keeping the camera at the minimum focal length (20 mm), while the image resolution was set at the highest level (4000×3000 pixels) in order to acquire good quality textures. The images were taken from a nadir-looking direction, and about 70% forward overlap and 60% side overlap.

Table 1

Drone features	Camera features
Name Model: DJI Phantom 4	Sensor 1/2.3” CMOS
Weight (Battery & Propellers Included) 1380 g	Effective pixels: 12.4 M
Max Ascent Speed S-mode: 6 m/s	Lens FOV 94° 20 mm (35 mm format equivalent) $f/2.8$ focus at ∞
Max Descent Speed S-mode: 4 m/s	ISO Range 100–3200 (video)
Max Speed S-mode: 20 m/s	100–1600 (photo)
Max Flight Time Approx. 28 minutes	Electronic Shutter Speed 8 – 1/8000 s
Satellite Positioning Systems GPS/GLONASS	Image Size 4000 × 3000, Photo JPEG, DNG (RAW)

2.2 Data Processing

The development of the 3D model has been performed with free and open source software like VisualSFM, Meshlab and Blender. For the orthorectification process 10 ground control points collected from a GPS survey were used as the geographic references.

Generally, the final goal of photograph processing with photogrammetry software is to build a Digital Elevation Model (DEM) or/and a Digital Terrain Model (DTM). For this goal, the procedure of photograph processing and 3D model construction comprised five main stages (Figure 4):

Figure 3: Drone flight plan during the survey. Red dots indicate the UAV position during the image acquisition.

1. *Image acquisition and selection*: Images were acquired through the use of a digital camera installed on the drone assuring a good amount of image overlapping. Preliminary processing was carried out in order to discard those of poor quality.
2. *Camera alignment*: This step consisted of searching for common points on photographs and matches through the use of appropriate software. It also identified the position of the camera for each picture and refined camera calibration parameters. As a result, a sparse point cloud and a set of camera positions were formed. The sparse point cloud represents the results of photo alignment which are not directly used in the 3D model construction procedure. On the contrary, the set of camera positions is required for further 3D model reconstruction.
3. *Building dense point cloud*: The third stage involved the building of a dense point cloud based on the estimated camera positions and pictures themselves. A dense point cloud may be edited and classified prior to export or proceeding to 3D mesh model generation.
4. *Building mesh*: At this stage the software was used to reconstruct a 3D polygonal mesh representing the object surface based on the dense or sparse point cloud according to the user's choice. Some corrections, such as mesh decimation, removal of detached components, closing of holes in the mesh, smoothing, were performed.
5. *Building texture*: After the geometry (i.e. mesh) was reconstructed, it could be textured and/or used for orthomosaic generation. After that, the 3D model was created and exported in several digital formats.

3 Results and Discussion

Using reality-based 3D models it was possible to derive metric data that are useful for several kinds of investigations such as the generation of ortho-images, detailed site maps, archaeological excavations and mapping, and segmented high-resolution 3D models to highlight construction techniques, sequences, restorations, etc. The photogrammetric techniques require experience and a correct acquisition of images. The technique used in this paper represents a good compromise in terms of cost effectiveness and a valid substitute for laser scanner survey which can be very expensive in terms of equipment and/or external surveys. Field application of a laser scanner also requires a lot of time and experience during laboratory post-processing stage.

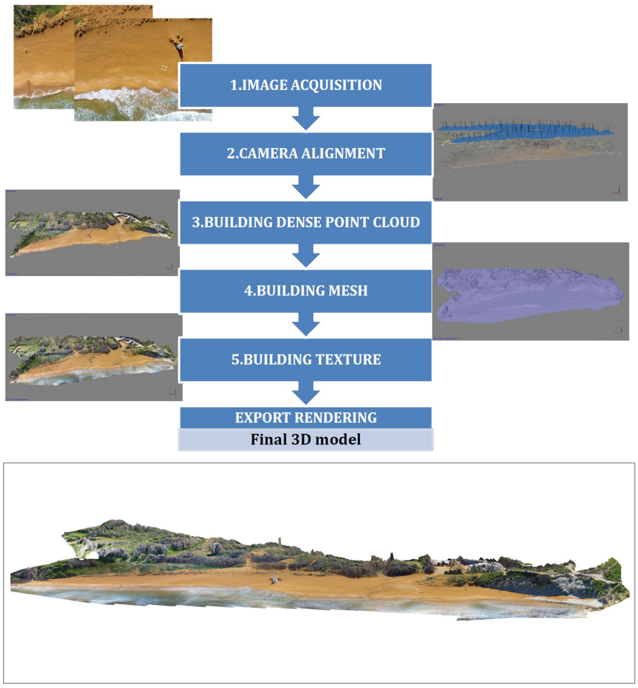

Figure 4: Workflow processing to obtain the final 3D model.

The high-resolution 3D model of Ramla Bay (Figure 5) allowed the construction of a detailed Digital Elevation Model (DEM). Comparison of this product with LiDAR-derived DEM (ERDF 156 Data, 2013) allowed the authors to make preliminary observations regarding the potential evolution of the coastal area over the last 5 years. LiDAR-derived DEM of the Ramla valley has already been used to map the degree of soil erosion in the area (Galdies, Azzopardi & Sacco, 2015).

Using the obtained 3D digital model, it was also possible to extract the profiles of the Ramla Bay's beach. DEMs obtained by LiDAR and Photogrammetry were superimposed and 4 topographical sections were tracked. Through a free and open source Geographic Information System software (QGIS) it was possible to extract 8 topographic profiles that were used for comparison. The obtained graphs have been superimposed to highlight the differences in profile elevations and it can be observed how the shape and volume of sand dune

Figure 5: High-resolution, oblique image of the 3D model generated for Ramla Bay.

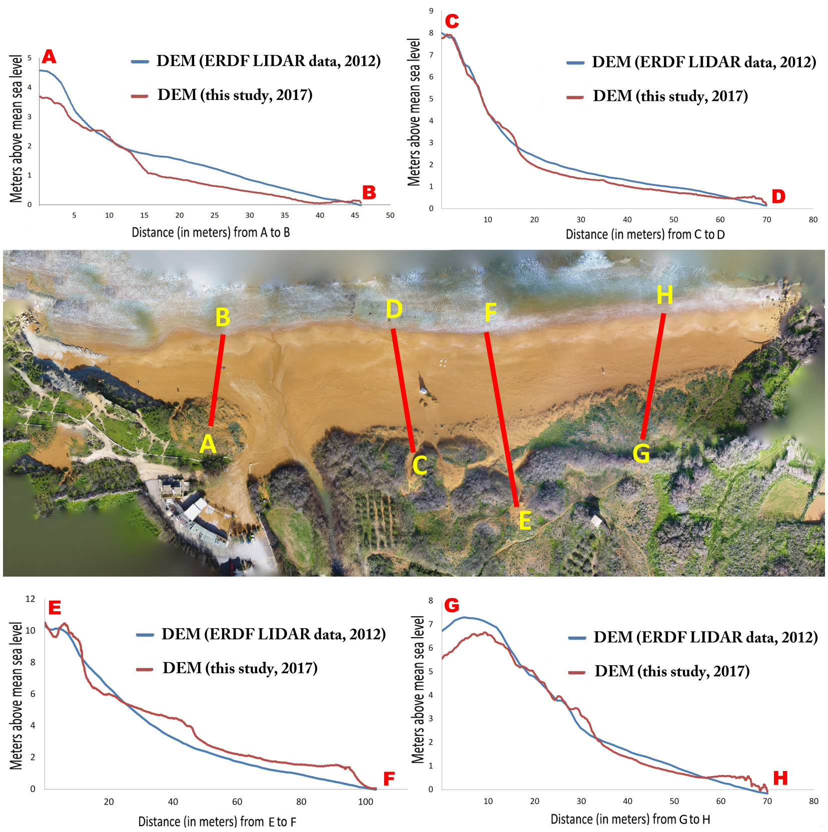

Figure 6: Comparison between DEM profiles by LiDAR (A) and DEM profiles obtained in this study (B).

has changed from 2012 to 2017 (Figure 6). This method has been useful to quantitatively analyze coastal development.

Observing the LiDAR DEM for the study area, it is possible to identify data gaps (yellow circle in Figure 7A) where it is impossible to detect the elevation. This is problematic for the purposes of this study since tracking a topographic section across such gaps could lead to inaccuracies in topography as shown by the graph in Figure 7 in which the profiles of section I-L are compared. Furthermore, the photogrammetric DEM (Figure 7B) obtained in this study has improved the visual definition of the area at about one order of magnitude with respect to the LiDAR data that is based on 1 m × 1 m horizontal resolution (Figure 7C).

Such beach profiles can be useful for monitoring the dynamics of the beach-dune system and the characterization of the coast in the mitigation of coastal erosion.

It is important to emphasize that UAV Photogrammetry has significant advantages over ground-based survey techniques and aerial photography using manned aircrafts (Galdies, Betts, Vassallo & Micallef, 2014); specifically, in areas with difficult access, high traffic, or disaster areas, these systems can significantly improve

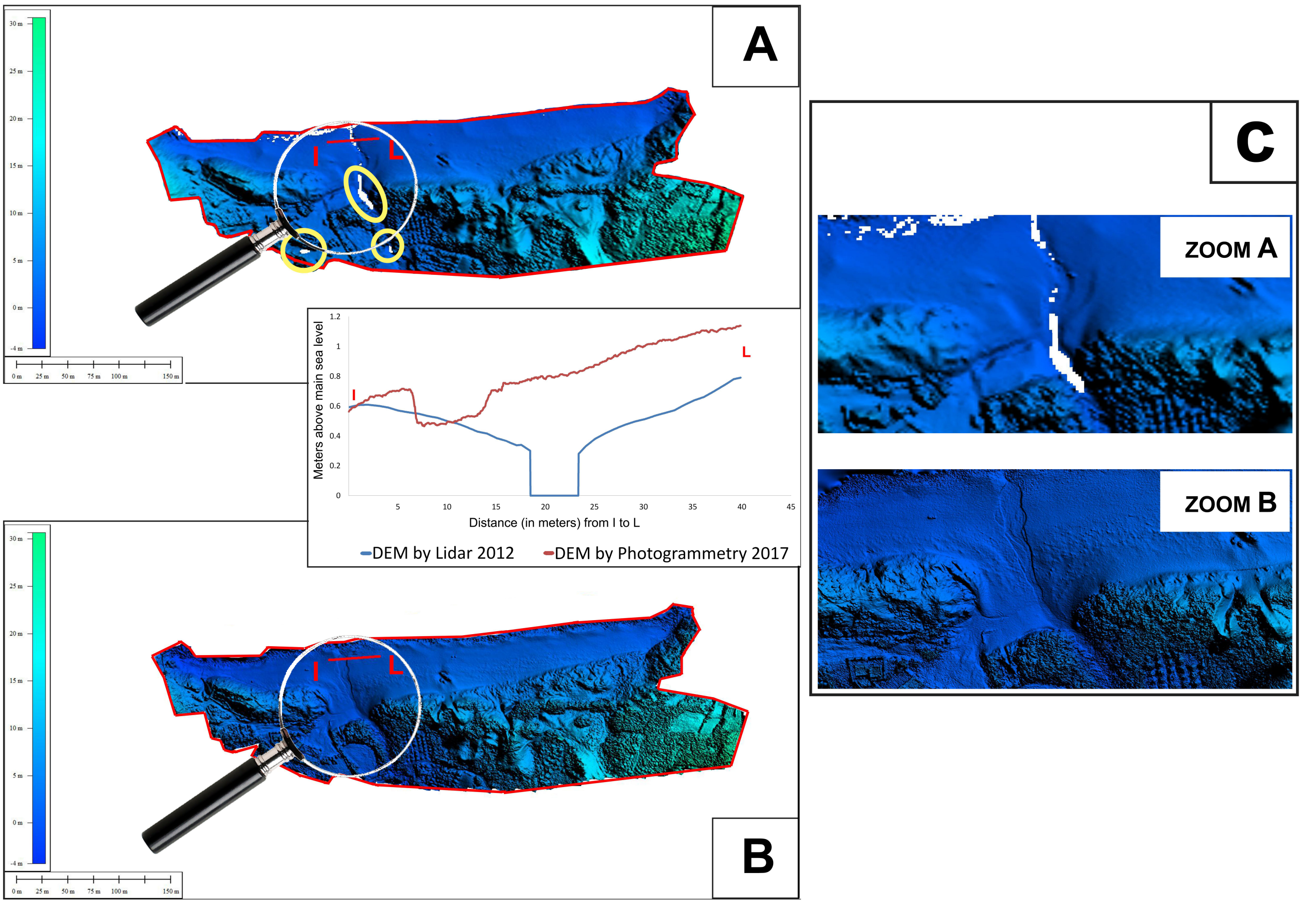

Figure 7: LiDAR DEM (A), Photogrammetric DEM (B), comparison between zoomed areas on LiDAR DEM and photogrammetric DEM.

worker safety by eliminating the need for an on-site presence.

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