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UAV Point Clouds for Semi-Automated Rockfall Hazard Assessment: a Post-Failure Application of a Novel Method in Plomari, Lesvos Island

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Abstract

Rockfalls constitute an abrupt type of landslide process with manifold impact at local level, on economy and mostly on a human modified environment. Over the past few decades, urban expansion in hazardous areas and development of modern transportation and energy infrastructure, combined with a global demand for higher safety standards, have rendered the assessment of rockfall hazard most urgent than ever. In this context, up to date, rapid automated and accurate mapping of rockfall characteristics is key to identifying hazardous areas and proposing mitigation measures in an efficient manner. The current study proposes a novel, semi-automated approach to detect rockfall hazard from detailed 3D point clouds and highlights the significance of UAV application in the landslides domain. A case study of a recent rockfall event, triggered by heavy rainfall in Plomari, Lesvos island is presented. The event occurred within the boundaries of the settlement and induced damage on several houses, forcing 37 people to evacuate the proximal area. Data was collected shortly post-failure with a commercial UAV platform and implemented in producing a high-resolution 3D point cloud from which block geometry measurements of sliding slope have been provided in relation with the geometrical characteristics of the main discontinuity surfaces and the slope morphology. Field measurements and laboratory tests of the rock joint strength were contributed for the analysis of the slope stability of the rock blocks. A practical, qualitative hazard assessment system is proposed, based on parameterization of corresponding rock discontinuity factors detected in terms of point cloud analysis. Results have demonstrated the capabilities of combining UAV platforms with computer-based methods for rapid and accurate identification of discontinuity parameters, objectively, and even in inaccessible areas of the rockfall body. These capabilities

Introduction

Rockfalls present a substantial increase in their spatial and temporal distribution over the last decade especially in developed societies with severe 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 landslide and rockfall prone areas (Glade et al., 2005). Geo-information techniques and remote sensing have played a vital role in the interpretation and understanding of landslide and rockfall kinematics. A variety of sensors and techniques have been implemented in the field, demonstrating a relationship between the desired application and the method of choice. Lately, Unmanned Aerial Vehicles (UAVs) are widely applied in harsh environments for utra-high resolution data acquisition and accurate 3D surface reconstruction (Nex et al., 2015). Their ability to collect data subjectively from different orientation angles and inaccessible steep rock faces, with very low operational cost and reduced risk for the surveyor make UAVs an integral tool for landslide assessment and rockmass characterization. The collected imagery is taking full advantage of Structure from Motion (SfM) technique with Multi-View Stereo (MVS) to build a 3D point cloud as well as a Digital Surface Model (DSM) and an orthophoto of the area. This work aims to point out the applicability of UAVs in detecting and characterizing rockfall hazard on mountainous environment based on photogrammetric 3D point clouds derived from low-cost UAVs. The acquisition survey aims to produce topographic-grade accurate 3D data from which reliable, valuable geotechnical information can be extracted in an effective manner. The focus of this study was mainly on geometric discontinuity information retrieval, specifically, orientation and and spacing of the main joint sets, through block volume measurements in 3D space. Field measurements were also exploited to assess the mechanical characteristics of the discontinuities as well as to cross-correlate the data derived from the UAV. The acquired discontinuity properties were parameterized and included in a formulated Hazard Index to provide concrete and accurate rockfall hazard analysis.

Methodology

The approach discussed involved the quantification of rock discontinuity characteristics; five major joint set properties were implemented in the hazard assessment system, namely: Joint Set Spacing, Orientation (dip/dip direction), Roughness, Joint Wall Compressive Strength and Persistence. A morphology factor was also introduced. All the data used in this study were collected shortly after the rockfall event of November 24, 2018. A commercial UAV platform with a built-in optical sensor was used to collect imagery. A total of 200 images were used to construct a dense point cloud of 20 million points (2100 points/m^2). Manual measurements were also made on the accessible foot of the slope using conventional equipment (compass clinometer, profilometer, Schmidt hammer, measure tape). For the hazard assessment process, Orientation and Spacing and Morphology have been derived from block volume measurements made on the obtained point cloud, while Roughness, Wall Strength and Persistence have been imported as-is from the manual survey. The data derived from the point cloud has been post-validated via the respective manual measurements. The hazard zonation has been categorized in three main qualitative fields, namely: i) *High*, where areas have a greater possibility to fail, ii) *Moderate* and iii) *Low*, where areas have a lesser possibility to fail. A novel qualitative hazard matrix has been developed, taking consideration on the aforementioned properties: each joint set property, except for the orientation, has been parameterized accordingly, to a Low-Moderate-High order. A multi-criteria process has been implemented to calculate a formulated Hazard Index (H.I.) in a GIS environment. The slope is sectioned in parts(planes), for each of which a separate H.I. is calculated, based on its discrete parameter values. The final product of the hazard assessment process is a hazard map, which includes an outline of the slope divided in polygons, each assigned a color according to its calculated H.I.

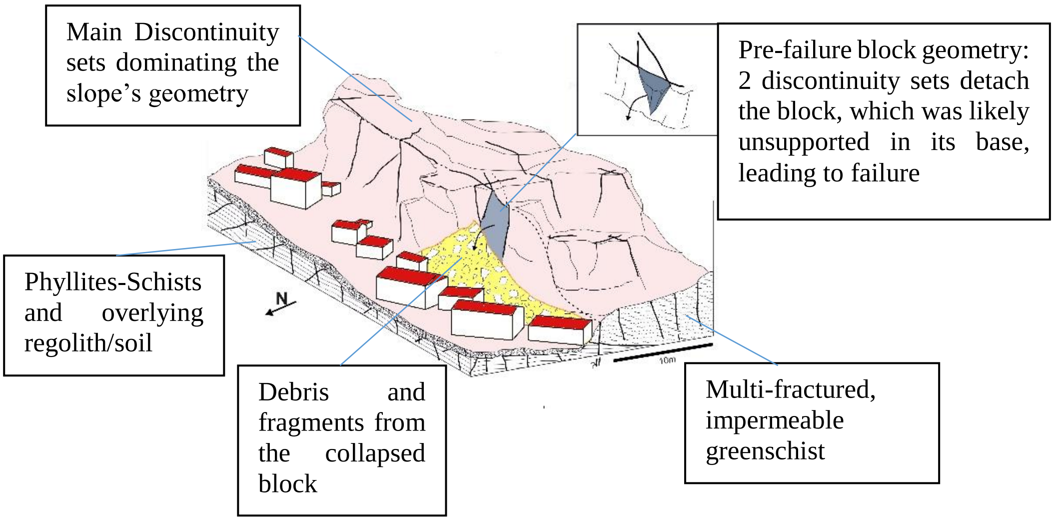

Figure 1: Conceptual block model of the case area

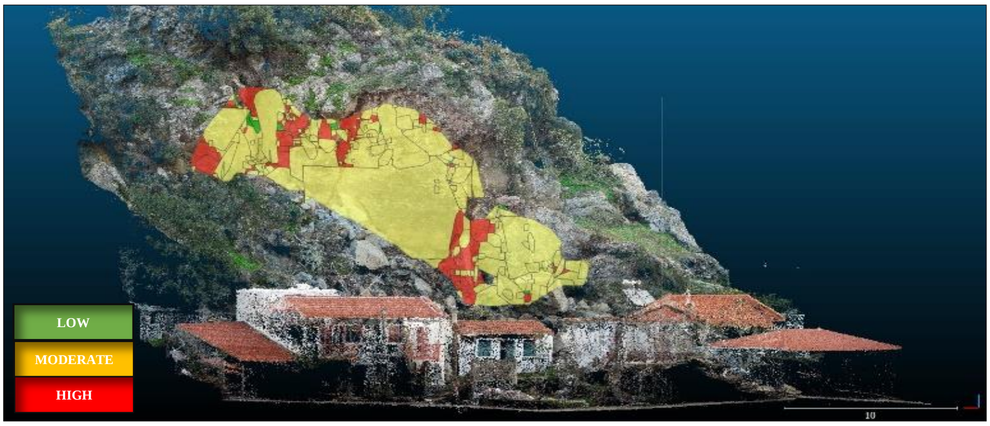

Figure 2: Hazard map overlaid on the point cloud of the failure slope.

Conclusions

Rapid rockfall mapping is important in post-disaster situations. UAVs, in combination with field investigations, have limitless advantages for emergency situations, in specific rockfall management, due to their clear benefits over conventional methods of collecting surface measurements, in harsh environments. Their main contribution in such cases, is the combined ability to provide holistic 3D topographic data in a time efficient manner and with minimized human exposure. The five selected parameters (Roughness, Wall Compressive Strength, Spacing and Persistence) tuned in the proposed Hazard Index revealed good results in comparison with the in-situ investigations and raised expectations for the discussed approach. At a subsequent time, the proposed method will be implemented in different case studies to validate its transferability in different rockfall scenarios. In addition, machine learning algorithms will be tested for exporting discontinuity properties in an automated and subjective way without user interaction.

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