Geological and geomorphological analysis of Doren Landslide (Vorarlberg, Austria) based on high resolution UAV and TLS DTM

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Digital elevation data computed from Unmanned Aerial Vehicle (UAV) imagery and Terrestrial Laser Scanning (TLS) are characterized by very high resolution and high accuracy. In order to make use of this data quality it is getting more and more important that we find effective ways to process and evaluate these DTMs for detailed geological, geomorphological and geomorphometric analysis. This kind of analysis can reveal micro-topographic features and tectonic faults not observed in the field.

The aim of our study is to map the range of information that can be extracted from high resolution UAV and TLS DTMs and compare them with the field observation data. During the quantitative DTMs analysis we get the opportunity to derive geomorphometric parameters and the elements of the landscape can be analysed further, e.g., can be divided into topographic domains.

The measurements were carried out at the Doren Landslide (Vorarlberg, Austria). This landslide situated in the Alpine molasse foreland. Geological field observations indicate some subrecent faulting activity with typical fault direction WSW-ENE. Several formations (Kojen Formation, Würmian glacial moraine sediments, Weissach Formation) were tectonized there (Oberhauser *et al.*, 2007). The sediments are characterized by varying grain sizes providing material for the different parts of the creeping and moving parts of the landslide at various rates.

The UAV measurements were carried out simultaneously with the TLS campaign. The UAV data acquisition focused just on the landslide scarp. The original image resolution was 4 mm/pixel. Image matching was implemented in pyramid level 2 and the achieved resolution of the DTM was 0.05 metre.

The TLS dataset includes 18 scan positions and ca. 300 million points for the whole landslide area have been acquired. The calculated DTM has 0.2 meter resolution after the removal of vegetation points via a hierarchic robust interpolation method (Kraus & Pfeifer, 1998).

The two types of DTMs were analysed with OPALS (Pfeifer *et al.*, 2013).

The UAV DTM point density was more homogenous than TLS datasets where the point density depends on different scan positions. SigmaZ value showed the reliability of the DTMs. Both model sigmaZ values (sigma value of residuals of each fitted planes) were under 0.01 m in the flat area but in the steep slope area had higher value (0.1 m). UAV data had some image matching problem where the texture did not show enough characteristic variations.

Aspect and slope parameters extracted more information about the geomorphological features, especially about toes of small internal sliding/creeping surfaces.

Visualizational interpretation of the datasets separated clearly scarp, selective denudation area (incipient incision) and different faults and rills. The TLS datasets reveal the surface under the vegetation to some extent and provided more geological information not accessible for the field work.

Both datasets provided linear features interpreted as displacements and eventually fault boundaries for the different hard surfaces. In the area of the toe such linear features are related to the creeping/plastic motion of the material of the landslide. Furthermore, on and along the scarp surface some tectonic activity indicators can be extracted, too.

Using the different derivative parameters of the DTMs we made a multi-channel (aspect-slope) raster database and applied ISODATA classification method for the study area in order to extract geomorphometric units automatically. The results were correlated with the Zámolyi & Székely (2009) interpretation study.

The conclusion is that both high resolution DTMs are able to represent interesting micro-topographic features. This study showed, what could be the advantages and reliability of each types of models. If the measurements are regularly repeated in the future, we can detect how the landslide develops and what happens to the features detected in this study. This knowledge will help to understand the movement of the landslide.

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