ΕΓΕ 2019
15th International Congress of the Geological Society of Greece
Athens, 22-24 May, 2019 | Harokopio University of Athens, Greece
Bulletin of the Geological Society of Greece, Sp. Publ. **Ext. Abs. 00000**

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. Late years, 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 with TLS due to their low-cost and ease of transportability in harsh environments but also with technology advancements such as maintaining of 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). 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 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. Structure from Motion (SfM) photogrammetry 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», which constitutes 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 with 80 m in height and 40 m wide, which results in continuous failures and road cuts after heavy rainfall events. The second test site was located on Santorini island which constitutes one of most unique geological structures as it compromises a distinctive Miocene volcano. Individually, in Red Beach area, rockfalls and landslides are widespread phenomena due to 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.

In the current research, proposed methodology was divided in four main working phases. First phase was including the 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 for the later processing stages. Second phase was the pre-processing and raw data preparation such as point cloud filtering and elimination of ambiguities; third phase was the image segmentation using the 3D point cloud where the main task was focused to identify the specific landslide elements using an object-based approach. Object-Based Image Analysis (OBIA) is an image analysis technique, remarkably developed during the last decade, resulting from recent advances in computer vision and machine learning with the main task to automatically replicate human interpretation to identify objects in remote sensing images (Blaschke, 2010). Last decade, 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 for landslide detection. 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 following 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. Last phase was the validation of the results based on accuracy assessment against a digitized landslide map and field investigations. The resulted models were used as reference to detect and characterize 3D landslide features and provide detailed identification of hazardous regions.

The proposed study presents the effectiveness and efficiency of UAV platforms to acquire accurate photogrammetric datasets from high-mountain environments and complex surface topographies and provide 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.

Acknowledgements

This research is co-financed by Greece and the European Union (European Social Fund- ESF) through the Operational Programme «Human Resources Development, Education and Lifelong Learning» in the context of the project "Strengthening Human Resources Research Potential via Doctorate Research" (MIS-5000432), implemented by the State Scholarships Foundation (IKY).

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