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3D Hazard Analysis and Object-Based Characterization of Landslide Motion Mechanism using UAV Imagery

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ABSTRACT:

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 surface morphology. Their main advantage stands on the fact that conventional methods are mainly collecting point measurements such as compass measurements of bedding and fracture orientation solely from accessible areas. The current research aims to demonstrate the applicability of UAVs in managing landslide and rockfall hazard in mountainous environments during emergency situations using object-based approach. Specifically, a detailed UAV survey took place in a test site namely as Proussos, one of the most visited and famous Monasteries in the territory of Evritania prefecture, in central Greece. An unstable steep slope across the sole road network results in continuous failures and road cuts after heavy rainfall events. Structure from Motion (SfM) photogrammetry is used to provide detailed 3D point clouds describing the surface morphology of landslide objects. The latter resulted from an object-based classification approach of the photogrammetric point cloud products into homogeneous and spatially connected elements. In specific, a knowledge-based ruleset has been developed in accordance with the local morphometric parameters. Orthomosaic and DSM were segmented in meaningful objects based on a number of geometrical and contextual properties and classified as a landslide object (scarp, depletion zone, accumulation zone). The resulted models were used to detect and characterize 3D landslide features and provide a hazard assessment in respect to the road network. Moreover, a detailed assessment of the identified failure mechanism has been provided. 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 object-based framework to characterize the failure site based on semantic classification of the landslide objects.

1. INTRODUCTION

Natural hazards present a substantial increase in their spatial and temporal distribution over the last decades especially in developed communities with significant impact on infrastructure and livehood. The latter has a direct link with the tremendous increase of population in urban areas where built-up zones extended in prone areas. Individually, landslides and rockfalls constitute abrupt types of geohazards posing disastrous effects when Elements of Risk overlay with the spatial extent of the event resulting in permanent interference with the natural environment (Van Westen et al., 2008). Significant proportion of resulted landslide damages often can be avoided by the early detection and capacity enhancement of the landslide or rockfall problem. Hence, there is essential requirement for detailed landslide hazard assessment in different spatial and contextual scales for site-specific case.

Remote sensing has played a significant role in the deeper understanding and monitoring of geohazards worldwide (Scaioni et al., 2014). Landslide detection using remote sensing images has been widely applied for automatic or semi-automatic landslide inventory mapping. Nowadays, UAVs tend to be more flexible and powerful tools for landslide and rockfall investigations 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 (Colomina et al., 2014). UAVs applications are widely used in post-disaster situations for emergency support, in infrastructure monitoring, in natural resources management, in geohazard monitoring etc. Individually, aerial platforms are able to overcome technical issues such as occlusions and unfavorable incidence angles due to their ability to capture imagery from multiple positions and with different angles. Also, concerning landslide application their contribution can be identified in different aspect of applications such as detection, mapping, monitoring and analysis (Giordan et al., 2017). 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.

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With the recent advances in computer vision domain and the capability of obtaining ultra high-resolution datasets, object-based classifications approaches have been introduced in the field of Geoscience demonstrating outstanding results compared with the traditional pixel-based (Strumpf et al., 2011). In detail, Object-Based Image Analysis (OBIA) approach constitutes an image analysis technique, remarkably developed during the last decade, with the main task to automatically replicate human interpretation to identify objects in remote sensing images (Blaschke et al., 2014). In a later stage, OBIA products can be imported in a GIS environment for advanced hazard and risk analysis. Research studies such as Martha et al., (2010) and Holbling et al., (2015) are highlighting the remarkable enhanced overall accuracies of object-based approaches for landslide inventorization compared with pixel-based ones.
Aim of the proposed research is to develop an object-based framework for automated landslide elements classification according to Varnes (1984) landslide categorization.

2. STUDY AREA

2.1 Location

The test site is located next to "Balta" bridge (38°46'43.3"N, 21°40'51.6"E) in the prefecture of Evritania, Greece along the road network heading to Proussos Monastery from city of Karpenisi. The wide area of study is compromised from dense vegetation mostly forest with occasional small shrubs. The slope has an average width of 10 m in the scarp zone and almost 70m in the depositional zone which at the same time it compromises the border edge with the road (Figure 1). The relative elevation from the top to the toe of the slide is regarded around 90m. The hillslope is approximately 70º steep, facing north-east (NE) and locating at 780m absolute elevation. Due to its intense morphological relief and complex rock mass coupled with intense precipitation, the wide area of Evritania prefecture, has been severely affected by landslides. More individually, in the test site, several complex landslides and rockfall events took place in the last decade with partial to complete destruction of the road network which resulted in partial alienation of Proussos Monastery and small villages. Most of these cases have been detected during spring months (February-May) from local communities while the majority of them have never been reported from any official authority due to their relatively small magnitude. Those events range in size from individual rockslides to massive falls of several hundred cubic meters. Due to continuous sliding material, small trees and shrubs are scattered across the borders of eroded zone and intact while in the depositional zone vegetation is discreet.

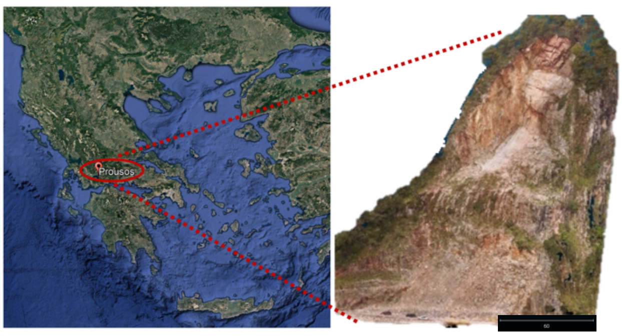

Figure 1. Index map of the Proussos area (left) and the 3D model of the landslide (right)

The continuous failures on the road network of Proussos region, is caused mainly by the creation of deep excavations as well as erosion on the toe of the slope due to river crossing underneath, which in the current case study is not supported by any kind of vegetation or special protective construction works.

2.2 Geological conditions

The tectonic conditions in the study area are described as significant complex due to its location on the wide area of Pindos mountain territory. Geologically the test site is placed in flysch environment of Pindos geotectonic unit, in central part of Greece (Aubouin et al., 1977). Flysch typically consists of a sequence of shales and siltstones rhythmically interbedded with hard layers of sandstone. Conglomerates and some limestones or marls may be present. Major characteristics of flysch formation is its diverse heterogeneity, its structural complexity due to folding and stress and persistence of discontinuities with low strength. In the figure 2 is illustrated a detailed schematic view of the geological conditions of the area under investigation.

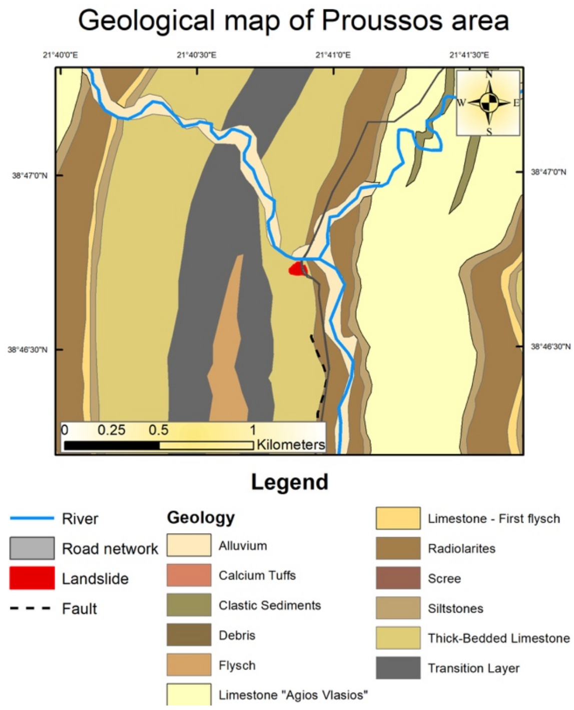

Figure 2. Geological map of Proussos area (Digitized from I.G.M.E.)

The geomorphological changes in the study area are also attributed to the unconditional excavations of the artificially modulated slopes of the road and in the continuous weather erosion which have resulted in disruption of the natural relief and slope instabilities. A panoramic view of the landslide spot can be seen in Figure 3.

Figure 3. Panoramic view of the landslide case site in Proussos area, Greece

2.3 Data

A detailed site investigation has been carried out days after the latest failure event had occurred. Several in-situ measurements have been performed on rock outcrops to investigate rock's mechanical properties and block volumes with tools such as geological compass, Schmidt hammer tests and joint roughness condition for rockmass quality assessment. Rapid, accurate and precise acquisition of topographic data is indispensable to landslide studies especially concerning in-situ and site-specific cases. To apply a cost-efficient UAV data collection for the area under investigation considering the permeable flight duration and the desired Ground Sampling Distance (GSD), a predefined flight plan was designed in laboratory environment. The mission planning for the case site included a detailed flight path with constant flight height, 80 % and 80 % sidelap and frontlap respectively, and a vertical camera angle which resulted in a GSD of 3 cm.
The UAV performed in the proposed study was a commercial DJI Phantom 4 Pro with a built-in camera mounted on the platform with a triaxial gimbal. In addition, targets were placed on the ground wherever was feasible to work as Ground Control Points (GCPs). Thus, stable man-made objects were referenced as GCPs to augment the correction. Finally, Real-Time Kinematic (RTK) GNSS equipment was used to measure the coordinates and control the ortho-rectification procedure of the produced models (Vassilakis et al., 2019). Details on the used flight parameters can be found Table 1.

Table 1. Mission parameters for Proussos case site

Mission parameters	
Number of images	100
Flying altitude (m)	60
Frontlap - Sidelap	80% - 80%
Ground Resolution (m)	0.3
Coverage area (km^2)	0.09
Number of tie points	432,147
Overall error in XY (m)	0.2
Overall error in Z (m)	0.4
Orthomosaic resolution	0.5
DSM resolution	0.5

To ensure the optimal coverage of the target area, a double grid flight path had been designed for avoiding possible occlusions due to inhomogeneous surfaces in respect with the camera angle. Specifically, a flight path with the above-mentioned parameters was executed as initial path. A second one was following with the same parametrization with the difference trending on the normally placed flight path with the previous one. As a result, the two acquisitions, followed the same parameterization but the flight paths and camera positions had a 90º difference. Higher density of the flight trajectory usually results in better 3D model quality always concerning the available processing effort. In addition, during the image acquisition stage, flying altitude was kept constant at 60 m Above ground Level at all times, as a result the used platform was following the surface topography of the landslide spot in order to perceive a constant GSD.

3. METHODOLOGY

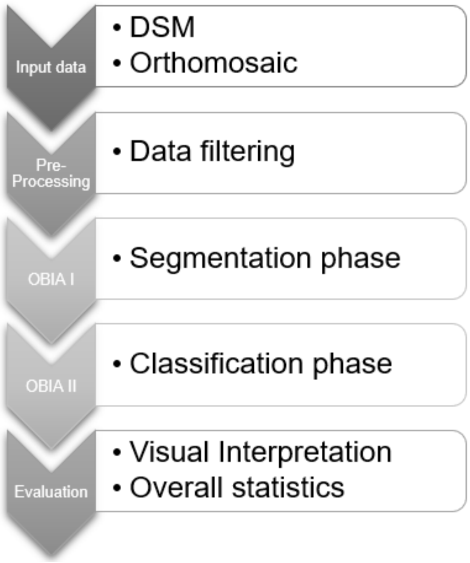

Figure 4. Flowchart of the proposed object-based methodology

3.1 Pre-processing

The initial phase was performed in three distinct steps. The first was the mission planning and execution, followed by point cloud creation and refinement and last step to import the Orthophoto and Digital Surface Model (DSM) for object-based analysis. During field investigations, image datasets were collected using an RGB sensor mounted on the UAV platform. Approximately, 100 images from a constant flight attitude of 60 meters have been collected from the landslide site with careful attention to keep frontlap and sidelap in 80% to guarantee optimal configurations for tie point matching and camera alignment. Later, they have been processed using a commercial Structure from Motion (SfM) photogrammetric software to produce the DSM, the orthophoto and the 3D mesh model of the area under investigation (Pix4D). Nevertheless, the landslide scene's tie points were chosen to fulfil the condition to be visible at least in six images. SfM procedure resulted in a dense point cloud constructed from up to 20 million points and the resulted accuracy of orthomosaic and the DTM was 0.5 m (Figure 5).

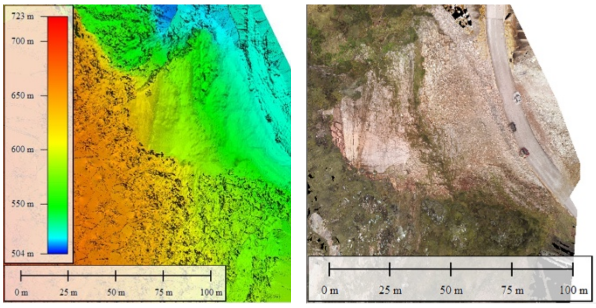

Figure 5. Map view of the DSM (left) and Orthomosaic (right) of the area under investigation at Proussos, Greece.

Due to that the case site was mainly characterized from low vegetation in the outer parts of the landslide while the inner part was completely bare rock, filtering of the scene was manually applied. In the end, an average RMSE value was obtained at 0.2 m in (XY) horizontal and 0.4 m in (Z) vertical axes respectively.

3.2 Object-Based approach

The current section presents the proposed object-based approach for the detailed characterization of the landslide site exploiting the semantic relationships among the landslide objects as it is defined by Varnes categorization. The OBIA approach consists of two distinct phases; segmentation and classification procedure. The first phase is constructed from the accurate identification of landslide objects on the ultra-high-resolution model from the UAV. The second phase coincides the precise classification of the resulted segments in landslide categories according to several spectral, textural and morphometric parameters. Last, the resulted classes of OBIA phase were validated against a manual digitized inventory from the landslide site. Statistics were applied to assess their respective accuracy and precision of classification process.

3.2.1 Segmentation phase

Image segmentation constitutes a vital stage for the object-based analysis, as it will spatially cluster the used imagery into homogenous and non-overlapping objects. The final quality of segmentation process will have a direct effect on a meaningful classification result. As a consequence, significant attention is needed on the selection of optimum parameters. In the current stage, several types of segmentation algorithms could be selected. In our case multiresolution segmentation (MLS) had been found more efficient which belongs in region-based algorithm category. The latter is compromised from three user-defined parameters (Scale - Shape - Compactness) which they have to be set up manually via trial and errors to proceed with the segmentation process. Several attempts such as the Estimation Scale Parameter (ESP) tool from Dragut (2010) have developed algorithms to investigate in advance the scene under segmentation and provide an optimum selection of parameters based on the analysed sequence of the image. In our study, 5 different levels were exploited to assess the optimum parameters selection.

3.2.2 Classification phase

The classification stage always follows segmentation; includes the categorization of segmented objects in appropriate classes according to their respective morphometric and contextual properties. The main task is to separate at first landslide objects with non-ones and at second phase to categorize landslide objects as one of their respective zones (scarp, depletion zone, accumulation zone). Object parameters such as mean slope, curvature, brightness length/width, texture, and relative border with their neighbours were used to classify an image entity into several landslide classes. Those object features were applied in the image scene to discriminate objects in one of the landslide classes. Careful choice of optimal thresholds will impact classification accuracy (Chen et al., 2014).

3.3 Accuracy assessment

The proposed methodology and results were examined in order to assess their efficiency and quality in properly detecting and classify objects. In the current study the validation procedure has been done in two steps. First a qualitative validation was applied by visual interpretation of the achieved classes; the second step was to assess the classification from OBIA against a manual digitized developed inventory of the wide area. The latter was necessary for evaluating the extent and actual boundaries of the landslide and non-landslide classes.

4. RESULTS

4.1 Segmentation process

A necessary objective of a successful object-based classification approach is an appropriate segmentation procedure. In order to derive a meaningful classification scheme segmentation process has to split image in homogeneous objective primitives that will form the basis for later classification. In our test site, different scenarios have been exploited in the multiresolution segmentation step. Different primitives' parameters such as shape, colour, size (scale) and compactness was set up by the user to identify the optimum selection. In the end, the parameter values that better defined the scene under investigation were set up to 700 for scale and 0.4 for shape and compactness criteria respectively. The latter enabled to avoid potential underfermentation and over-segmentation issues (Figure 6).

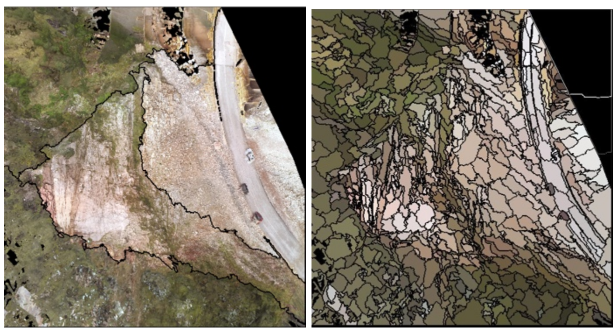

Figure 6. Characteristic examples of Under-segmentation (left) and Over-segmentation (right)

4.2 Classification process

In the current sub stage, appropriate threshold parameterization for each resulted feature has been set up to eliminate non-landslide object and classify accordingly the landslide classes based on their respective morphometric and contextual information. In specific, for classifying landslide object their respective spectral information (e.g. brightness) from orthomosaic in combination with morphometric and elevation information resulted from DSM have been implemented. Concerning brightness information, it has to be mention that landslide affected area usually has higher values due to bare soil in contrast with healthy surface which are vegetated resulting in darker values. In addition, contextual information concerning the neighbourhood of the landslide object has been taken into account to classify scarp, depletion and accumulation landslide zones (Figure 7).

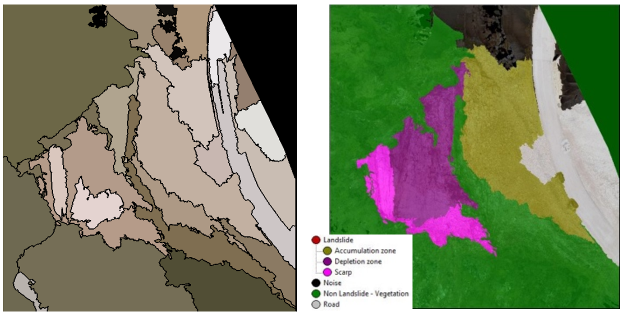

Figure 7. Final segmentation (left) and classification (right) result in object-based approach

4.3 Evaluation of accuracy

The results of qualitative accuracy assessment via visual interpretation can be seen in Figure 8. For the quantitative accuracy assessment precision and recall results can be seen in table 2. It must be mentioned that manual digitization seems too generic compared with the OBIA result. This is due to that human eye is not able to include all the available parameters in the classification process as it can relate the information to a single layer.

Table 2. Accuracy statistics of OBIA evaluation

TP	FP	TN	FN	Overall
84 %	72 %	78 %	62 %	79.6 %

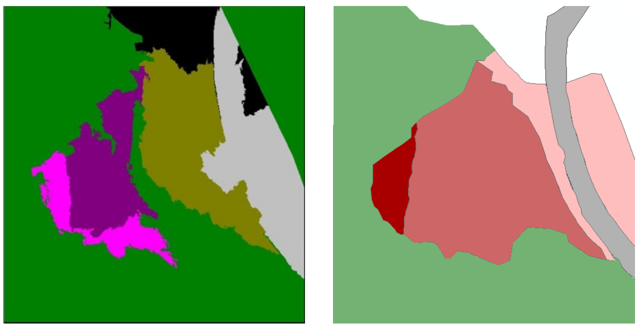

Figure 8. OBIA knowledge-based classification result (left) and manual digitization result (right)

5. CONCLUSIONS

During the last decade, UAVs and computer vision enabled landslide studies to import new ways of data representation. Individually what concerns the real-time application in combination with the elimination of human risk constitute UAVs effective and efficient tools for data collection in terms of cost and extent. New methodologies in remote sensing lead to incorporate artificial intelligence and ultra-high spatial resolution datasets to classify a scene according to human perception, closing the gap between machines and humans. Future looks promising with new opportunities for remote sensing and 3D modelling to introduce affordable advanced sensors (LiDAR, Multispectral) maintained on UAVs for landslide management application.

The current research mainly aimed to explore and propose an object-based framework to automatic identify and characterize landslide elements according to their respective morphometric and spectral properties in landslide categories according to Varnes holistic classification. There is a demand to provide objective and automated ways to assess landslide and rockfall phenomena in a quantitative approach.

For future studies, more object indicators will be exploited in order to enhance the results of classification process. In addition, it should be noted that the developed knowledge-based ruleset will be transferred in a similar landslide scenario to test its applicability in different case.

ACKNOWLEDGEMENTS

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REFERENCES

Aubouin, J., Desprairies, A., Terry J., 1977. Le synclinal d'Epire - Akarnanie, la nappe du Pinde-Olonos & la nappe ophiolitique, *Bull. Soc. Géol. France*, 19, 20-27.

Blaschke T, Hay GJ, Kelly M, Lang S, Hofmann P, Addink E, Feitosa RQ, van der Meer F, van der Werff H, van Coillie F, Tiede D., 2014. Geographic object-based image analysis - towards a new paradigm. *ISPRS Journal of Photogrammetry and Remote Sensing* 87, 180–191.

Chen, G., Zhao K., and R. Powers. 2014. Assessment of the Image Misregistration Effects on Object-Based Change Detection." *ISPRS Journal of Photogrammetry and Remote Sensing* 87, 19–27.

Colomina, I., and Molina, P., 2014. Unmanned aerial systems for photogrammetry and remote sensing: A review. *ISPRS Journal of Photogrammetry and Remote Sensing*, 92, 9–97.

Drăgut, L., Tiede, D., and Levick, S.R., 2010. ESP: A Tool to Estimate Scale Parameter for Multiresolution Image Segmentation of Remotely Sensed Data. *International Journal of Geographical Information Science* 24(6), 859–871.

Giordan, D., Manconi, A., Remondino, F., Nex, F., 2017. Use of Unmanned aerial vehicles in monitoring application and management of natural hazards. *Geomatics, Natural Hazards and Risk*, 8, 1–4.

Hölbling, D., Friedl, B., and Eisank, C., 2015. An object-based approach for semi-automated landslide change detection and attribution of changes to landslide classes in northern Taiwan. *Earth Science Informatics*, 1-9.

Martha TR, Kerle N., Jetten V., van Westen CJ., and Kumar KV., 2010. Characterising spectral, spatial and morphometric properties of landslides for semi-automatic detection using object-oriented methods. *Geomorphology* 116(1–2), 24–36.

Scaioni, M., Longoni, L., Melillo, V., and Papini, M., 2014. Remote sensing for landslide investigations: An overview of recent achievements and perspectives. *Remote Sens.*, *6*, 9600–9652.

Stumpf, A. and Kerle, N., 2011. Object-oriented mapping of landslides using Random Forests, *Remote Sens. Environment*, 115, 2564– 2577.

Van Westen, CJ, Castellanos, E., Kuriakose, S.L., 2008. Spatial data for landslide susceptibility, hazards and vulnerability assessment: an overview. *Eng Geol* 102(34), 112–131.

Varnes, D.J., 1984. Landslide hazard zonation: a review of principles and practice. *Natural Hazard Series*, 3.

Vassilakis, E, Foumelis, M, Erkeki, A, Kotsi, E, Parcharidis, I, Lekkas, E., 2019. Multitemporal Surface Deformation Analysis of Amyntaio Slide (Greece) using Remotely Piloted Airborne System and Structure-from-Motion photogrammetry. 4th Joint International Symposium on Deformation Monitoring.