Structure-from-Motion photogrammetry as a tool for harvest residue pile measurement

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Abstract

The issue of harvest residue management has been brought to the forefront of public knowledge after recent storms. Key to managing residue piles is the ability to measure them in a repeatable manner. This work aims to evaluate the method of Structure-from-Motion (SfM) photogrammetry for determining the bulk volume of piled harvest residues. A series of piles were photographed and reconstructed as Point Clouds and Digital Elevation Models (DEMs) using SfM for the measurement of bulk volume.

True dimensions of the piles were well preserved in the models, with most models reproducing to within 0.1 m of actual dimensions. The DEMs, from which bulk volumes were determined, had resolutions ranging from 3.36 to 1.51 cm/pixel. The combination of these factors indicates that the volumes determined from the models were accurate representations of actual pile volumes.

It is concluded that SfM photogrammetry is a reasonable method to be employed by harvest managers looking to determine the volume of piled forestry slash. Due to the time involved in processing the imagery, which ranges from 30 minutes to over three hours, it is likely that its use is targeted at high-risk residue piles or as a part of a residue monitoring study.

Introduction

The impact of recent cyclones has highlighted shortcomings in harvest residue management in commercial production forests. Cyclonic weather events have resulted in large volumes of harvest residues being discharged from steepland forests to coastal river flats. The extensive media coverage following these events has brought the issue to the public eye and added to pressure on the forestry industry to better manage its by-products and harvest practices (Bayne, 2019).

The Environmental Code of Practice (ECoP) for New Zealand Forestry (NZFOA, 2007) includes in its operational rules for slash management that it is necessary to, 'monitor slash piles to ensure that they are always stable and fully utilise the available space.' The National Environmental Standard for Plantation Forestry (NES-PF) (2017) states similarly to the ECoP that, 'Slash from harvesting that is on the edge of landing sites must be managed to avoid the collapse of slash piles' (MPI, 2018). Neither the NES-PF Regulations nor the ECoP allow for uncontrolled movement of harvest residue piles.

Key to managing a problem is the ability to measure it in some quantifiable and repeatable manner. Previous work by Peter Hall for the Logging Industry Research Organisation (LIRO) in the 1990s established knowledge of harvest residues, both in the cutover (Hall, 1999) as well as on harvest residue piles (Hall, 1994; Hall, 1998). By measuring the residues generated on four cable yarder landings, Hall's work established an approximate estimate of bulk residue volume as a proportion of recovered volume (Hall, 1993). Simply multiplying the total recovered volume extracted to the landing (in m^3) by 0.2 can give a harvest manager an estimate of the bulk volume of the residue pile (i.e. 5,000 m^3 of logs made at a landing yields an estimated pile volume of 1,000 m^3).

Currently, the method for obtaining the volume of piled harvest residues involves approximating the shape of the pile with a geometric solid (Hardy, 1996). This method is capable of providing an estimate of the volume of a pile and has been used in the US for post-harvest residue pile burn planning, but it is not accurate due to the irregular shape of piles. Structure-from-Motion (SfM) photogrammetry, utilising images captured with cameras mounted on Unmanned Aerial Vehicles (UAVs), can be employed as an alternative to the geometric method, Light Detection And Ranging (LiDAR) or professional surveys. SfM photogrammetry is not only accurate, but it is also a relatively straightforward and accessible technology, with companies now offering online-based cloud computing services.

SfM photogrammetry utilises a series of regular digital photographs with significant overlap between images to generate a 3D model of a scene. The SfM photogrammetry software computes the geometry between the camera, its orientation and the common points in the photos, and solves these simultaneously with an iterative bundle adjustment procedure. With this, the software can assign the common points a location in 3D space. With the internal GPS receiver of the UAV adding a geo-tag to each image, the resulting model may also be approximately georeferenced when using a supporting software package. SfM surveys can be completed at a fraction of the cost of a LiDAR survey by in-house personnel and with relatively little investment.

There are a number of SfM photogrammetry software packages available, both commercial and open-source. Westoby et al. (2012) utilised SFMToolkit3, while Agisoft Photoscan (now Agisoft Metashape) was used in a number of studies (Casella, 2017; Sanz-Ablanedo, 2018). The Metashape platform allows the creation of 3D models from images that can be captured from any position through fully automated image alignment and 3D model reconstruction (Agisoft, 2019).

A 2016 study by Karl Forsman (Forsman, 2016) into the use of SfM photogrammetry for measuring the volume of log stockpiles in a sawmill yard determined that SfM was a viable technology for evaluating the volume of the stockpiles. The study found that the total modelled pile volumes ranged between 5% and 25% of the 'true' value, which was determined with terrestrial laser scanning.

The application of SfM photogrammetry has also been investigated for the purpose of modelling accumulations of large woody debris in fluvial systems (Spreitzer et al., 2020). The research focused on scale models of large wood accumulations in varying arrangements using PIX4DMapper photogrammetry software. The conclusion was that SfM photogrammetry was well suited to the application, and could be considered a valuable tool for quantifying volumes of large wood accumulations due to savings in both cost and time when compared to conventional surveying techniques.

With a need to plan for the accumulation and handling of residues on steepland sites, UAV imagery coupled with SfM photogrammetry is a relatively new and accessible tool that has the potential to measure complex residue piles. In this study, SfM photogrammetry software and methods have been investigated for their agreement with physical measures, comparison of results to the earlier geometric method, and also processing time on a desktop computer.

Methods

SfM is a photogrammetric process whereby it is possible to create 3D Point Clouds – similar to those obtainable through LiDAR sensing – from digital images taken by many common cameras. There are a number of software packages available at both the commercial and recreational levels, including Agisoft Metashape and PIX4D Cloud. The SfM process involves the identification of common points between images, for instance the end of a log. The software is then capable of determining that point's location in space, based on the geometry of the camera's lens and the other points that are visible.

The accuracy achieved with SfM photogrammetry is largely dependent on the overlap of the images collected, as the SfM process relies on the ability to identify common points between images. As such, the larger the number of common points between two photos, the higher the accuracy of the output model (Iglhaut, 2019).

The residue piles used in this study were selected on near-flat terrain for ease of estimating the ground surface level. A secondary criterion was for suitable access by foot on all sides for manual measurements. The residue piles used are generally representative of piles generated by ground-based harvest operations. They are generally located on the edge of the skid site, and shaped into a distinct pile by a machine with a clearly identifiable edge between the pile and ground. The piles used were not representative of cable extraction systems, or ground-based extraction on steepland sites, where residues are often located on the edge of the landing, draping over a curved ground surface.

Piles were surveyed in two forests over the course of several weeks. Digital still images of each residue pile were captured with DJI Mavic Pro UAV by the model's standard 12.35 megapixel camera. This was done flying first around the pile, capturing images at an oblique perspective at an elevation of 5–7 m, depending on the size of the pile, and then at an elevation of 20 m flying directly over the pile (see Figure 1). Images were captured on average every 1 m around the pile, and every 5 m when flying over the pile.

The imagery for each pile was input to Agisoft Metashape software, where a model was constructed. Default settings for aligning images and matching points were used; 40,000 and 4,000 on Key Points and Tie Points, respectively. The settings put upper limits on the number of matched points used to align the images.

After alignment, a low resolution model of the slash pile is created with the points that were identified during the alignment process. Using the points from the alignment, a 'dense cloud' is constructed (see Figure 2), with default settings for both quality and depth filtering. Generating the dense cloud consumes the most processing time of all the steps. The variation of processing time based on the number of input images was one of the questions of this study. To assess this, three different models of each pile were made with varying number of images (i.e. two models for each pile have significant numbers of images removed).

A Digital Elevation Model (DEM) is constructed from the dense cloud using Agisoft Metashape's default settings. DEM creation is the fastest of all the steps in Metashape, taking no more than 30 seconds to finish.

The DEM is used to measure the bulk volume of the pile using a built-in measurement tool. The soil-harvest residue boundary must be delineated and the volume is determined once the polygon is closed around the pile. Metashape creates a basic Triangular Area Network (TIN) using the nodes on the user-defined boundary as the estimate for the ground surface beneath the pile. The DEM, pile boundary and volume output can be seen in Figure 3.

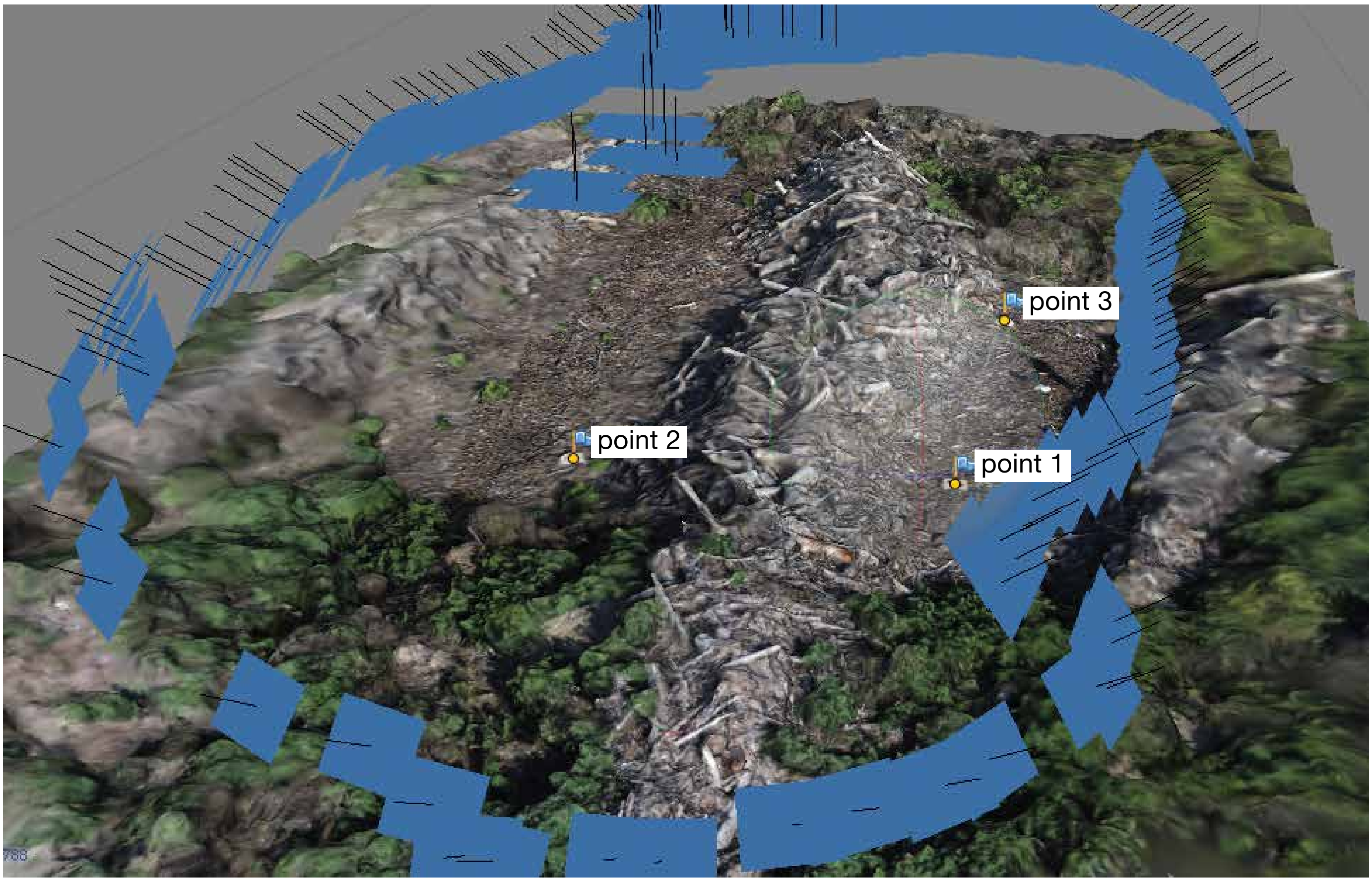

Figure 1: Orientation of imagery used in this study (blue rectangles) and the resulting model

Figure 2: Dense cloud output from Agisoft Metashape

The reliability of the volumes derived from the SfM process was assessed by comparing the volumes to those calculated by the geometric method. While the geometric method was expected to give volumes that were not accurate, the method is an accepted simplification without the aid of modern technology, given the complexity of residue pile shapes. The volumes obtained through the SfM process were expected to be generally lower than those derived through the geometric method.

Results

Nine harvest residue piles were imaged in total, with three models variants made of each pile. Of the 27 models, two failed to align the images (not enough matched points resulting in a failed model), and one model (using one-quarter of the total number of images captured for that pile) aligned in such a way that it was not possible to measure the volume. The remaining 24 models generated correctly, and all measurements were able to be collected from the models. Some

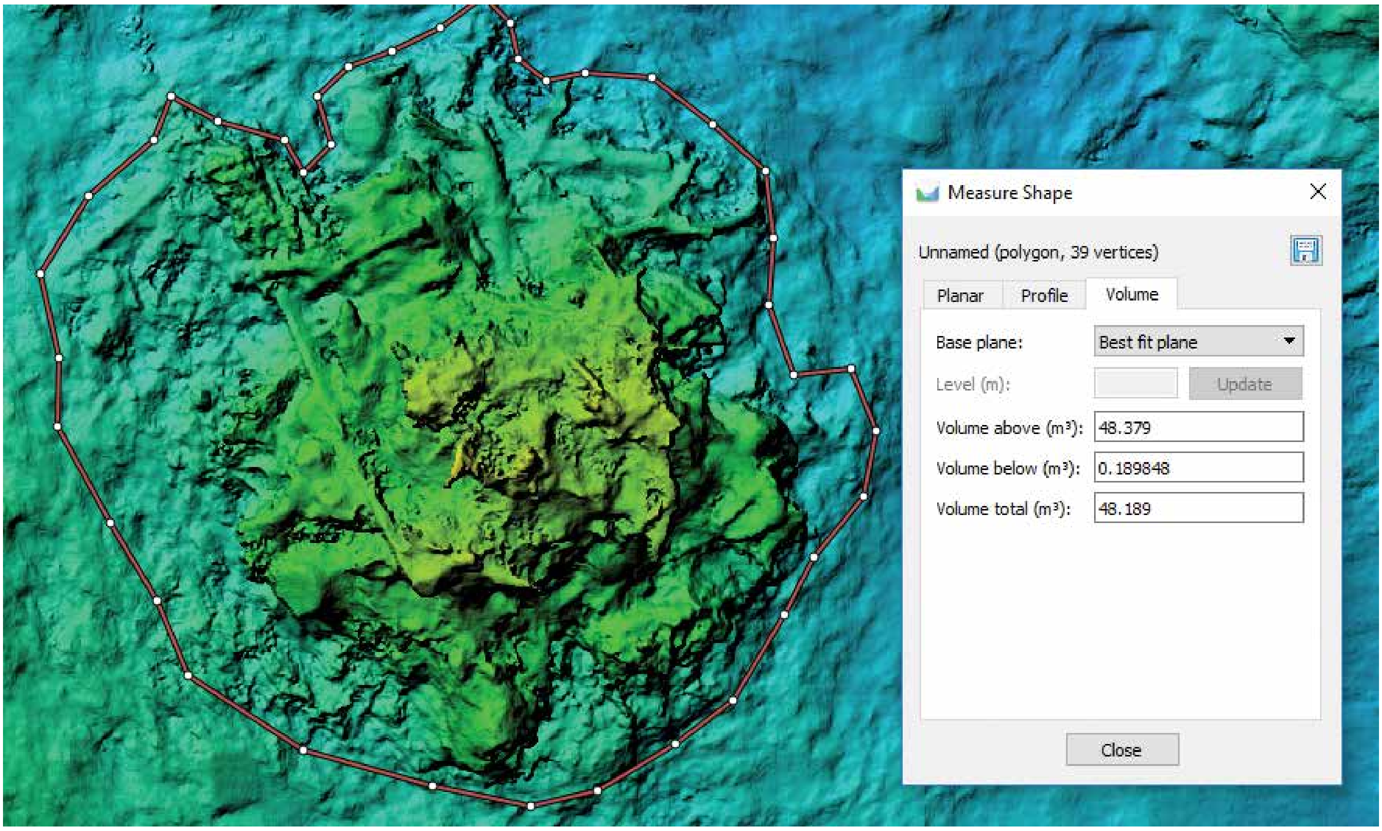

Figure 3: Volume measurement in Agisoft Metashape. The polygon outlining the pile is shown in red and the volume measurements are in the pop-up window to the right. 'Volume above' is taken as the volume of the pile

models, when created with one-quarter of the input images, returned error messages for images not aligned. However, this was only for one, two or three images in each case. These images were removed, and the alignment process was re-run, with the images aligning properly on the second attempt. Non-aligned images were typically of the very edge or the corner of a pile and tended to include more background than pile.

The piles were generally reproduced with reasonable quality. Many of the intricate features of the piles were captured, as evidenced in Figure 1. Individual logs on the surface of the pile can be clearly identified, with some even protruding from the pile, showing reasonable reconstruction of features. Details of length, width and height correlations, as well as the resolution of the DTMs, can be found in the original dissertation publication by the author (Riedinger, 2020).

Volumes obtained here have been through the geometric method or volume measurement from a SfM-derived DEM. The geometric method is generally not considered an accurate measure of pile volume, due to its approximation of the pile as a smooth solid. In this work, the geometric method was used as a basis volume measurement, to allow comparison. While it is not accurate, it provides a not-unreasonable estimate of volume and a 'common sense' method of checking the volume derived from the DEM.

Previous work by Long (2014) compared the geometric method to LiDAR-derived volume measurement. Figure 4 displays both Long's results and those obtained in this work. The graph also includes black lines indicating ±15% volume from the 1 to 1 line in the middle of the graph. This ±15% threshold was proposed by members of industry as to what might constitute a reasonable level of accuracy for volume measurements.

As the dimensions of the piles were preserved sufficiently well in the modelling process, it suggests that the application of the geometric method is the likely cause for the variation observed in the means of the differences. This is reasonable to assume, due to the difficulty encountered estimating the height of the piles for the application of the geometric method. All piles were approximated with shapes which require a height

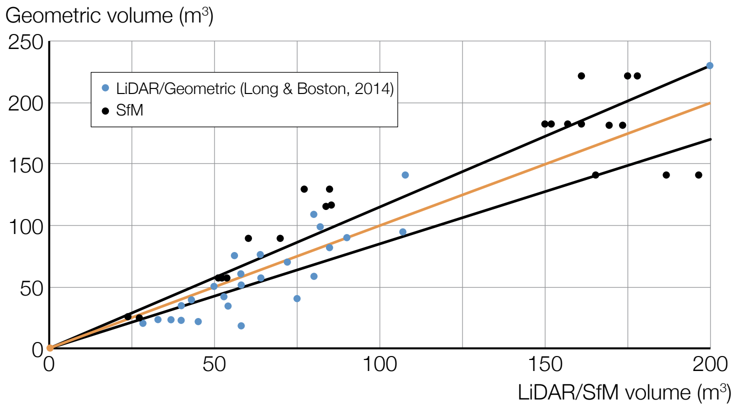

Figure 4: Pile volumes as determined by SfM (black) and LiDAR (blue) against the volume computed with the geometric method

measurement. This may have inflated the calculated volume of the piles, with a significant number of results appearing above the 1 to 1 line. This indicates a possible overestimation of volume from the geometric method, if the SfM volume is presumed to be more accurate. This was the case in 20 of 27 models, of which 24 volumes were measurable, resulting in 83% of geometric method volumes higher than the SfM volume.

The results obtained in this work are similar to those found by Long and Boston (2014) at low residue pile volumes. At large volumes, it is expected that the geometric method will produce inaccurate volumes that would tend to overestimate pile volume. This has been the case here, with three of the four large piles falling above the 1 to 1 line. Based on the good dimensional preservation, as discussed earlier, there is no reason to suspect that the increase in pile volume would lead to a decrease in the accuracy of the volume measurement. However, to fully check the validity of SfM derived volumes, it would be necessary to complete a high accuracy survey of the pile(s) and/or collect LiDAR data.

Processing time was also studied also as industry stakeholders were concerned about how much management time the processes might require. The total processing time required by Agisoft Metashape was recorded for each model and is presented in Figure 5 against the number of images used in the model. The computer used for the study ran a 64-bit version of Windows 10 Enterprise with an Intel Core i7-6700 processor and NVIDIA GeForce GTX1050 Ti graphics card. The total processing time is calculated as the total time taken to match/align the imagery, and generate the depth map and dense cloud. The time taken to generate the DEM was omitted, as it was less than 30 seconds in all cases.

Processing time is highly dependent on the number of images used. This is to be expected, as more images result in a larger number of Tie Points, which in turn creates a higher resolution dense Point Cloud compared to using fewer images.

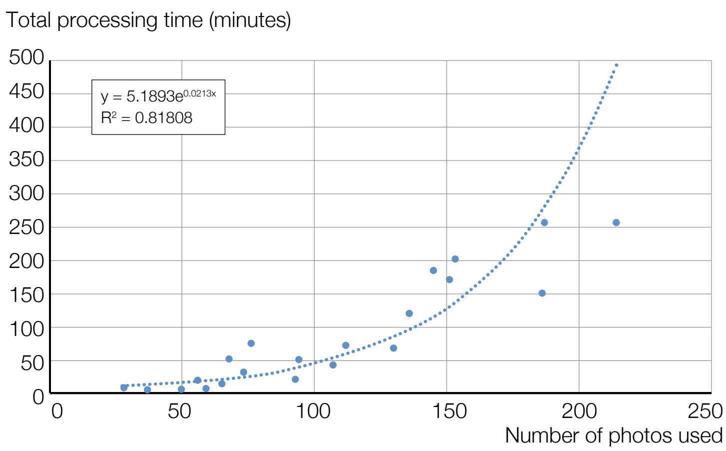

Figure 5: Effect of number of images used on the processing time required

Conclusions

This work has aimed to determine whether the SfM photogrammetry process, applied using basic methods, is a viable method for determining the volume of piled harvesting residues. Nine residue piles were surveyed, with three SfM models constructed of each pile to obtain 27 models. By measuring the length and width of the piles on-site with manual methods, and in the SfM model, it was concluded that the measurements of the piles were well preserved in the models.

SfM photogrammetry shows promise as being part of the solution for determining the bulk volume of harvest residue piles, especially where the pile shapes are complex. There is also potential for the SfM process to be used as a method for ongoing monitoring of harvest residue piles.

Using a similar process of modelling piles over time, even more accurate pile volumes may be measured using the original built landing surface as the datum surface. With enough pile volumes from harvest areas measured and compared against stand statistics, forest managers may be able to more reliably predict future pile volumes as a part of the harvest planning process.

The full process has several steps including image capture on-site, image retrieval, and model processing and measurement, which all require time. With the method employed in this study it would likely only be applied to high-risk residue piles or as a part of a focused residue volume study, due to the time required to obtain a model and a volume output. Cloud computing capabilities promise to cut down the time taken to build models, potentially only at the expense of freedom to adjust model parameters. Capital invested is not seen as a major concern as the UAV used is a consumer grade model and cloud computing services are available for building SfM models at a reasonable price.

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