Using Point Clouds as Topography Input for 3D Rockfall Modeling

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ABSTRACT: To increase the accuracy of 3D rockfall trajectography analysis, we propose a tool that uses point cloud data directly as the input topography for 3D rockfall modeling as opposed to gridded-digital elevation models (DEM) that are used in current softwares. The goal is to take into account overhanging slopes and other irregular features that are smoothed or suppressed in the rasterizing/gridding process. Point clouds acquired obliquely to a rock cliff, either by laser scanner or photogrammetry, accurately represent its topography and they are now used for structural analysis, volume calculation, change detection and displacement analysis. We propose a rockfall simulation algorithm that uses a vegetation-free point cloud as the topography input. It enhances the analysis: for example, an overhanging slope can be used as a rockfall source. A future research avenue of using point clouds instead of a gridded-DEM is the study of the impact of vegetation on rockfall travel.

1 INTRODUCTION

Most current 3D rockfall simulation programs use gridded-digital elevation models (DEM) as their topographic input (Li et al. 2015). Near-vertical cliffs are under-represented, even in high resolution DEM, and appear strongly smoothed compared to their point cloud representation (Fig. 1a and b)(Noël et al. 2015). Simulation results depend of the DEM scale, with a tendency to overestimate velocities and underestimate heights and the lateral distribution as the DEM's resolution decreases, or as the smoothing increases (Agliardi & Crosta 2003, Crosta et al. 2015).

Various rock slope analyses can already be done directly on point clouds, such as structural analysis (Riquelme et al. 2016, Assali 2014, Matasci et al., 2015, Slob et al. 2010, Lato 2012) and change detection between two point clouds (Gauthier et al. 2015, Bell et al. 2014, Kromer et al. 2015). We developed an algorithm to detect impacts on point clouds to run 3D rockfall simulations directly on point clouds. The proposed methodology offers a way to incorporate a higher level of details of the modeled terrain than is done using gridded-DEM. For example, overhanging slopes, ditch, wall, or catch fences can be part of the terrain model, so their effect on trajectories can be considered.

In this brief paper, we describe the characteristics of the point cloud to be use as the topographic input in the impact-detection algorithm that is described afterward. Then, some simulation examples are shown and the methodology is discussed. Further development and more details on this method can be found in Noël et al. (in prep.).

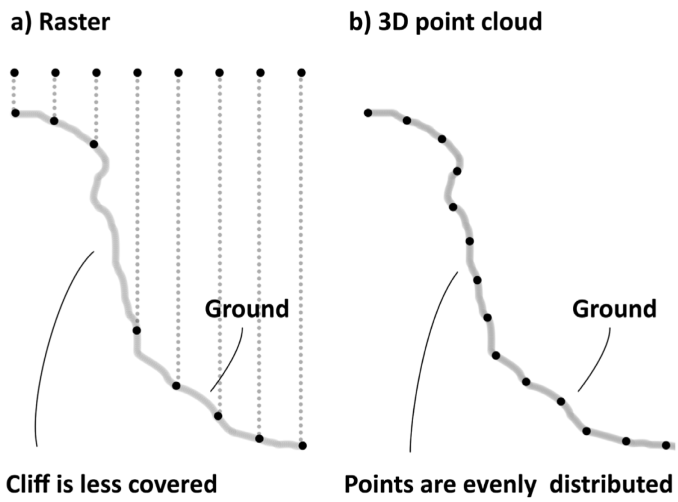

Figure 1. Comparison of rasterized and point clouds terrain models. Elevation points are regularly projected on the gridded-terrain surface (a) but the near vertical face is poorly constrained, while the points are evenly distributed on the surface by using the 3D point cloud approach in (b).

2 POINT CLOUD CHARACTERISTICS

The impact-detection algorithm uses a point cloud as the topographic input.

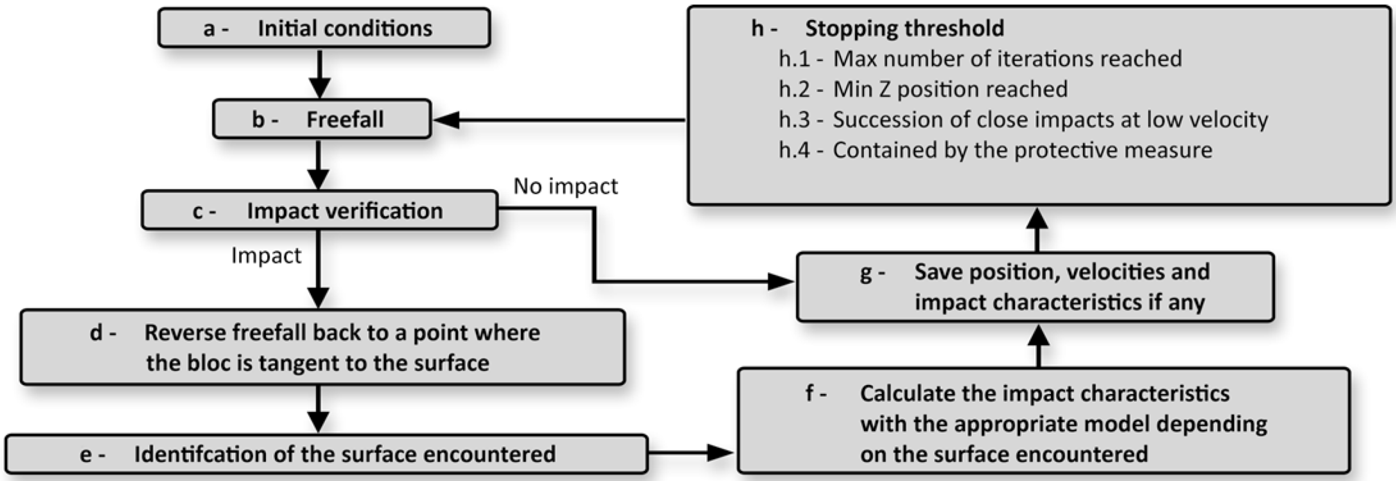

Figure 2. Principal steps of the detection algorithm of impacts on point clouds.

It must be classified to isolate the ground, remove vegetation, recognize infrastructures, and reduce its noise if necessary, which can be done with tools like CANUPO (Brodu & Lague 2011), CloudCompare (Girardeau-Montaut 2006) or Statistical Outlier Removal (SOR) from the Point Cloud Library (PCL) (Rusu & Cousins 2011).

Surface orientations (slope and aspect) are also needed with the 3D classified point cloud as input of the proposed impact-detection algorithm. The slope and aspect of a point can be expressed with a normal vector to the ground surface extrapolated from points within a determined radius from the point of interest. A point's normal vector can be computed with various tools, e.g. Coltop 3D (Jaboyedoff et al. 2007, Terr@num, 2011), CloudCompare (Girardeau-Montaut 2006), PCL (Rusu & Cousins 2011), Polyworks (Innovmetric, 2014).

3 IMPACT DETECTION ALGORITHM

The detection algorithm of impacts on point clouds is schematized in 8 steps in Fig. 2.

The first step (Fig. 2a) consists in positioning the particle to its initial location. This location should be chosen so to create some free fall so it does not stop at the first iteration.

The second step (Figs. 2b and 3) consists in the particle free falling on a distance slightly less than its diameter (F_d), to verify if it passes through points of the cloud. F_d can be optimized in function of the largest space in between points (P_{ch}) and the particle's diameter using Eq. 1:

$$F_d = \sqrt{diameter^2 - P_{ch}^2} \tag{1}$$

The equation is valid only if the diameter is larger than P_{ch}, otherwise the particle will falls in a hole in between two points, no impact will be detected and the particle will free fall under the point cloud leading to erroneous results. Thus, to work correctly with the algorithm, the point cloud should have a point density that matches the size of the simulated rock block and be gap-free.

The third step (Fig. 2c and Fig. 3) verifies if there is or not an impact of the particle with one or many points. This verification is carried out by looking if there are points at a distance shorter than the particle's radius from the centre of the particle. If yes, there is an impact. It means that the free fall displacement was too large and that the particle partly passed through the terrain surface. The previous free fall distance must be rewound until the particle is tangent to the surface, which is done in step 4 (Figs. 2d). If no, there is no impact and the location and velocities of the particles are saved and verification is made if stopping thresholds are met (Figs. 2g and h). If stopping thresholds are not met, the process starts back at step 2 (Fig. 2b).

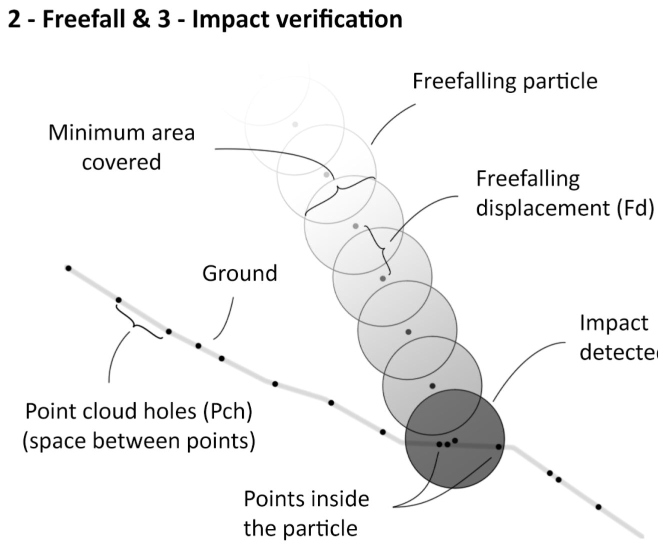

Figure 3. Algorithm Step 2 & 3. Free falling positions are shown in grading grey. Impact verification is made for each position. An impact is detected when there are ground points inside the particle.

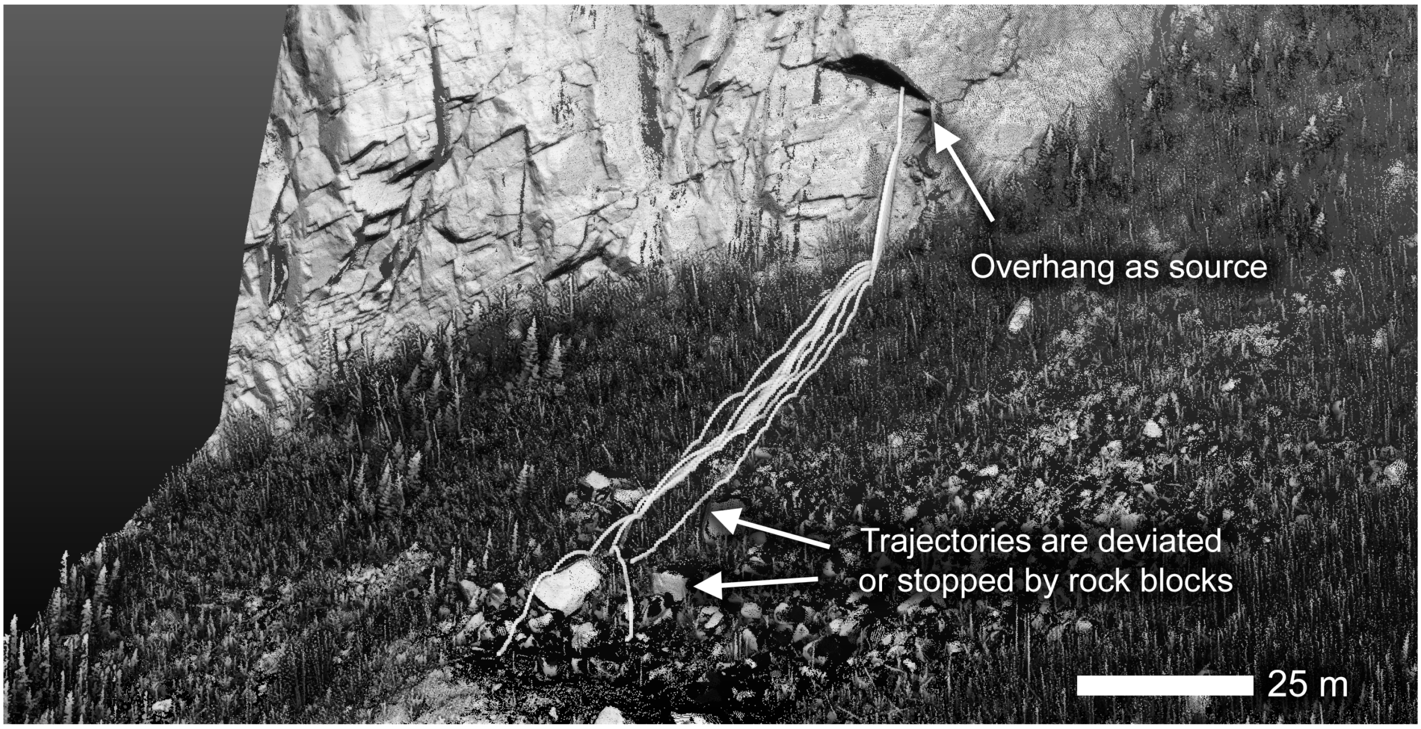

Figure 4. Portion of a cliff rendered with 10 white simulated rock fall paths showing the high level of detail the proposed method can handle. The simulations were run on a vegetation-free point cloud. The vegetation was added to the figure for clarity. The rockfall source (diameter of 2 m) was manually selected near the base of the overhang. Trajectories are slightly deviated at the base of the cliff following in 3D the aspect orientation of the slope. They then gradually loose energy and stop in the boulder field. Some of them are stopped by rock blocks. Others can be seen being deviated when impacting against large boulders.

In step 4, the surface characteristics are approximated by the normal vector of the last point remaining in the particle during the rewind freefall process. This point is tangent to the particle.

In step 5 (Fig. 2e), the type of surface impacted by the particle is determined in order to choose the right impact model and characteristics. The surface could be rock, soil, an infrastructure, mitigation works, etc. The impact is calculated in step 6 (Fig. 2f).

Step 7 simply consists in saving the particle's location and velocities (spin and displacement) and the impact's characteristics, if needed.

The last step (Fig. 2h) consists in stopping the simulation if: 1) a pre-determined number of iterations are completed, 2) the vertical location of the particle is below the point cloud, 3) there is a succession of closely-spaced low-velocity impacts, or 4) a particle is contained by mitigation work. The two first criteria should not be met if the input parameters are adequate and if the point cloud is sufficiently large to fully contain the rockfall propagation. If stopping thresholds are not met, freefall continues (step 2, Fig. 2b).

4 APPLICATION OF THE IMPACT-DETECTION ALGORITHM

In this section, we illustrate how the impact detection can be used in a rockfall simulation program. To do so, an impact model must be integrated to the algorithm to compute how the block will rebound when impacting the surface. For this exercise, the impact model used is based on the one proposed by Wyllie (2014a, b). Some modifications were made arbitrarily to the equations proposed by Wyllie (2014a, b) so they would work with our code. Rockfall simulations were run using a numerically-created perfectly smooth slope and results were compared to those obtained for the same slope geometry in the commercial software Rockfall 5.0 (Rocscience Inc. 2014). We were satisfied with the results and no more validation of the impact model was carried out for this paper, as the objective was to develop an impact-detection algorithm and not an impact model.

The code was tested on real point clouds of different rock cuts and natural slopes acquired with a terrestrial laser scanner (Optech Ilris 3D) (Fig. 4). We embedded the algorithm and the impact model in a simulation program that has a simple and intuitive graphical user interface. The user can select sources locations to simulate rockfall simply by clicking on the desired points. In the example shown in Figure 4, the source is an overhanging area of the cliff. The simulated paths follow the 3D aspect of the terrain and are affected by rock blocks on the talus slope (Fig. 4).

5 DISCUSSION

The algorithm presented in this paper can simulate rockfalls using a point cloud topography input. At this time, it uses a lumped-mass approach and only free fall and rebound modes of propagation are modelled.

The normal vector of the points are used to determine the slope and aspect of the surface impacted by the rock block, and thus, they dictate in which direction the block rebounds. We suggest that the search radius looking for points to be used to calculate a normal vector should be similar to the radius of the simulated rock blocks, so the local surface orientation will approximate the footprint size of the particle. The idea is to introduce some smoothing in the point cloud so its resulting roughness corresponds to the one that can influence a block of a certain size. For example, the trajectories of a metric-scale rock should not be influenced by a millimetric-scale surface roughness (Wyllie 2014a). A roughness too small compared to the particle size will have the same effect than noise and will tend to create rebounds in random directions.

A limitation of the algorithm is concerning the tangent impacts on noisy surfaces, which can result in the particle being trapped in the point cloud. This unrealistic situation could occur as following: the particle rebounds in a direction tangent to the point cloud surface, then, the particle impacts the adjacent points of the cloud leading to a rapid loss of speed, thus the particle stops abruptly. This problematic situation can be encountered more or less often depending on the chosen impact-model and on the relative particle size compared to the point cloud noise dispersion. Such a situation should be rare with the impact model proposed by Wyllie (2014a) because the normal coefficient of restitution increases with diminishing incident angle of the particles with the ground surface at impact. This type of error will increase with the noise in the point cloud.

6 CONCLUDING REMARKS

The proposed algorithm uses a point cloud as the input topography of rockfall simulations and allows fairly rapid simulations with 100 to 200 trajectories computed per second. The advantages of using a point clouds are: 1) overhanging slopes are represented and can be identified as sources, 2) it eliminates the bias linked to gridded-DEM (under representation of steep slopes and smoothing), and 3) it can be detailed to simulate the effect of protective measures.

Future developments of the methodology should focus on calibration of our method.

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