INTEGRATED GEOPHYSICAL AND GEOMATICS STUDY AT XROBB L-GHAGIN ARCHAEOLOGICAL SITE: PRELIMINARY RESULTS

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Abstract. This study reports the results obtained by combining geophysical methods and geomatis techniques to study the Xrobb l-Ghagin archaeological site. We use unmanned aerial vehicle equipped with different sensors in order to reconstruct the 3D digital model of the area with the main goal of obtaining quantitative information. In particular, we used optical and Lidar sensors mounted on our drone and we perform also ground-based topographic survey in order to properly georeferenced the obtained 3D digital model. Geophysics data (e.g. ambient noise vibration, electrical resistivity tomography and ground penetrating radar) have been collected to study potential buried features present at the site. The 3D model and geophysical investigations helped in identifying potential buried archeological structures as well as the mapping of shallow geological features as fractures, faults and caves.

1. Introduction

In this study a multidisciplinary geophysical and geomatics investigation of the region shown in Figure 1, which includes the Xrobb l-Ghagin area (Southern Malta, Central Mediterranean) where some temple and archaeological remains are supposed to be located. The primary aim of the investigation was to quantify the soil coverage in the area estimating the thickness of deposits, to map particular geological features such as fractures in the cliff and size and extension of the cavity underneath the investigated site as well as to identify possible features potentially related to archaeological remains. The results should contribute to the evaluation of the risk of future collapse (that can pose the archaeological heritage at risk) and give useful information to assist the archaeological excavations planned by Heritage Malta. The area investigated covers 44,000 m² and includes also the survey of the vertical cliff where cavities and evidence of surface cracks (parallel to the cliff edge) are present. The geology of the study area is mainly characterized by the outcropping [1] of the Globigerina Limestone (GL), a soft yellowish fine-grained limestone of Lower Miocene. The -GL is very highly porous limestone, mainly composed of calcite crystals and fossils. The members of the GL outcropping in the area are the Upper globigerina limestone and the middle globigerina limestone members [1]. The presence of unconsolidated sediments overlays the globigerina limestone formation with different thickness and in general ranging from few tens of centimeters to a couple of meters. In the area, there is also the presence of presumed fault lines not mapped in the official geological map.

2. Methodology, Data Acquisition and Processing

Applications of non-invasive sensing techniques to explore internal and superficial structures of precious and delicate targets are becoming a very important research field in the context of Cultural Heritage knowledge and conservation as well as to tackle problems related to environmental issues. In this study was reconstructed a 3D digital model of the Xrobb L-Ghagin cliff by using close-range remote sensing techniques. In particular, we used digital photogrammetry coupled with Lidar acquisition for the 3D model reconstruction and this data were integrated with a drone-based ground-penetrating radar (GPR) survey.

Photogrammetry can be described as the science to obtain reliable information about the spatial properties of land surfaces and objects, without physical contact [2,3]. By using reference terrain coordinates, it is possible to determine distance, area and other geographical information, as well as create detailed cartography. A further advantage of photogrammetric matching techniques is the fact that they are relatively fast and cheap. For images acquisition, we installed a digital camera on a three-axis gimbal carried by an Unmanned Aerial Vehicle (UAV). To ensure correct georeferencing of the model and properly export the final 3D to scale, we placed on the ground 14 markers throughout the area of interest and the relative spatial coordinates were taken through the use of a differential Global Navigation Satellite System (GNSS). Through photogrammetric processing, a 3D digital model, a digital elevation model (DEM) were generated. The workflow of image processing and details of the photogrammetric process can be found in [2]. Due to the particular morphology of the coast, the area below the cliff was not reachable, then it was not covered by the markers. Therefore, to improve the accuracy of the photogrammetric model, we also acquired Lidar data using a DJI M600 Pro equipped with a long-range dual return Lidar sensor integrated with a double GNSS antenna and an Inertial Measurement Unit (IMU). In addition, a GNSS base (model Topcon Hiper HR) was installed near the take-off area to correct in postprocessing the trajectory position errors of the UAV Lidar System. To precisely define the trajectories that the UAV should have followed during the Lidar scan, it was necessary to import the digital elevation model (DEM) and an orthomosaic generated by the photogrammetric process into the flight planning software. This allowed us to fly by varying the flight height in automatic flight over the area to be investigated and parallel to the cliff to accurately reconstruct the shape of the cave. In addition, the data acquired with the double return Lidar system allowed the construction of a digital terrain model (DTM) filtering the high vegetation present in the area of the archaeological site. Finally, the Lidar point cloud was coloured using the texture generated by the photogrammetric process (Figure 1).

The GPR method is based on the generation of an electromagnetic pulse (EM) through a signal generator, connected to a transmitting antenna (Tx) and a receiving antenna (Rx). In archaeological research, the GPR survey is used to correlate the electromagnetic impedance contrasts to any submerged remains. Common GPR surveys are carried out along the profiles, with the aim of obtaining two-dimensional (2-D) sections of the subsoil. A radar profile is a composition of all the recorded signals, called traces, and allows to understand the inhomogeneity of the subsoil or dielectric interfaces.

3. Results and concluding remarks

Generally, the ultimate aim of using close-range remote sensing techniques is to reconstruct a precise and scaled 3D model to be used for several goals. Given the size and morphology of the area and the need to reconstruct a 3D model of the promontory, cliff and cave, it was necessary to plan several automatic flights (Figure 1) aiming to collect data for the reconstruction also of the cliff face. From the combination of digital photogrammetry and the Lidar survey, we were able to reconstruct a digital 3D model of the area with an accuracy of the order of a few centimeters. Using the 3D digital model, it was possible to evaluate the size of the caves underneath the test site as well as map several cracks and fractures along the cliff face (Figure 2).

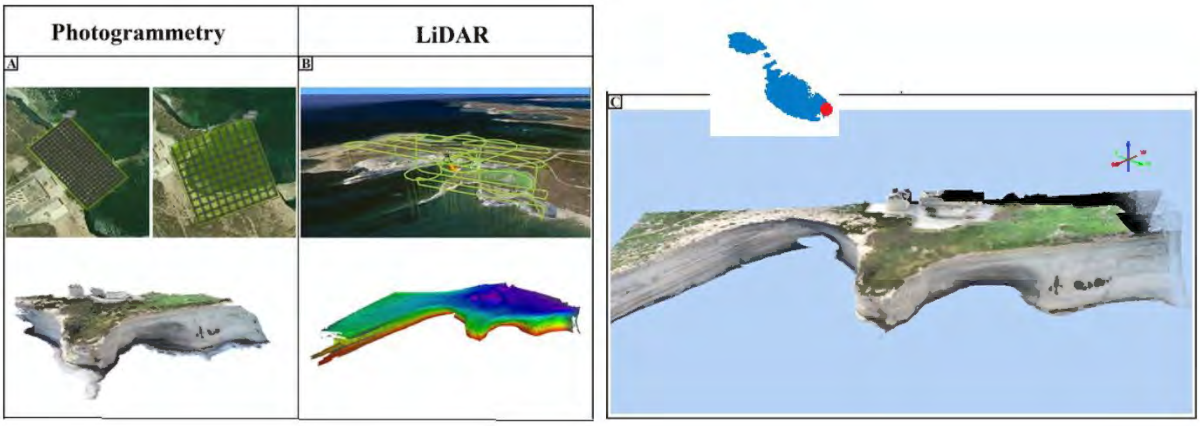

Figure 1: Panel A shows examples of drone flight plans related to the photogrammetry survey (top part) and the dense point cloud obtained (bottom panel). Panel B shows the LiDAR scan flight plan (top part), the point cloud obtained by UAV LiDAR System (bottom panel). Panel C reports the final 3D model for the study area.

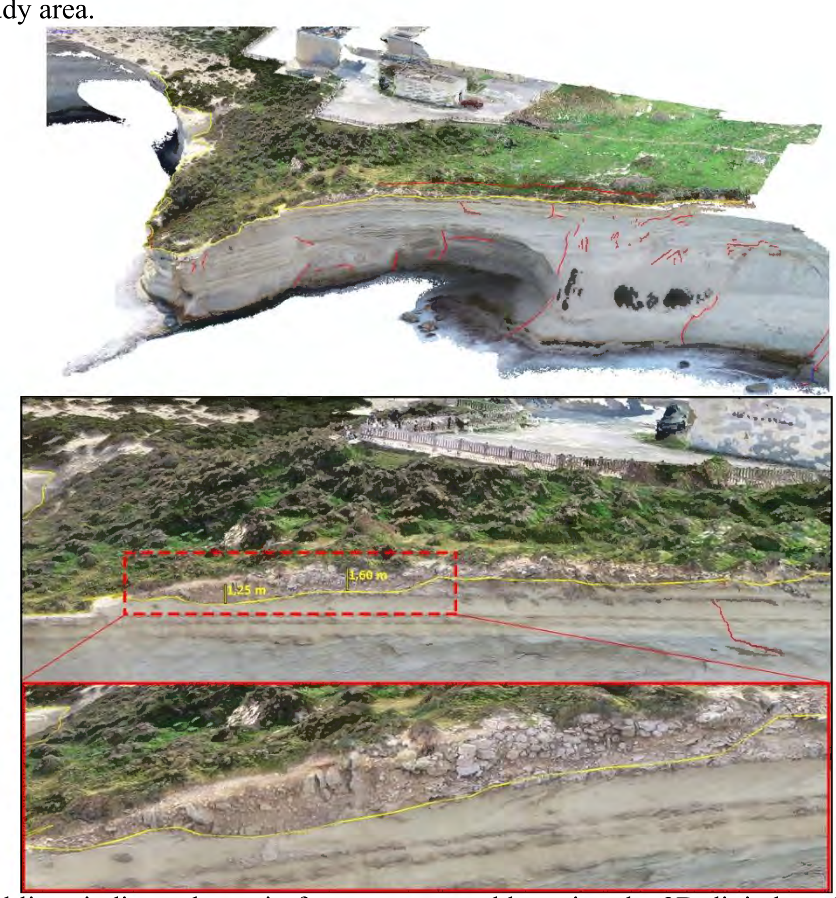

Figure 2: The red lines indicate the main fractures mapped by using the 3D digital model. The yellow line delimits the contact between the sediment deposit and the rock along the cliff face (bottom panel). The dotted red rectangle indicates the zoomed part in the inset within the red box.

In particular, a large crack parallel to the cliff face (Figure 3, dashed red line) has been mapped and measured where it was exposed. In addition, from the GPR survey, it was possible to see its continuity in places where the recognition from the 3D digital model was impossible given the dense vegetation or overlying sediments. Furthermore, we were able to map and follow the contact interface between the sediments and the underlying Globigerina limestone along the cliff. Sediment's coverage is estimated in the range of a few centimeters to up to about 1.6m. In particular, in this area, we highlight the presence of features (resembling a dry-stone wall), which can be related to the archaeological site (Figure 2). We were also able to measure the size and thickness of the rock underneath the investigated area and properly identify the cave which has a rock thickness ranging between 4-5 m to about 20 m. Although no conclusions can be drawn about any imminent danger of collapse, these results do indicate that the mass of rock on the seaward side of the indicated large fracture is undergoing a process that might lead to future collapse. This could also be induced as a result of the underlying cave which renders the overlying rock more vulnerable and, in several points the rock thickness is not larger than 5 m. It is also fair to mention that any sustained ground motion (e.g. local or regional earthquakes, vibrations from excavation machinery etc.) would enhance the vibration of this block and cave formation facilitating a potential collapse. Figure **3** reports the preliminary results of the ground-penetrating radar (GPR) investigation [4,5,6] in the area. The survey was conducted by using a UAV mounted GPR. Data shows several anomalies due to the presence of metallic objects at the surface (e.g. cans, lead from hunting pellets etc.) as well as in some areas the presence of dense vegetation has generated some noisy scans. features that can be interpreted as the bad coupling of the antenna with the ground because of the presence of vegetation. Furthermore, the reflection due to the interface between the soil coverage and the underlying rock is quite weak.

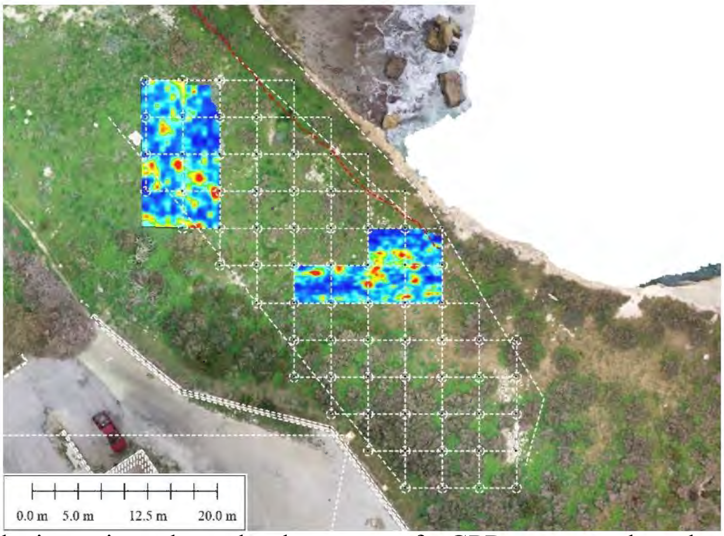

Figure 3: Results of the investigated area by the means of a GPR system onboard a drone DJI M600 Pro. The white grid represents the area that has been investigated and data are not fully processed yet. The red dashed line represents the main fracture on the rock mapped in this study. The GPR slices are given at a depth of about 1.5m below the soil level.

This is probably due to the fact that the soil has a quite high salt content that can cause a high attenuation of the signal. Low permittivity contrast between the limestone and the overlying sediments could also contribute to this. From the results, we can infer that the soil coverage estimated is in the order of 1-2m, in agreement with the HVSR results. More importantly, several anomalies can be seen and they can be associated with the presence of anthropogenic material and most probably related to the archaeological remains. Moreover, results clearly show the presence of the main crack (FIG 3) which has a depth of about 1m at that location.

The integration of different diagnostics techniques has recently led to advances in many aspects of knowledge construction and application developed specifically for Cultural Heritage targets, including data collection, processing, visualization, interpretation, data fusion, scenarios reconstruction, virtual fruition and musealization, virtual restoration, hazards reduction, preservation and repair actions.

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