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Object-Based Characterization and Semantic Labeling of Landslide and Rockfall phenomena using UAV photogrammetry

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A variety of remote sensing tools have been extensively used in the past years for landslide detection and mapping purposes. In addition, detection and mapping of landslide and rockfall events using remote sensing products has been proved to be an effective approach to provide landslide inventories (Scaioni *et al*., 2014). However, most of the studies are lacking valuable semantic information about landslide elements and how they react with the surrounding environment; natural and man-made primitives. In addition, post classification object-based approaches have been proved to result in better accuracies compared with the pixel-based (Martha *et al*., 2011). Lately, innovative close-range remote sensing technology such as Unmanned Aerial Vehicle (UAV) photogrammetry and Terrestrial Laser Scanning (TLS) are widely applied in the field of geoscience due to their efficiency in collecting data about terrain morphology rapidly. Their main advantage stands on the fact that conventional methods are mainly collecting point measurements such as compass measurements of bedding and fracture orientation only from areas that were accessible. Aerial platforms are capable to overcome technical issues such as potential occlusions and unfavorable incidence angles due to their ability to capture imagery from multiple positions and with different angles. Nowadays, UAVs tend to be more flexible and powerful tools for landslide and rockfall investigations compared to TLS, due to their low-cost and ease of transportability in harsh environments but also with technology advances such as maintaining of Real Time Kinematic (RTK) positioning. An important factor of their usefulness is their capability to offer unprecedented spatial resolution over wide inaccessible areas, maintain a variability of different sensors (optical, laser, thermal, multispectral) and great ability to reach remote areas and acquire data as close as the user defines. UAVs applications are widely used in post-disaster situations for emergency support, in infrastructure monitoring, in natural resources management, in geohazard monitoring etc. (Corominas *et al*., 2016; Vassilakis *et al*., 2019). The latter proves that UAV market has been rapidly growing over the last decade and in future more applications will be introduced in the public. Thus, rapidness and efficiency of Structure-from-Motion (SfM) technology in landslide management provides numerous advantages such as creating landslide inventory maps providing 3D information of large areas.

This research aims to demonstrate the applicability of UAV technology for automated semantic labeling in managing landslide and rockfall hazard in mountainous environments during emergency situations. SfM photogrammetry in addition to high accuracy RTK-GNSS ground control point establishment, is used to provide detailed 3D point clouds describing the surface morphology of the landslide and rockfall elements. Specifically, two test sites were exploited, a detailed UAV survey took place in a landslide case site, on Santorini island and specifically in Red Beach which constitutes one of the most touristic places on the island. In addition, a rockfall test site namely as «Proussos», near one of the most visited and famous Monasteries in the territory of Evritania prefecture, in Greece, was investigated via detailed UAV flight plans. The latter site is formed as an unstable steep slope across the main road network, on which continuous failures and road cuts appear after heavy rainfall events (Figure 1). The Red Beach test site is located on Santorini island, which in turn represents one of the most unique geological structures as it is formed around the caldera of an active volcano. Moreover, rockfalls and landslides are widespread phenomena due to the orientation and steepness of the cliffs (Karantanellis *et al*., 2019) which are mainly formed as high elevated lava domes (>50 m) with loose material inside, extruded by sticky, slow-flowing dacite lava due to continuous coastal erosion.

The proposed methodology was divided in five main working phases. The first phase includes designing and execution of an optimal UAV flight planning in order to collect accurate 3D data. The current step is crucial in order to provide complete and precise model at the later processing stages. During the second phase, the pre-processing and raw data preparation such as point cloud filtering and elimination of ambiguities is taking place, while at the next phase an image segmentation using the 3D point cloud RGB information is created. The main task was focused on identifying the specific landslide elements by using an object-based approach. Object-Based Image Analysis (OBIA) is an image analysis technique, remarkably developed during the last decade, since recent advances in computer vision and machine learning with the main task to automatically replicate human interpretation to identify objects in remote sensing images brought impressive results (Blaschke, 2010). It is only during the last decade, that OBIA methods have proved to outperform the pixel ones such as elimination of false positives which are missed by pixel-based approaches (Keyport *et al*., 2018). A sequence of image-based processes was applied, including multi-scale object segmentation, spectral, morphometric and contextual information extraction aiming to detect the landslide among other features. The latter is mainly developed as a knowledge-driven ruleset to serve for identifying individual landslide objects based on their morphometric and spectral parameters. The next phase was set up for object classification in meaningful and homogeneous landslide classes (e.g. scarp, depletion zone, accumulation zone) which are spatially connected by introducing contextual information in the ruleset. The validation of the results represents the final phase, which is based on accuracy assessment against a digitized

landslide map and field observations. The resulted models were used as reference to detect and characterize 3D landslide features and provide detailed identification of hazardous regions.

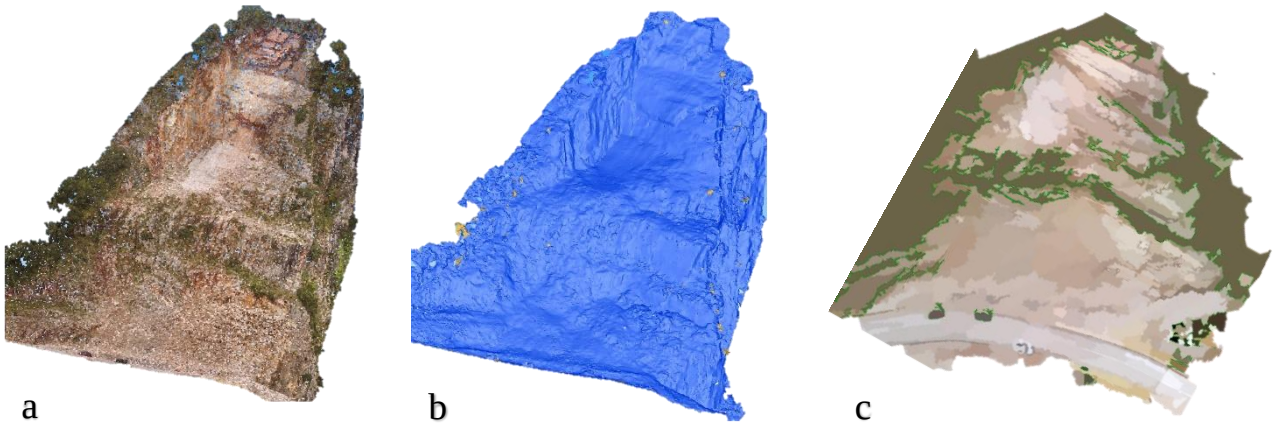

Figure 1. a) 3D point cloud of Proussos case site, b) 3D mesh model of Proussos case site, c) 3D point cloud segmentation and classification – OBIA initial result

The proposed methodology presents the effectiveness and efficiency of UAV platforms to acquire accurate photogrammetric datasets from intense relief environments and complex surface topographies by providing a holistic assessment and characterization of the failure site based on semantic classification of the landslide and rockfall objects. Results have demonstrated the capabilities of combining UAV platforms with computer-based methods for rapid and accurate identification of valuable semantic information subjectively and even from inaccessible areas of the landslide and rockfall body.

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