Very-high resolution monitoring of movement of surface material within a landslide

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Abstract—**UAV-based aerial pictures processed with Structure-from-Motion algorithms provide an efficient, low-cost and rapid framework for remote monitoring of dynamic environments. This methodology is particularly suitable for repeated topographic surveys in remote or poorly accessible areas. The aim of the study is to assess differential movement of surface material within a landslide located in the northern foothills of the Swiss Alps based on a time series of digital surface models derived from the UAV-SfM framework. Based on two digital surface models reconstructed with aerial pictures taken within a 6-months time interval, first results show that the central part of the landslide is very dynamic with horizontal movements up to several meters.**

I. INTRODUCTION

The study and monitoring of mass movements require accurate and high-resolution representations of the earth surface. For this purpose, topographic surveys are typically conducted using real-time kinematic (RTK) global positioning system (GPS) [1], total stations [2], terrestrial laser scanning (TLS) [3] and aerial laser scanning (ALS) [4]. While these acquisition techniques are increasingly used in geomorphology and result in rich observational datasets, they are often time-consuming and costly. Recent developments in image processing, with the application of computer vision algorithms as *Structure-from-Motion* (SfM), and the availability of reliable, low-cost and lightweight unmanned aerial vehicles (UAVs), permit to overcome some of these drawbacks [5].

During the last years, exploratory research has shown that UAV-based image acquisition is suitable for environmental remote sensing and monitoring [6], [7]. Image acquisition with cameras mounted on an UAV can be performed at very-high spatial resolution (centimeter) and high temporal frequency in the most dynamic environments [8], [9]. Besides, the SfM technique allows reconstructing landform topography based on an unoriented set of pictures (i.e. without spatial orientation or georeferencing information) and taken with consumer grade uncalibrated cameras without having prior information on the location of the principal point, radial distortion, focal length or distance to the surveyed topography [10].

The UAV-SfM framework is now capable of providing digital surface models (DSM) which are highly accurate when compared to other very-high resolution topographic datasets and highly reproducible for repeated measurements over the same study area [11]. As DSM differencing automatically leads to error propagation, the approach requires both a high accuracy for topographic representation and consistency between measurements over time.

Based on a time series of digital surface models derived from the UAV-SfM framework, the aim of the study is to assess the differential movement of surface material within a landslide located in the Swiss Alps over a period of 6 months. In addition to this, very high-resolution topographic monitoring of the landslide will help understanding the sediment fluxes at short term and enable comparison with studies over the same area at different time scales.

II. STUDY AREA

The study area is the Schimbrig landslide located in the northern foothills of the central Swiss Alps. The landslide is part

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of the Entlen catchment whose outlet is located near the town of Entlebuch and its elevation is ranging between 1150 m and 1300 m above sea level. The landslide is located in Flysch terrain which promotes hillslope instability due to the low mechanical strength of this geological material. The landslide reactivation activity is mainly linked to precipitation events. [12].

Previous studies on the Schimbrig landslide activity were carried out at the decadal scale based on classic photogrammetry datasets [13] and at the centennial scale based on dendrogeomorphic data [14].

III. Methodology

To acquire aerial photographs over the study area, we equipped an eight-propeller drone with a standard reflex camera. The flight speed and altitude, the focal length and the acquisition rate were tuned to provide the best trade-off between image overlap, pixel resolution and efficiency of the field survey. Ground control points (GCP), consisting of white and orange targets, were regularly scattered over the study area for further point cloud georeferencing. The GCPs were surveyed with sub-meter accuracy GPS.

Then, the SfM algorithm was applied to airphoto datasets in order to derive unoriented 3D point clouds. Scene structure is rendered as a 3D sparse point cloud generated in an arbitrary coordinate system, lacking spatial scale and orientation. This cloud is then projected in a real-world coordinate system using ground control points that are visible in the point cloud and were surveyed with a GPS in the field. To this end, a 7-parameter Helmert transformation, with a single factor of scale, three factors of translation and three of rotation, is computed based on the GCP coordinates in both arbitrary and real-world coordinate systems. In a next step, the similarity transformation is applied to the entire set of 3D point arbitrary coordinates in order to have a properly georeferenced output.

Finally, each georeferenced point cloud was converted into a triangulated irregular network (TIN) and then linearly interpolated into a raster surface with a pixel resolution of 0.1m, in order to avoid the use of complex statistical interpolation methods to transform 3D points to raster format.

IV. Results

Two datasets of aerial pictures of the Schimbrig landslide were acquired, i.e. (1) October 2013 and (2) June 2014, and used to reconstruct un-oriented 3D point clouds. Regarding the georeferencing step, 29 ground control points were used for the 2013 dataset and 32 for the 2014 dataset in order to compute the 7 parameters of the Helmert transformation.

The associated errors are the Root Mean Square Errors (RMSE) derived from the simple linear regression computed by comparing the coordinates measured with GPS receiver and SfM coordinates of the targets after georeferencing (Table 1). For both datasets, the horizontal error is ranging between 0.24 m and 0.31 m while the vertical error is slightly higher with a value of 0.44 m. Also, the average point density is about 120 points per square meter.

Based on the two very-high resolution digital surface models of the landslide at the two different time steps, e.g. the Fig. 1 showing the DSM of June 2014, we are able to compute the difference between both surfaces. The extent of the final study area, i.e. the intersection of both datasets, is 2.94 ha and cover the major part of dynamic section of the landslide. After removing differences of elevation smaller than the vertical error on the georeferencing, we obtain a map quantifying erosion and accumulation of sediments for the period of interest (Fig. 2).

Preliminary analysis shows that erosion and sedimentation occur in the landslide during the 6-month period of interest. However, the most remarkable result is that horizontal movements within the central part of the landslide are large. This can be inferred by the analysis of the pattern of erosion, i.e. negative values, and sedimentation, i.e. positive values, at various places within the central part of the landslide. These shapes are similar in form, size and intensity, and in fact represent vegetation, i.e. bushes and small trees, which move downward. The intensity of these horizontal movements is up to 8 meters.

TABLE I. ACCURACY ASSESSMENT OF HELMERT TRANSFORMATION FOR POINT CLOUD GEOREFERENCING.

Dataset		**October 2013**	**June 2014**
Nb of Targets		29	32
R^2 (GPS vs SfM)	***X***	1	1
	y	1	1
	z	0.9996	0.9996
RMSE (m)	***x***	0.3144	0.2499
	y	0.2448	0.2932
	z	0.4358	0.4411

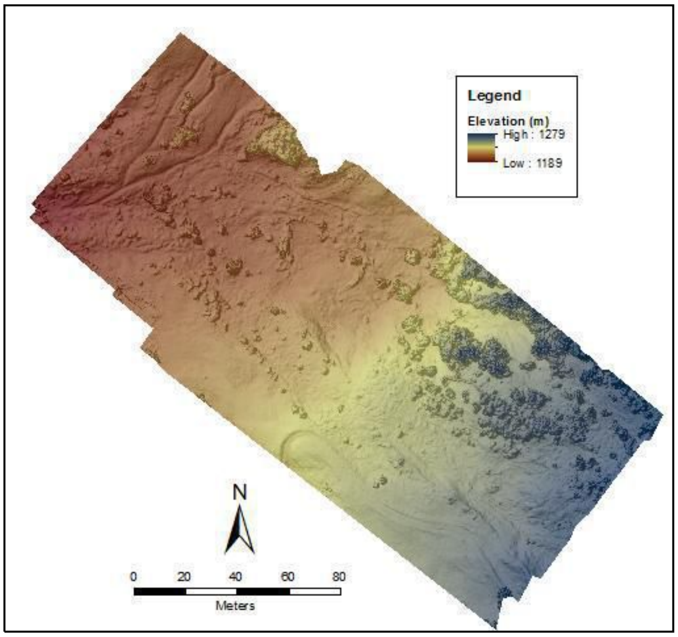

Figure 1. Digital Surface Model reconstructed based on the 2014 survey.

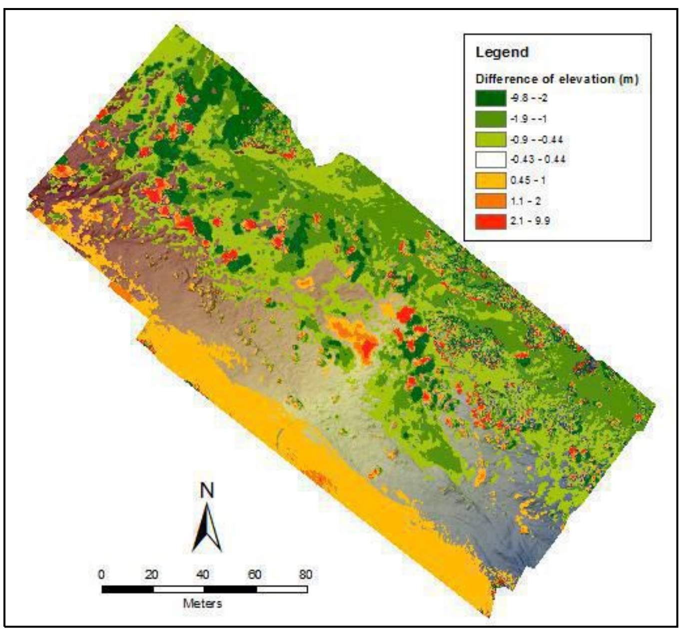

Figure 2. Difference of elevation between the digital surface models of October 2013 and June 2014. Negative values correspond to erosion and positive values to accumulation.

V. Conclusion

Based on aerial pictures taken by an UAV platform equipped with a standard reflex camera and the SfM algorithm, we reconstructed the topography of the Schimbrig landslide for two time steps: October 2013 and June 2014. The vertical accuracy of both datasets is 0.44 m, which could be improved for further surveys by using a RTK GPS for GCP georeferencing.

By DEM of difference, we highlighted large horizontal movements within the central part of the landslide up to several meters by detecting vegetation shifts downward.

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