USING PHOTOGRAMMETRY TO TEMPORALLY COMPARE SNOWPACK THICKNESSES AND CALCULATE VOLUMES

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ABSTRACT: Photogrammetric techniques have recently been researched and applied in the avalanche field. Numerous photos taken of a particular location can be combined using photogrammetry modelling software to produce three-dimension mesh or point cloud models. After referencing in relative space, models of the same location can be quantitatively compared to determine snowpack thickness and volume changes. We tested this approach at two locations in western Canada. The results suggest that this technique is possible with realistic measurements, although some conditions must be met. This technique is useful for operations that are interested in comparing the snow cover to previous times of the year, previous years, or to the snow-free ground cover. For example, it could highlight areas of thin and thick snowpack in starting zones or study plots. Snowpack height and volume changes could be used to obtain better avalanche slab and deposit volumes. Such measurements can be obtained with approximately 20 to 30 minutes of hands-on work. Photogrammetry is relatively easy to perform, inexpensive, and allows for a magnitude of different analyses to be conducted.

KEYWORDS: photogrammetry, point cloud, change detection, snowpack height, volume estimates.

1. INTRODUCTION

Structure-from-motion photogrammetry is a relatively new technology that is being applied to a variety of scientific fields. Photogrammetry was first applied in the 19th century (Doyle, 1964). Structure-from-motion photogrammetry uses mathematical calculation to match coordinates of points in object space from various photographs based on camera parameters, measured coordinates, and ground control (Wolf and Dewitt, 2000). Modern technology allows for high-resolution three-dimensional point cloud or mesh models to be produced from tens to hundreds of photographs.

This approach has recently been applied to a variety of geotechnical and geohazard applications, such as rock slopes (Haneberg, 2008; Sturznegger and Stead, 2009), landslides (Ganzalez-Diaz et al., 2013; Wolter et al., 2014), and glacial changes (Whitehead et al., 2013; Ryan et al., 2015), and river flood plains (Javernick et al., 2014). Photogrammetry has also been used to assess vegetation damage from past avalanches and model a fracture line from a deep slab avalanche (Gauthier et al., 2014), snow depth mapping for widescale applications using aerial imagery (Buhler et al., 2015), the determination of ablation rates and snowcover depletion over complex terrain (Schirmer et al., 2016), and to create models of avalanche flow (Thibert et al., 2015; Dreier et al., 2016). Snow depth measurements on roofs using photogrammetry were recently analysed, comparing modelled depths with physical measurements (Chiba and Thiis, 2016).

When two or more models of the same area are produced, changes between them can be assessed. This paper examines the ability to measure quantitative differences between surfaces over various time periods and consequently snow depths. Potential applications to the snow and avalanche field are also discussed.

2. METHODS

Photographs were taken with a 12-megapixel digital SLR camera. Between 10 to 20 photographs were taken for each study site, with adequate overlap of each photo to compute a model. The photogrammetry models were created using the program Photoscan Pro by Agisoft (www.agisoft.ru). Photoscan uses a structure-from-motion open source code to determine the relative locations and orientations of each photograph by matching certain point locations within the photographs. The program produces both three-dimensional point clouds and meshes. Gauthier et

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al. (2014) further describes this method and photograph requirements.

The models were compared for differences and volumes were calculated using the three-dimensional cloud and mesh processing software CloudCompare, which is an open source project (http://www.danielgm.net/cc/). This program quantitatively detects changes between models. Volumes were calculated using the volume calculation function within the program.

Photographs were taken at two study sites for change detection. Unique characteristics of the sites included 1) a quinzee and 2) a building. Models were created first in the winter and second in the spring for the study sites.

3. RESULTS AND DISCUSSION

3.1 Model creation

The three-dimensional models were realistic, with resolutions on the centimetre scale. For example, footprints and a walking path within the snow were simulated (Figure 1). The models adequately simulated the snow surface, allowing for the comparison between the models.

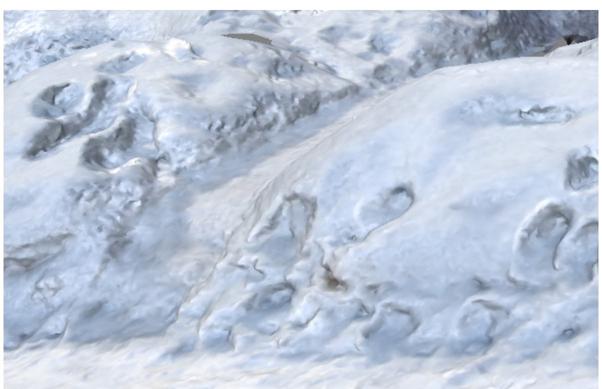

Fig 1. Three-dimensional modelled Footprints and a walking path in the snow.

3.2 Change detection

Detecting changes in the models for both study sites was successful. The quinzee study site was located in open and flat terrain with surrounding trees. The trees were used to reference the temporally different models. The change detection found between 0.1 and 0.5 m of snow loss over the timescale of approximately one month between the two models (Figure 2). The colour scheme (red for snow gain and blue for snow loss) indicates the amount of change detected and is superimposed on the model surface. Point measurements obtained in the field had changes on a similar scale. Snow loss was observed from consolidation and snow melt. Footsteps on the roof of the quinzee were modelled well in the spring model, which is where the highest amount of change was detected.

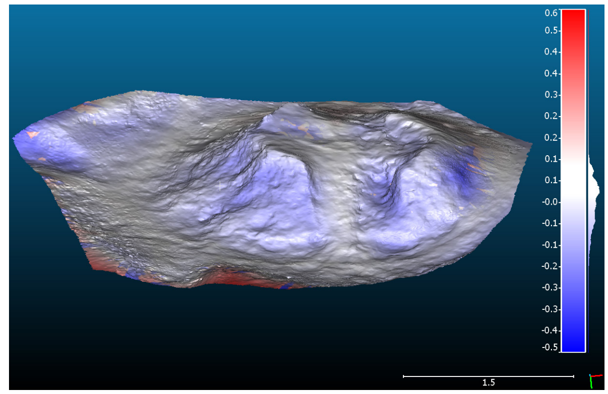

Fig 2. Change detection for quinzee study site, with the spring model shown. Differences are measured in metres, with blue showing snow loss and red showing snow gain.

For the building study site, one model was from photographs in mid-winter with ample snow and the second model was conducted in the late spring without much snow. The building was used to reference the two models. The change detection determined the snow depths to be approximately 0.5 to 2 m (Figure 3), which are comparable to point measurements obtained in the field. The calculated changes were particularly realistic for the snow on top of the building roof as well as for the snowpack in front of the building.

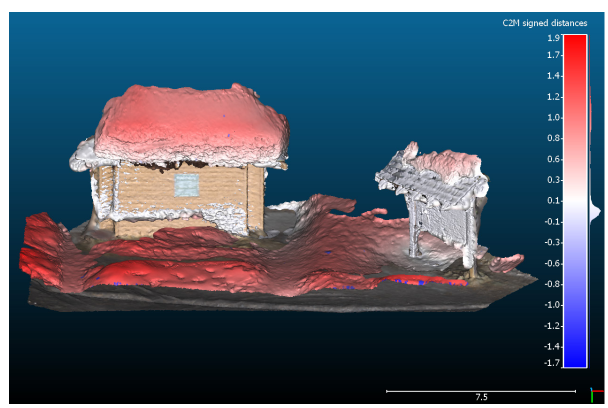

Fig 3. Change detection for the building study site. Both models are shown, with the change detection colours on the winter model and real-life colours shown for the spring model. Differences are measured in metres, with blue indicating snow loss and red indicating snow gain.

3.3 Volumes

Volume calculations are easy to conduct from photogrammetry models. For the quinzee study site, the volume of the quinzee itself was calculated for each separate model. The volume from the winter model was 2.8 m^3 and the volume from the spring model was 2.4 m^3. The difference between the models was 0.4 m^3, which is from snow melt and consolidation of the snow.

Multiple volume calculations were conducted for the building study site. The first comparison was for the snow on the roof of the building (Figure 4). A volume change calculation was completed between these two layers, which calculated a volume difference of 11.8 m^3. This amount of snow was estimated from Figure 4, with a roof width of about 6 m, depth of 2 m, and snow thickness of about 1 m from the change detection.

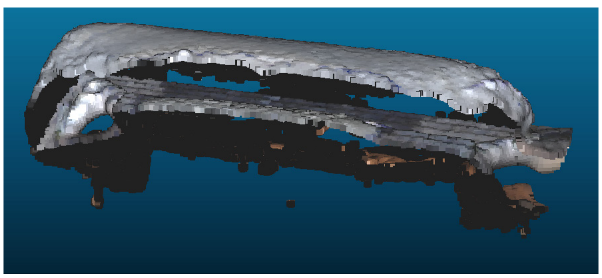

Fig 4. Looking from the side at the roof of the building with both models present. The top layer is the snow from the winter model and the bottom layer is the roof of the building from the spring model.

Next, the volume of snow of a portion of the snow in front of the building was calculated. The volume of snow was calculated three ways for comparison. The first was using the ruler function to measure the length, width, and average thickness of snow. This method produced a volume of approximately 7 m^3. The second method was to assume a flat ground surface and measure the snow surface volume from the flat surface. This method produced an estimate of 7.9 m^3. The third method was to use the volume change function, which measured a volume of 7.4 m^3 (Figure 5). The third method is not only the most accurate but is also the simplest to perform. However, a model with a ground surface is not always obtained, in which case the second method would be best.

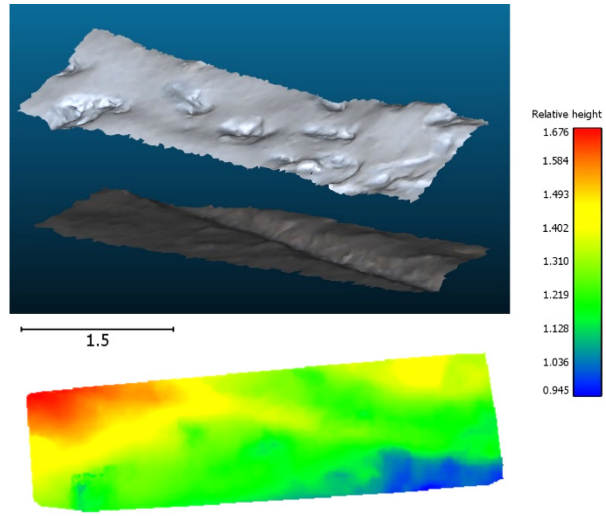

Fig 5. A patch of snow in front of the building. The top layer is the snow with footsteps present and the bottom layer is the snow-free ground surface with a drainage ditch. The relative height is in metres and is looking down on the snow surface.

4. APPLICATIONS OF PHOTOGRAMMETRY IN THE AVALANCHE FIELD

The models and change detection performed in this analysis are relatively simple to create and cost-efficient. For the analyses conducted in this paper, the photographs took approximately 5 minutes, each model took about 5 minutes of hands-on computer time and 20 to 60 minutes of run time, and the change detection and volume estimates took about 10 to 20 minutes. Within 20 to 30 minutes of hands-on work, quantitative measurements of snowpack changes and volumes can be obtained.

These models could be created either at the terrestrial level or using photographs from an aerial level, such as with a helicopter or drone. Helicopters are often used by avalanche professionals, such as with heli-skiing, explosive control, and avalanche investigations. Below are some examples where creating photogrammetry models could be useful to avalanche professionals.

4.1 Slab measurements

Currently, slab measurements are estimated, often using expert judgement or from approximations using programs such as Google Earth. However, these estimations usually only provide a single value or range for the slab depth, width, and length, and may often be underestimated (e.g. Jamieson et al., 2014). Producing a photogrammetry model would allow for quantitative estimates of the slab properties. For example, Figure 6 shows an example of a quick model created from five photographs taken from a helicopter (not taken for the purpose of creating a model). From this model, an average crown depth of 1 m was measured. Profiles conducted along the crown were between 0.5 and 1.5 m, averaging approximately 1.0 m. Avalanche crowns and slabs were also successfully modelled with photogrammetry by Gauthier et al. (2014).

From a safety and time perspective, measuring slab characteristics from a photogrammetry model could be completed without even setting foot within the starting zone, if an object within the model has a measured size associated with it. Creating a model would also allow for the slab to be spatially mapped for comparison over future years.

Producing a photogrammetry model may more easily determine the stauchwall (prior to erosion by the avalanche) than field measurements, as it could detect the indistinct differences often observed at the stauchwall. Having complete slab volume estimates would be useful to determine snow supply and the volumes are required in complex dynamic models.

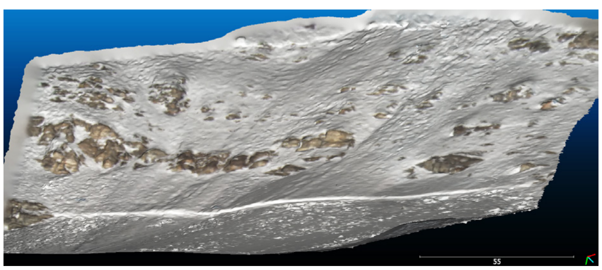

Fig 6. Avalanche starting zone and crown modelled using five photographs.

4.2 Avalanche deposit volumes

Deposit volumes are often estimated in highway operations in western Canada (e.g. Jamieson et al., 2014). The estimates usually include information such as maximum deposit thickness, average deposit thickness, deposit length, and deposit width. Such estimates are relatively coarse, and are difficult to record when the deposit is not a simple, uniform shape. Photogrammetry models of deposits would provide much more realistic volume measurements. An example of a modelled deposit is presented in Figure 7, which was created using ten photographs from a helicopter, which were not taken for this purpose.

Obtaining accurate deposit volumes would be useful for a variety of reasons, such as estimation of avalanche size, estimation of amount of snow that remains in the path (e.g. Vallet et al., 2001; Sovilla et al., 2006), and calibration of avalanche runout models.

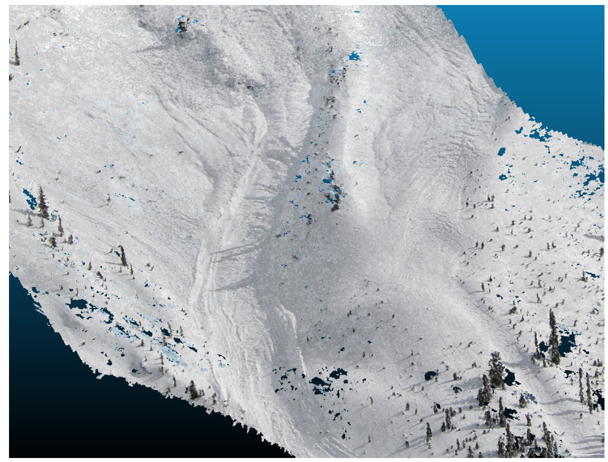

Fig 7. An avalanche deposit modelled from ten photographs.

4.3 Spatial variations

Avalanche professionals are interested in the spatial variability of snowpack thicknesses for numerous reasons. Guides are interested in locating areas of thick and thin snowpack for route selection. Ski patrols and highway operation personnel are interested in locating thin snowpack areas for explosive control.

Locating spatial variations in the snowpack is possible with the approaches discussed in our analysis. A model of the snow-free terrain would be required, which could be conducted during the summer. Any model conducted thereafter in the winter could be compared to the summer model using change detection. The only differences between the models should be the snow, providing an indication of where the snowpack is thicker and where it is thinner.

4.4 Snow study plot changes

Snow study plots are often maintained by ski patrols, guides, highway operations, etc. Temporal models could be useful in assessing thickness and volume changes over a larger scale than solely a snow board or height of snow stick. By creating a model of the ground surface followed by models during the winter, the snow depth could be calculated over the entire area. For this to work, stationary objects would be required to match the models, such as placed poles, trees, or buildings.

4.5 Other applications

Producing photogrammetry models is useful for a variety of other applications, such as for terrain mapping (e.g. three-dimensional avalanche atlas), obtaining path characteristics and measurements for hazard and risk assessments, and assessing vegetative damage from downed avalanches. Many further applications likely exist for particular professionals.

5. LIMITATIONS

To produce high-quality models of the snow surface, it is best to take the photographs during clear, sunny days. The model software requires points that it can match, which is often difficult during cloudy days because the snow surface does not show distinct patterns. This was shown by Chiba and Thiis (2016), where models created during cloudy days were of much lower resolution than those created during sunny days. Similarly, the models would not produce good models if the photographs were taken when it was snowing, as the software may try to match distinct snowflakes within the photos.

Photogrammetry does not penetrate vegetation; the surface you see is what you get. This differs from other three-dimensional model creation techniques, such as LiDAR, where vegetation can be computationally removed from the model. This, however, is not generally an issue for snowpack assessments, as the vegetation is an important aspect for avalanche formation and movement.

Although it is a relatively easy technique, some level of training is required to take useful photographs and to create and analyse the models. The level of training is relatively low and can be learned after testing a few models. Gauther et al. (2014) highlights some of the requirements.

6. SUMMARY

We have tested structure-from-motion photogrammetry for determining changes in snow depth and volume. The results suggest that this is possible and can produce realistic measurements. Future testing will be conducted, with higher resolution models and better quantitative measurements of temporal snow changes to assess the accuracy of the model at different scales.

Photogrammetry is a useful tool that could be used in many applications for avalanche professionals. With further use, avalanche slab height and deposit volume could be better quantified, snowpack spatial variability can be assessed over large areas, and avalanche mapping can be better defined.

ACKNOWLEDGEMENTS

We thank Bruce Jamieson for proof reading this paper.

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