Photogrammetrically UAV based terrain data generation and automatic extraction of torrential properties

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Abstract. Debris flows are a severe hazard in mountainous regions. However, cost-effective long-term studies of debris flows are seldom, which leads to substantial uncertainties in hazard mitigation methods. This paper investigates whether cost-effective remote sensing techniques can be applied to assess the hazards of mountain torrents and to gather accurate long-term information on the development of the watershed. Torrents that are prone to debris flows are often devoid of vegetation and can thus be well surveyed using photogrammetric methods based on uncrewed aerial vehicle (UAV) surveys. The possibility of extracting automatically torrent parameters from high-resolution terrain models, such as cross-sectional area or slope, is explored. The presented methodology yields continuous and automatically derived parameters along the torrent, which is a major advantage over pointwise field surveys. Cross-validation with field measurements reveals a strong agreement. These parameters are very accurate along highly incised sections, while they are severely limited along sections with steep adjacent hillslopes and/or dense vegetation. We show that these kinds of assessments greatly gain from UAV data followed by automatic parameter extraction. The extracted parameters provide insights so that key sections and weak points can be identified and accurately assessed in the field. We find that UAV data can contribute to a comprehensive, reproducible and objective assessment of torrent processes and predispositions. However, ground-based fieldwork is still essential and further research on remote sensing-based hazard assessment of torrents prone to debris flows is crucial.

1 Introduction

The way debris-flow hazard analyses are performed vary greatly [1]. In Switzerland, some geomorphological assessment approaches are at disposal to assess debris-flow prone catchments [2-5]. So far, none of these methods have become an established standard in engineering practice. The amount of available time and money for field investigations are important factors for practitioners. As a result, often only a limited amount of field work can be conducted. Nevertheless, accurate, up-to-date and in-depth information about a study site is of very great importance and crucial for the quality of the hazard assessment. The use of UAV may open up new opportunities for more objective and time-efficient hazard assessments. We address the question of how cost-effective remote sensing techniques can be used in torrent hazard assessment. In particular, whether ground classification algorithms applied on photogrammetrically derived point clouds allow for the derivation of high resolution digital terrain models which aid in an automatic extraction of continuous data along the torrent. The advantages of UAV derived terrain data can be found in its high spatial resolution and a representation of the current state of the torrent morphology. These days photogrammetric derived point cloud can be produced to significant lower costs compared to LiDAR UAV surveys. The acquisition costs of a LiDAR UAV are many times higher than those of a photogrammetric UAV. Here, we investigated the ground classification of photogrammetric point clouds, knowing that LiDAR based products would provide highly more accurate results.

A detailed comparison of LiDAR and photogrammetric derived terrain models and an in-depth analysis of how (photogrammetric) UAV data may be used within the hazard assessment of torrents can be found in [6].

2 Point Cloud Classification

We classified photogrammetric point clouds in high alpine terrain. As conventional standard classification routines perform poorly, we develop dedicated routines which succeed in such complex alpine terrain. Photogrammetrical approaches which make use of RGB information seem to provide the best results [7]. Followingly, we highlight two methods based on the proprietary software LAStools and Terrasolid (see Figure 1).

2.1 Terrasolid based Approach

TerraScan is a powerful software solution for processing LiDAR point clouds [8]. With the Terrasolid software, the aim was to create a classification routine by generating a smooth surface that can then be classified while disregarding residual noise. From the original point cloud, less reliable, noisy and isolated points are removed. In a subsequent step, a smoothed surface is

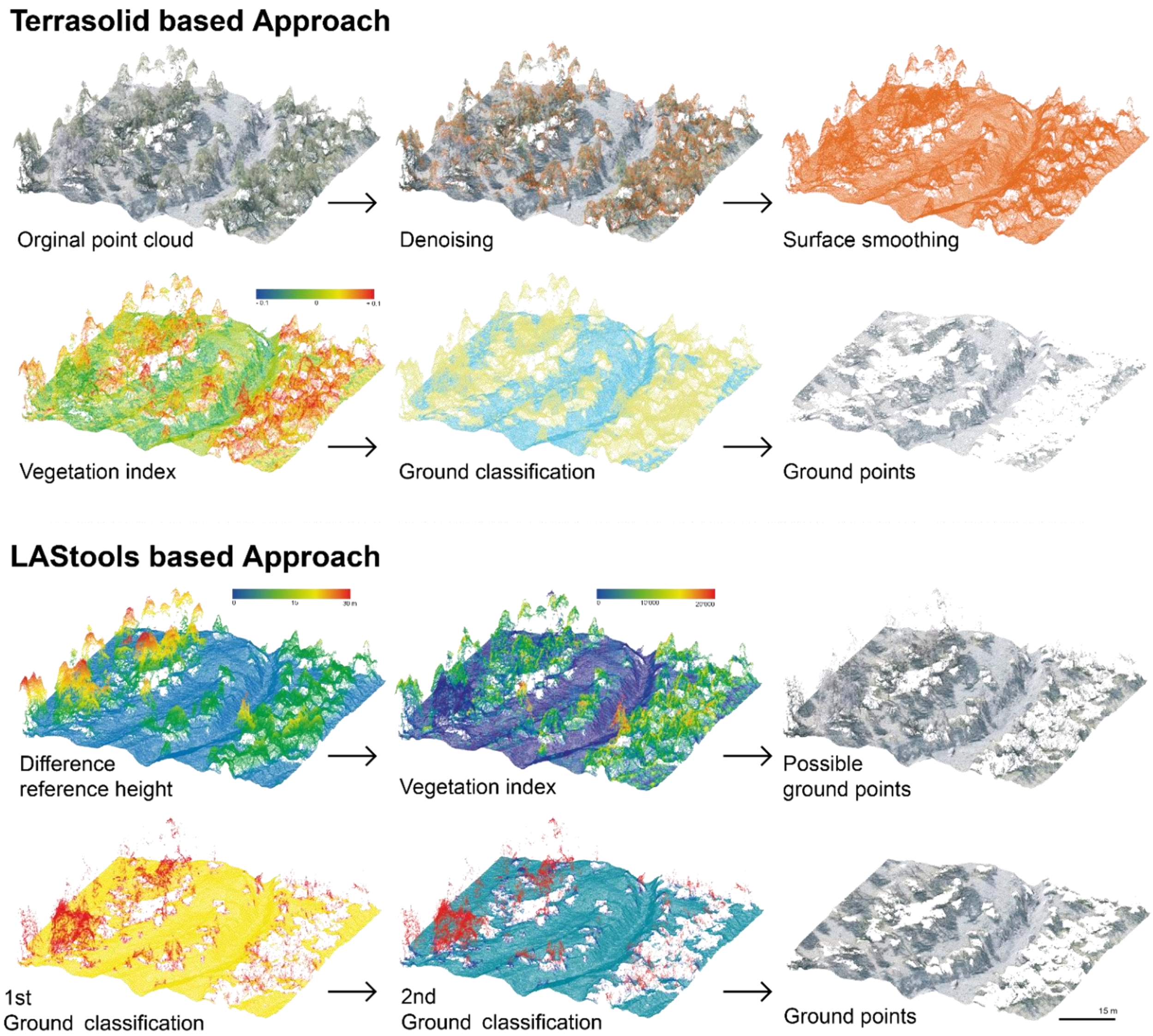

Fig. 1. Two point cloud classification approaches based on the dedicated software tools Terrasolid and LAStools after [8].

generated and a vegetation index is calculated for the ensuing ground classification.

The Terrasolid-based ground classification algorithm is limited in distinguishing between grass vegetation and higher vegetation such as shrubs and trees. Along the channel bed, this limitation has little significance. However, when the derived terrain model is used for numerical simulations, the results require a great deal of caution when analysing them.

2.2 LAStools based Approach

LAStools is a another dedicated tool for post-processing LiDAR point clouds, which allows the workflow to be adapted to the specific requirements [9]. Here we aimed for a ground classification that considers all potential ground points, even below the top vegetation layer, which is applicable in steep, densely vegetated terrain.

In a first step, the potential ground points (low vegetation and bare ground) are selected based on the calculation of a difference to a reference height model and the computation of a vegetation index. The resulting possible ground points are then classified using a highly coarse step size. Within a subsequent iterative triangulated irregular network (TIN) densification with different step sizes, the remaining noise points are removed. However, sharp edges such as artificial constructions are cut off in the final DTM through this process. A further limitation is that the methodology relies on a coarse reference height model to distinguish between high vegetation and grass vegetation. In regions of the world where there is no such data available this approach will unfortunately not be applicable.

Both approaches presented have limitations that need to be carefully considered. Depending on the terrain, the more powerful algorithm should be chosen. If the torrent is densely covered with vegetation, a photogrammetric UAV flight during the leaf-free season or a LiDAR-based flight may improve the results implying higher costs, obviously.

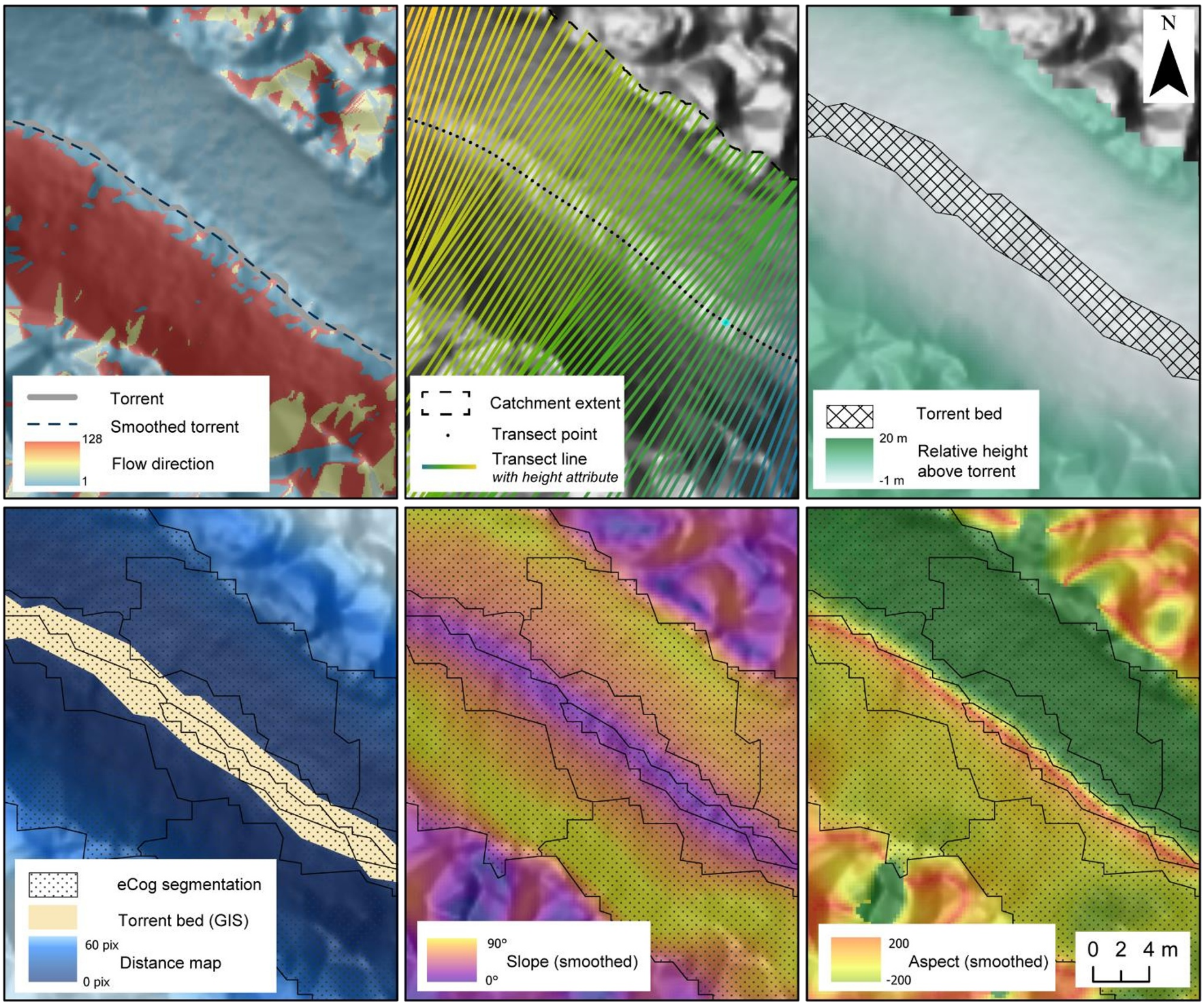

Fig. 2. Automatically extracted torrential properties within a GIS and Object-based Image Analysis (OBIA) based workflow.

3 Torrential Properties Extraction

Field observations are crucial when assessing the potential magnitude of debris-flow prone torrent. Many assessment approaches aim to estimate the geometric features of the torrent in order to obtain an estimate of potential depth and embankment erosion. As these field measurements are very time-consuming, discrete and based on subjective expert judgement, the goal is to automatically extract the required parameters through a GIS and Object-based Image Analysis (OBIA) workflow (see Figure 2).

Based on a hydrological analysis, we extracted a polyline representing the torrent. Along this line, transect lines were created perpendicular to the torrent. The elevation attribute of the transect point was transferred to the transect lines and gridded with this attribute to create a continuous surface representing the elevation of the torrent bed. Subtracting the elevation of the torrent bed from the elevation of the DTM provides a representation of the relative elevation above the torrent. A suitable threshold is chosen to extract the bottom of the torrent.

The embankment extraction was performed using OBIA in eCognition. A multi-resolution segmentation was performed based on a calculated distance map, slope and orientation. The objects representing the slope were selected based on different conditions. This segmentation works well in terrain with a highly variable inclination between the adjacent slope and the embankment. Along areas with a steep adjacent slope, automatic extraction of the torrent bed is severely limited. Another main limitation was found along densely vegetated areas where the derived photogrammetrical terrain models are strongly triangulated.

As can be seen in Figure 3, the method allows for a continuous computation of the torrent properties along the torrent. Since the fully automatic OBIA-based extraction was severely limited in complex terrain, we additionally drew manual polygons representing the slopes. The cross-section area derived from GIS in Figure 3 shows the calculated cross-section based on the manually drawn polygon. There are some strong variations in the upper catchment. However, the main patterns along the torrent can be found in both versions.

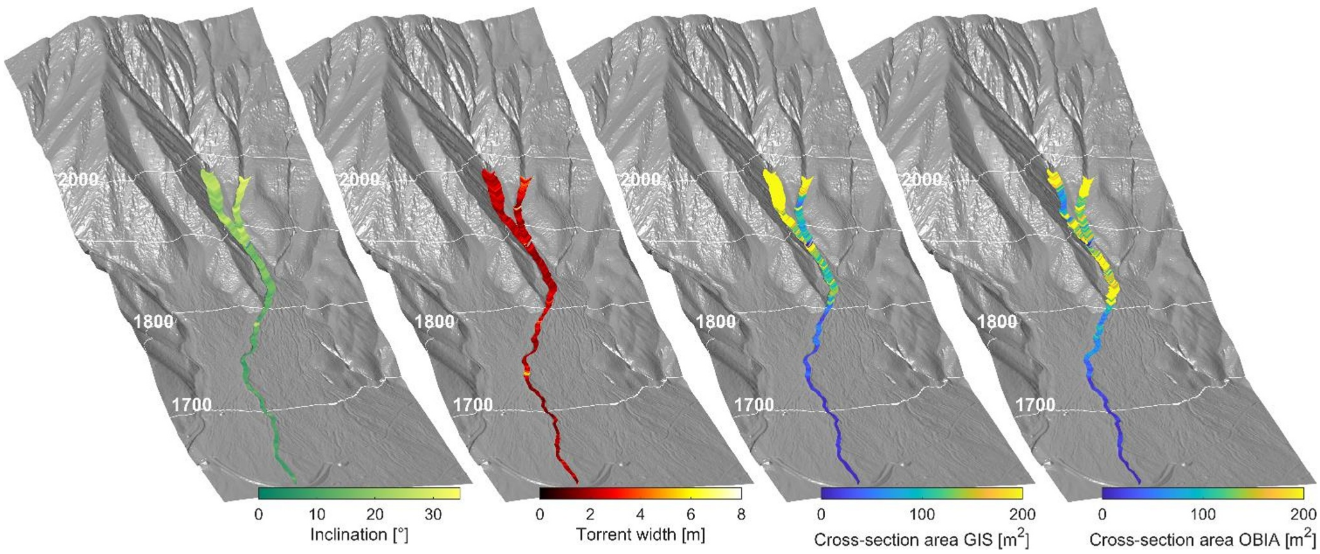

Fig. 3. Continuous illustration of the GIS and OBIA based torrential parameters of the Arelen Catchment near Davos CH.

The derived measures can be used for assessing weak points, bedload capacity thresholds, dividing the torrent into homogenous sections or intercompare it with temporally spaced surveys.

4 Conclusions and Outlook

We introduce approaches for the automatic extraction of torrent properties based on photogrammetrically derived UAV data. We show how hazard assessments may be enriched and complemented by objective, fast and spatially complete key parameters. The proposed approaches particularly lead to a faster, more reproducible and objective torrent analysis. The presented methodology provides continuous geometry data along the torrent, which is a great advantage over the often locally limited field measurements. Cross-validation with field measurements reveals good agreement. However, a large-scale independent study with accurate independent field measurements would need to be conducted by practitioners to prove the validity of these results. Problems with dense vegetation along the embankment could be solved by applying the algorithm to LiDAR-UAV terrain data. Difficulties caused by steep adjacent slopes remain.
At this stage, the cost of LiDAR-based surveys is multiple times higher than photogrammetric surveys. We therefore recommend that the data be acquired photogrammetrically and processed using the proposed classification routines. Along densely vegetated areas of the catchment, additional LiDAR flights may be considered to further improve the results.
In summary, in-depth hazard assessment remains a challenge. Further interdisciplinary research combining remote sensing techniques and hazard assessment methods for a wider variety of study areas is crucial. Fieldwork will always remain a compulsory part of the assessment process. At this stage, the available sediment, erosion capacity, slope processes and the condition of mitigation structures can only be properly assessed on the basis of accurate fieldwork. UAV data and its derivatives have the potential to provide a stepping stone towards reproducible and objective hazard assessment. We urge to combine proper fieldwork and automatic extraction of torrent dimensions to be implemented in modern torrent hazard assessment procedures.

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