Using structure from motion for stockpile inventory in the forest industry

Karl Forsman

Arbetsrapport 464 2016
Master thesis in Forest Management 30 credits A2E
Jägmästarprogrammet

Handledare:
Jonas Bohlin

Sveriges lantbruksuniversitet
Institutionen för skoglig resurshushållning
901 83 UMEÅ
www.slu.se/srh
Tfn: 090-786 81 00

ISSN 1401–1204
ISRN SLU–SRG–AR–464–SE

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Keywords: Photogrammetry, image analysis, stock management, drone

Master thesis in forest management at the Dept. of Forest Resource Management, 30 credits
EX0768, A2E, Forest Science - Master's Programme
Supervisor: Jonas Bohlin, SLU, dept. of Forest Resource Management, remote sensing
Examiner: Mats Nilsson, SLU, dept. of Forest Resource Management, remote sensing

Sveriges lantbruksuniversitet
Institutionen för skoglig resurshushållning
Place of publication: Umeå
Year of publication: 2016

ISSN 1401–1204
ISRN SLU–SRG–AR–464–SE

Preface

First and foremost I would like to thank my supervisors during this study; Jonas Bohlin and Mattias Nyström have been an incredible resource for knowledge for the technical as well as academical part of this paper. I also would like to thank Fredrik Samuelsson and the VMF Nord crew at Sävarsågen (Norra Skogsägarna) for their assistance during the field survey of this study. Katarina Levin and Magnus Sjödin at Tunadalssågen (SCA) have been a good resource for consultation regarding the industrial demand of the services investigated in this study. I would like to thank the Ljungberg foundation for their financial support of the Remote Sensing Lab at SLU without which this study would not have been possible. Also the researchers and employees of the remote sensing department who are eager to discuss aspects the remote sensing field and share cutting edge research. Lastly I would like to thank my fellow colleagues in the Remote Sensing Lab; Anton Romlin, Edward Sjödin, Andre Wästlund and Daniel Bertilsson, for the creative environment that we have established in the Remote Sensing Lab during this period of time.

Summary

Supply line management is a big factor in the success of any forest company’s ability to produce competitive forest products from raw materials. To achieve an efficient and profitable procurement of these raw materials it is important to have satisfactory inventory of the resources throughout the supply line. The present method for inventory of stockpiles in lumberyards and terminals is a manual mensuration process with subjective assessments of the stockpiles. The precision requirement of today is that the result needs to be within 10 % of the true value. The aim of this study is to test if the volume estimations can be made using Structure from Motion (SfM) for mantle volume estimations and image segmentation for wood proportion assessment. The traditional wood proportion estimation was also used for the final volume estimations thus two results are compared to each stockpile. The study was conducted on four stockpiles of two different assortments of lumber at Norra Skogsägarnas sawmill “Sävarsågen” with assistance from VMF Nord for reference data to compare the final volume estimations with. A terrestrial laser scanner was used on one of the stockpiles for validation of the mantel model produced by the SfM process. The final wood volume from the SfM process in combination with the traditional wood proportion assessment made overestimations between 5.78 % and 25.56 % of the true value. Two out of the four piles made volume estimations in accordance to present standards. For the volume estimations using image segmentation for assessing the solid wood proportion the accuracy ranged from -0.04 % to 3.58 % of the real value. All four estimations was within present requirements using image analysis. This study concludes that SfM is a viable option for stockpile inventory that replicates present day methods but with the possibility of superior accuracy in measurement of the mantle volume. Also the method has the possibility of being conducted objectively.

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Introduction

Supply line management is a big factor in the success of any forest company's ability to produce competitive forest products from raw materials. To achieve an efficient and profitable procurement of these raw materials it is important to have satisfactory data of the resources throughout the supply line.

Industrial forest companies keep decentralized stock throughout their supply chain where assets at different parts of the supply chain carry different value per unit. The possibilities and methods for stock inventory also differ between different parts of the supply chain. Uncut resources (still growing forest stands) are divided into homogenous parts (stands) for which forest variables such as volume, tree height and tree species mixture are estimated either through traditional field inventories (Albrektson et al. 2012) or by using remote sensing techniques, for example airborne laser scanning (ALS) (Næsset 2002). Resources kept in stockpiles in lumberyards and terminals are also inventoried. Saw logs and round wood is usually described in cubic meters (m^3), for saw logs an evolvement of the measurement is used where the volumetric measurement is developed to describe the potential saw exchange from each log ($m^3{}_f$).

The total cost of keeping stock is divided into a few categories where the biggest parts are: handling cost, cost for locale and most important is the cost for bound capital. Bound capital has a cost relative to the interest rate as well as the amount of inventory kept in stock (Lohmander 1992). Therefore, the total cost of keeping resources in stock increases with a larger stock. Although keeping stock is a source of costs, insufficient stock might result in a failure to meet client demand that in turn creates lost revenue or increased shortage costs. (Pewe et al. 1993)

Swedish companies that do financial accounting according to the laws of accounting (SFS 1995:1554) and carry a stock of resources or products are obliged to conduct inventory to said stock (SFS 1999:1078, SFS1955:257).

Swedish legislation concerning the auditing process states that the accountant responsible for auditing a Swedish company has the task to control that the proper taxes have been paid during the correct timespan to determine whether the company has completed their responsibilities against the auditing act (SFS 1999:1079). The International Standard on Auditing (ISA) 500 states that the auditor has to be part of or in conjunction with the inventory process. ISA 501 states that if an expert has created the material of evidence, the auditor has to evaluate the process of inventory (Schockaert and Houyoux 2007).

For the inventory of stockpiles and lumberyards to be unbiased, an independent organization, whose main objective is to measure roundwood for the forest industry, carries out the volume estimations. For this study Virkesmätarföreningen Nord (VMF) has been providing assistance with traditional methods for assessment of the wood proportion of the sample stockpiles as well as reference data. The method for inventory of lumber kept at a terminal is called stockpile inventory.

Stockpile inventory consists of two steps: Step one is to describe the outer dimensions of the stockpile to calculate a volume for the stockpile. This volume describes the pile as if it was a solid object and is hereby referred to as "mantle volume". Step two is where the solid wood proportion of the stockpile is estimated. This step is referred to as estimation of the solid wood proportion in this study. Combining step one and two results in the actual wood volume of the stockpile.

Traditionally the mantle volume is obtained by an experienced operator trough measurement of the piles outer dimensions to create an imagined box, Fig 1, wherein the stockpile fits. Piles with longer baseline, TL in Fig. 1, than 3 m are divided into compartments to account for the varying height throughout the pile. In the same fashion the ends of the pile are imagined within the box.

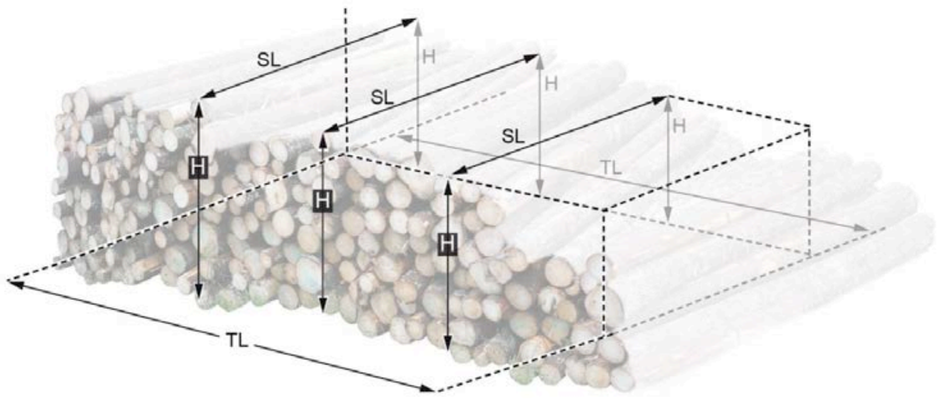

Figure 1. Description of the traditional process of assessing the mantle volume. H = height of the stack, TL = Length of the stack, SL = Length of the logs (depth of the stack). Image source: SDC 2014.

The solid wood proportion of the stockpile has to be subjectively determined by an operator (Anon 2014). To determine this proportion several aspects of the pile is considered: species of wood, the mean diameter for the logs, the mean length of the logs, how much bark the logs have, how straight they are, how well the wood has been piled, height of the stock pile, proportion of root logs, offsetting stem form, branches in the pile and if there is any snow or other particles in the stockpile. These factors affect the amount of cavity in the stockpile and add up to a factor which represents the relation between the mantle volume and the solid wood volume of the stockpile.

VMF states that their estimates of solid wood volume for stockpiles are within 10 % of the true value, and it is considered as the required accuracy of stockpile inventory with present methods (Anon 2008a).

At industries and terminals the woodpiles are stacked close together to use the available space as effectively as possible, Fig. 2. To conduct an inventory of such lumber yard the same method as with the single woodpile is utilized but another subjective step is added. Measurements are made on the piles that are accessible from the side but estimations of the rest of the piles are then made with consideration to how they look relatively to the measured stockpile, i.e., the operator has to determine if the mantle volume of inaccessible piles is larger or smaller than the mantle volume of the pile measured and used as reference. With this method the vast majority, area outlined by red border in Fig. 2, of the volume is subjectively determined in comparison to the measured stockpiles during inventory. This introduces a great source of uncertainty to the result.

Figure 2. Lumberyard with effectively stacked stockpiles, subjectively assessed volumes within red border. Image source: Lantmäteriet 2016

Legislation concerning the measurement of wood and stockpiles declares that methods and equipment has to obtain documented precision that is satisfactory (SKFS 2014:11). The pulpwood committee that acts under the VMR (Virkesmätningsrådet) has expressed strong support for automatic and semi-automatic stockpile measurements with the help from camera technology (Anon 2008b). Different versions of manual and semi manual camera technology estimations of truck loaded pulp wood volume has been evaluated and reported to be efficient (Börjegren 2011). The method used for volumetric measurement in Börjegrens study assesses the mantle volume and solid wood proportion from video streams of two cameras around the timber vehicle in conjunction with the weight of the load. The method utilized is called the 5:2-method where the weight of the load is used together with experience data and subjectively assessed factors of the actual load from the video stream. This method has been deemed an appropriate replacement for traditional methods which is made on site by hand and eye. In the mining industry, volume estimations are facing the same practical difficulties as the forest industry. In open pit mining, the usual approach for change detection throughout production, used for pricing and conduct workflow planning, is to use geodetic terrestrial measurement, i.e., total station. This type of survey is highly accurate for every individually measured point but also very time consuming because of the sheer number of measurements needed to survey an open pit (Patikova 2004). This method of geodetic measurement to determine and describe a mantle of a three dimensional object bears strong resemblance to step one in stockpile inventory where a few precise measurements are representing a larger surface.

Patikova (2004) illustrates the possibility of using close range photogrammetry (CRP) to make satisfying volume estimations in open pit mines although the individual point accuracy o is lower than for the geodetic measurements. The reason that CRP provides satisfying volume estimates is that a dense set of point measurements are provided for the whole area (Patikova 2004). When comparing terrestrial laser scanning (TLS) to a close range photogrammetry for inventory of stockpiles in the mining industry, Yakar et al.(2013) found that both TLS and CRP made estimations of 95 % accuracy of the stockpiles.

Structure from motion (SfM) and CRP are similar techniques where photographs are used to accurately describe the geometry of an object captured at close range. The technique uses overlapping images of the object taken from different perspectives to create 3D models (Kraus and Waldhäusl 1993). Information of the position of the camera is not required because the relation between the camera and the objects geometry is established from the images directly. The requirements are a digital camera and knowledge of the internal metrics (such as focal length, sensor size and pixel count). The software used for the CRP process then needs to identify at least three common points in both images as well as a reference scale then the rest of the points in the image can be plotted in three dimensions with a metric value (Atkinson 2001, Cooper and Robson 1996).The SfM approach has been evaluated for different applications with satisfactory result. For digital terrain model generation studies have found that the photometric approach was satisfactory to the SIS-TS 21144:2013 standard used for geometric measurement in construction and land surveys (Anon 2013, Trafikverket 2014) .

TLS may be the most evident option for these kind of surveys because of the high quality and resolution of the data (Alho et al. 2009, Heritage and Hetherington 2007, Hodge et al. 2009, Schaefer and Inkpen 2010). TLS equipment is relatively expensive and requires expertise to produce high quality results. In comparison SfM offer the opportunity to generate three dimensional data with less supervision and investment (Micheletti et al. 2015).

Objective

The hypothesis for this study is that volumetric estimations of stockpiles in the forest industry can be made using the same SfM methods as used in the mining industry and that the proportion of wood within the stockpile can be assed from the images produced in the SfM procedure.

Materials and methods

Study overview

The volume estimations consist of two parts, describing the mantle volume of a stockpile and determining what proportion of the stockpile consists of wood in comparison to cavity.

The two methods used to estimate stockpile volume, Fig. 3, can both be divided into two steps. The first step is the same for both methods and includes a photographic survey, model generation and mantle volume calculation. In the second step, two different ways of estimating the solid wood proportion of the stockpiles are used.

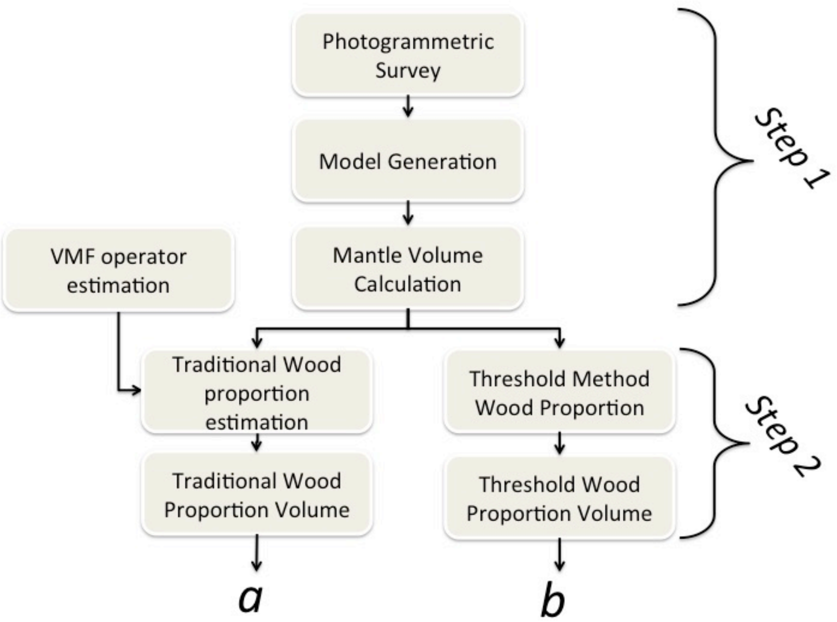

Figure 3. Layout of the study

Study subject

The photogrammetric survey was conducted at Norra Skogsägarna sawmill in Sävar, Västerbotten. Table 1 features a description of the two different assortments of lumber which are subjects of this study; the two stockpiles were surveyed at two dates with ten days apart. Both stock piles were accessible from all sides during the survey. The stockpiles consisted of two assortments of lumber, “Gran25L” and “Furu19R”. These divisions are used by the sawmill when handling the saw logs and are defined in the table below.

Table 1. Summary of stockpiles

Assortment names	Top diameter interval (mm)	Mean Length (cm)	Species	Common name
Gran 25L	228 - 231	554	Picea abies	Spruce
Furu 19R	204 - 210	446	Pinus sylvestris	Pine

More logs were added to the stockpiles in the time period between the two surveys. The stockpiles grew according to Table 2 between the two dates. The growth of the stockpiles created a new mantle surface for each date. The volumes in Table 2 are the result of the validation procedure described later in this chapter.

Table 2. Description of the stockpiles at the two survey dates

Stockpile	Volume ($m^3{}_f$)	Increase	Date of field survey
Spruce 1	313.0	N/A	2015-10-19
Pine 1	124.5	N/A	2015-10-19
Spruce 2	384.6	22.9%	2015-10-29
Pine 2	181.7	45.9%	2015-10-29

Image material

The photogrammetric survey was designed with two oblique patterns and one nadir. To be able to make metric calculations from the photogrammetric survey ground control points (GCP) were marked with an X on the ground using spray paint and measured with a RTK GNSS. The nadir pattern where photographed at an altitude of 48 m above ground with a 90 % forward overlap and 80 % sideways overlap (the camera facing the ground), rendering a ground sampling distance (GSD) of 0.94 cm. The ground level oblique pattern was photographed at approximately 90 degrees from the nadir direction (camera facing the stockpile) at eye level altitude (1.6 m) around the stockpiles with approximately 5 m apart, rendering a GSD of approximately 0.03 cm. The 9 m oblique pattern was photographed at 45 degrees from the nadir direction producing a GSD of 0.18 cm. The image materials for the different stockpiles are accounted for in Table 3.

Table 3. Summary of photographic surveys

Model	Oblique (ground level)	Oblique 9 m (n)	Nadir 48 m (n)	Sum (n)	GCP (n)
Spruce 1	46	275	23	344	6
Pine 1	69	151	52	272	9
Spruce 2	37	219	79	335	5
Pine 2	40	213	75	328	9

The images was captured using the Sony a-5100 (Sony 2015b) paired with a fixed 20 mm lens (Sony 2015a)

The nadir pattern and the 9 m oblique pattern were photographed using an autonomous Tarot 810 hexacopter utilizing a 2 dimensional gimbal.

Mantle volume estimation

The SfM workflow in Agisoft Photoscan pro included these steps of operation

- Photo alignment
- Cloud georeferencing
- Optimisation
- Dense point cloud generation
- Mesh model generation

In the first step, photos are aligned to determine camera position and orientation for every image. Features, such as points or angles, are identified in an image and trough the matching algorithm of Photoscan overlapping images are scanned for the same features and matched (Cimoli 2015). When the features are matched, generating a sparse point cloud, the relative coordinates and orientation of the cameras can be triangulated.

To create an absolute position and orientation of the cameras, i.e., orient them in the geographic coordinate system, the pixels that make out the GCP’s are pointed out manually in the image dataset. These pixels are given coordinates from the GNSS survey. When at least three GCP’s have been pointed out, the model is georeferenced through a Helmert-like 7 parameter transformation (Cimoli 2015, Harwin and Lucieer 2012, Lantmäteriet 2016). The transformation compensate for linear misalignments of points, which means that the transformation translates, rotates and scales the model to compensate for linear difference to the measured GCPs.

The next step is an optimisation of the photo alignment, this process preforms a full photogrammetric adjustment which considers the constraints of the ground control data by minimising the projection error and the GCPs misalignment error (Cimoli 2015, Agisoft 2013). The optimisation process is designed so that adjustments are made with consideration to the varying accuracy between different GCPs.

With the camera orientation defined all pixels in the images are triangulated generating a dense point cloud. From this dense point cloud a triangulated irregular network is generated by interpolating triangular surfaces between the points (Peucker et al. 1978). This surface model is referred to as a mesh model.

In the process of making mesh models from images there are different parameters being chosen and adjusted in order to get an accurate model. In the process of making these four models these parameters have been kept as similar as possible. The amount of images used in the generation has been the maximum (all the images taken of each pile) possible to ensure as good a model as possible have been created.

The parameters used for SfM in Photoscan are:

- <u>Photo alignment</u>
  Accuracy: High
  Pair pre selection: Disabled
- <u>Dense point cloud generation</u>
  Quality: High
  Filtrering mode: Aggressive
- <u>Mesh model generation</u>
  Surface type: arbitrary
  Face count: High
  Source: Dense point cloud
  Interpolation: enabled
  Quality: High
  Depth filtering: Aggressive

Aggressive depth filtering refers to Agisofts outlier filter which is set to filter away outliers to a high degree (Agisoft 2013). The arbitrary surface types renders a more complicated mesh than the alternative, height field, which generates a surface model which describes the surface when viewed from above, applicable for the mapping of flat surfaces.

After the mesh model has been generated a manual part of the process serves to trim away all the parts of the model which are not to be measured in the volume calculation. The result of this mesh generation leaves problematic areas with few points as open gaps where the triangulation algorithm has failed due to lack of information or other problems, see Fig. 4.

Figure 4. Example of open gap (in grey)

Before calculating the volume for the model these and smaller holes all need to be filled. This is a one-step function called “close holes” where surface are interpolated between the two closest points and results in a solid 3D mesh model. The result of this step also interpolates areas where the matching algorithm has failed, as described above, and creates a solid surface between the known points. The resulting surface describes the stockpile to a varying degree. As long as there are enough points to get the rough model, the mesh model should represent a mantle that at least is as good as the traditional way of measuring stockpiles.

The final step is the actual volume calculation that is a one-step, black-box operation within Photoscan that calculates the total area and volume of the mesh model.

Wood proportion estimation

Traditional method

An operator from VMF made an estimation of the solid wood proportion of the stockpiles as described earlier.

Image analysis method

The images used for wood proportion estimations from image analysis where captured from the ground and subjectively inspected to see if they were appropriate for calculation of the solid wood proportion of the stockpiles. To be appropriate, the images had to be taken in a direction perpendicular to the face of the stockpile. To reduce the effect of barrel distortion from the lens as well as make most of the image "near nadir" in relation to the faces of the logs, only the central part of the image (Fig. 5) was used.

Figure 5. Example of an image (a) and the central part used to estimate solid wood proportion (b).

In the next step a threshold filter (Shapiro and Stockman 2001) was applied to the central part of the image. The threshold filter creates a binary image by transforming pixels with a low value to 0 and pixels with a high value to 1, Fig. 6. This is done by setting the threshold parameter so that all pixel values below that value is set to 0 and the ones above is set to 1. Since wood in the image is lighter than the cavities, which are basically shadows in the image, the white pixel (pixel value = 1) proportion of the image could represent the wood proportion of the stockpile.

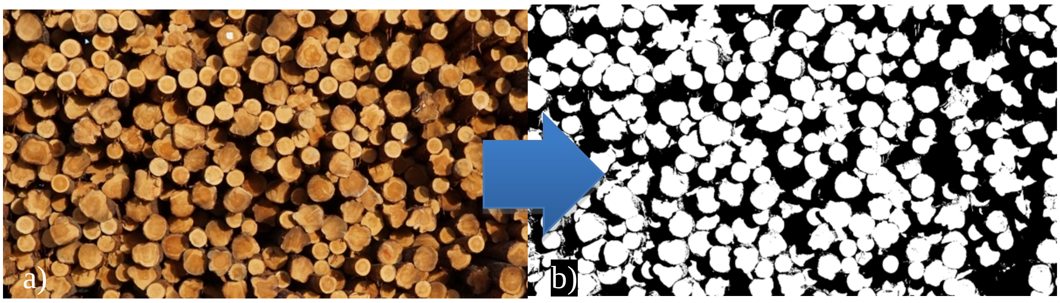

Figure 6. Result of threshold filter a) before b) after

For this to work, the threshold value that would result in an image that had representable proportions of white and black pixels needed to be found. To estimate solid wood proportion of the actual stockpile the reference volume provided by VMF (see below) was divided by the mantle volume of the generated 3D model. The portion of the reference volume compared to the mantle volume was considered to represent the proportion of actual wood within the stockpile – the true wood proportion. Using this true wood proportion as reference the calculation model was trained until it correctly estimated the wood proportion for the stockpile,, i.e., a number of different threshold values was tested until the distribution between white and black pixels was the same as the true wood proportion of that stockpile.

The training was conducted on a single picture for a single stockpile: Spruce 2. The same resulting threshold value was then applied to a total of three images per stockpile using the average value of those three as the final assessment of wood proportion. The number of images used for the analysis of every stock pile was chosen due to the sparsity of suitable images for this application. This threshold value from the training was then used to model the wood proportion of the rest of the piles by a threshold filter. Since the white pixel proportion varies between the individual images of the same pile an average of the three images from the different stockpiles was calculated and used for the final volume calculations.

Estimation of the actual volume for the stockpile

The final estimation of the log volume for the stockpiles was made both by multiplying the traditional wood proportion assessments as well as the result of the image analysis to the mantle volume, respectively.

Validation

Mesh model validation

The photogrammetric point cloud was validated using a point cloud derived using a Trimble TX8 terrestrial laser scanner. The TLS point cloud was generated by placing the TLS at four locations around the stockpile spruce 1, generating a complete coverage of the stockpile (Anon 2016). The point cloud from SfM was then compared to the TLS-point cloud using cloud compare. In cloud compare the two point clouds where fitted together and analysed using a tool called “point to point-distance”. This tool creates an illustration of how far it is for each point in the TLS point cloud to the nearest point in the photogrammetric point cloud. The points in the TLS point cloud is visualized with a colour gradient representing the distance between the TLS point and the photogrammetric point.

This illustrates how well the photogrammetric approach describes the surface in comparison to the result of the TLS.

Validation of the resulting stockpile volume

To validate the result of the stockpile volume estimation VMF provided a reference volume measured in a broom laser frame. Before the logs were placed in stockpiles the assortment was empty, data for each assortment was cleared so that the new volumes would start at zero. The total volume of the stockpile used for validation therefore consists of a scan of each log. The broom-laser measuring frame is equipped with three sensors mounted at a 120 degree separation from each other around the log. The measuring frame is controlled against a known body to stay within +/- 2 mm accuracy for diameter and +/- 2 cm for length (Stefan Rudolfsson 2016).

The two different methods of solid wood proportion estimation are compared to two different versions of the same volumetric measurement. Since the traditional wood proportion estimation, provided by VMF, is in relation to the measurement called m^3_{fub}, i.e., translates mantle volume to the volume of the logs in the unit of m^3_{fub}.The metric m^3_{fub} is calculated from the top diameter of the log and describe the actual log volume with consideration to the diameter, length and quality of the log. This metric is designed to be correct for a big population of logs while any single log might be over or underestimated. The result of SfM in combination with the traditional wood proportion estimation is therefore compared to this metric.

The image analysis method is compared to a measurement called m^3_{fys} (cubic meter “fys”, fys refers to the term physical, meaning the actual shape of each log). M3fys is a measurement created in the laser frame with calculations made to subtract the bark of each log. The frame measures the log intervals along the length of the log making data about the log with relative high resolution in comparison to traditional metrics. Since the method to calculate translation from m^3_{fys} to m^3_{f} is dependent on a couple of variables for the logs and unknown for this study, therefore the method b is compared to a more native measurement of the logs themselves.

Both metrics originated from the same laser scan but recalculated with consideration to the utilisation of the metric.

Result

TLS reference data.

It is clear that the TLS generates a satisfactory point cloud where it has the ability to cover the stockpile. Fig. 7 illustrates that the TLS resulted in a satisfactory point cloud for all sides of the stockpile. However, the TLS does not cover the top of the stockpile (Fig. 8). The colour gradients displays the height from the ground where blue is the highest and orange is the lowest heights.

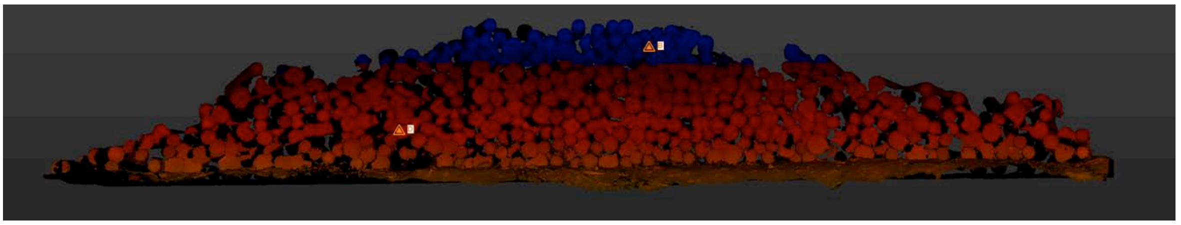

Figure 7. Point cloud from laser scanner. Side view. Colour gradient illustrates height from ground. From orange, lowest, to blue, highest.

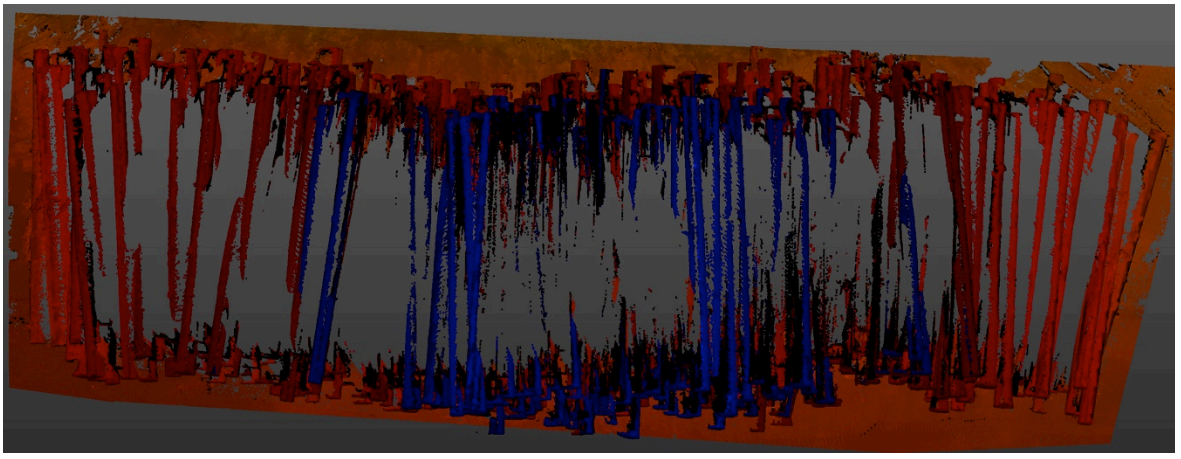

Figure 8. Point cloud from laser scanner. Top View. Colour gradient illustrates height from ground. From orange, lowest, to blue, highest. The grey areas lack points of measurement.

Mantel model validation

The point-to-point distance cloud has a colour gradient where the blue colour represents points that are 1 mm or less form their closest point the photogrammetric point cloud. Red points on the other hand are 1 cm or more from the nearest neighbour. The yellow and green points are the gradient in between where the difference is more than 1 mm but less than 1 cm.

Where there is a higher density of laser points the result however seems to be satisfactory as seen in Fig. 9 and Fig. 10. The majority of points seem to have a higher accuracy than 1 cm.

Figure 9. Point-to point distance, side view 1. Blue points < 1mm from reference, red points > 1cm from reference. Green and yellow points are a gradient between the low and high threshold..

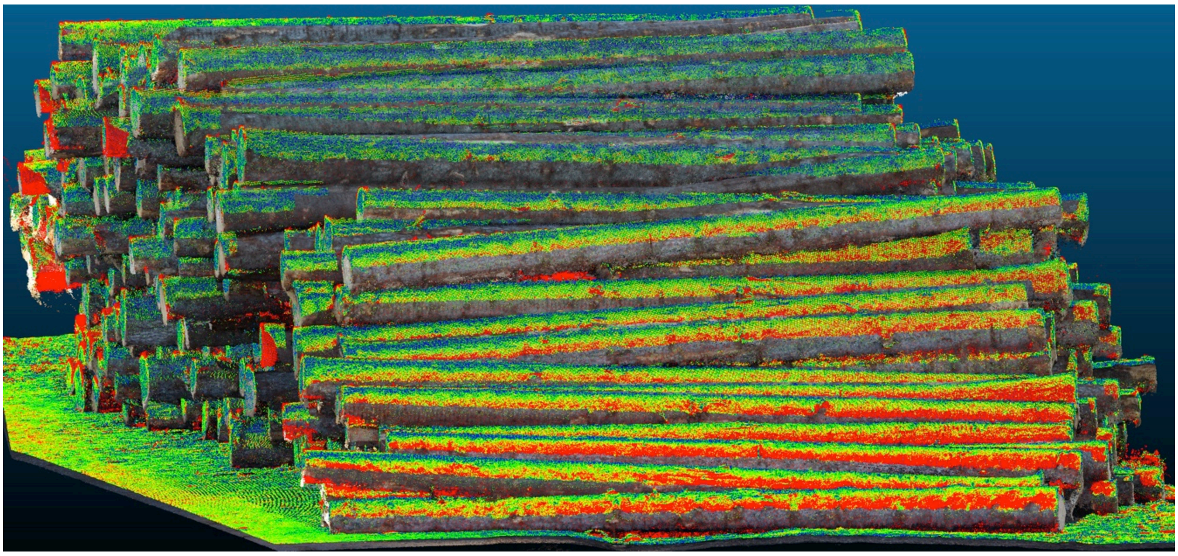

Figure 10. Point-to point distance, side view 2 Blue points < 1mm from reference, red points > 1cm from reference. Green and yellow points are a gradient between the low and high threshold.

Fig. 11 and Fig. 12 are examples of problem areas with a lot of red points (> 1 cm difference in the photogrammetric point cloud). They are displayed from the side both with and without the point-to-point distance gradient. The red areas are located in the shadows of the photogrammetric point cloud where the algorithm has had problems identifying points to triangulate.

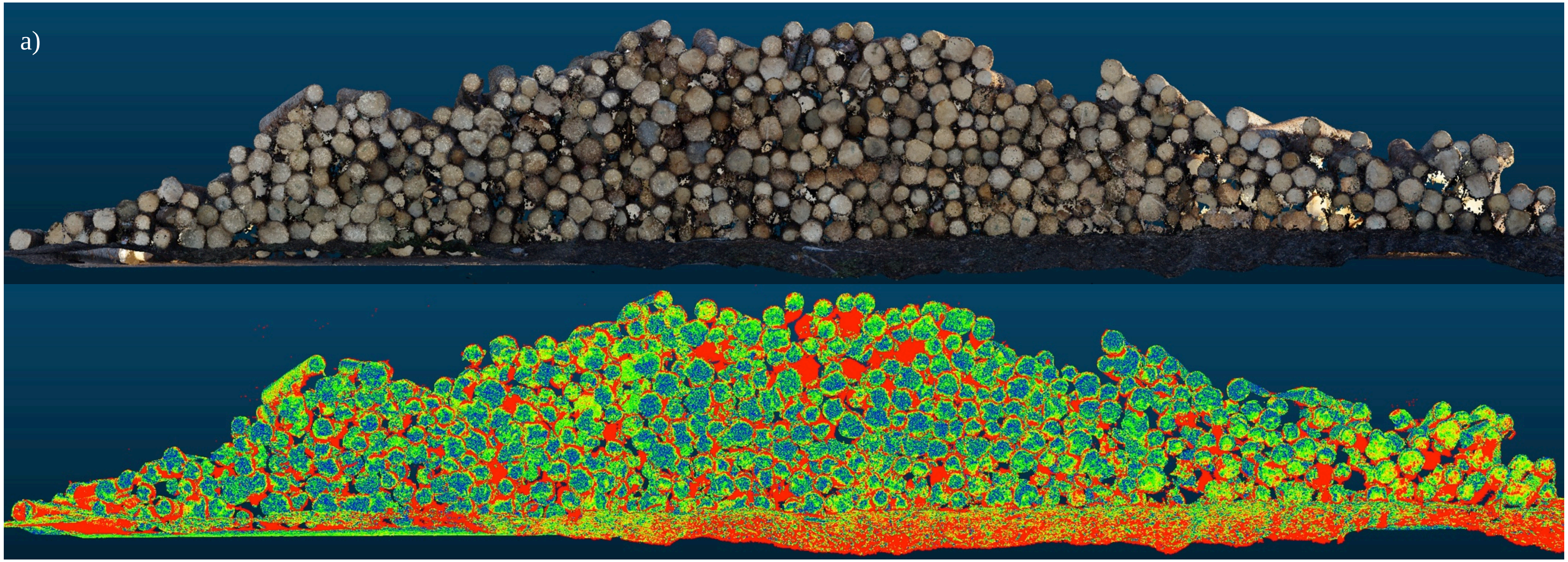

Figure 11. a) Side view of the SfM point cloud b) Side view of the TLS point cloud Blue points < 1mm from reference, red points > 1cm from reference. Green and yellow points are a gradient between the low and high threshold.

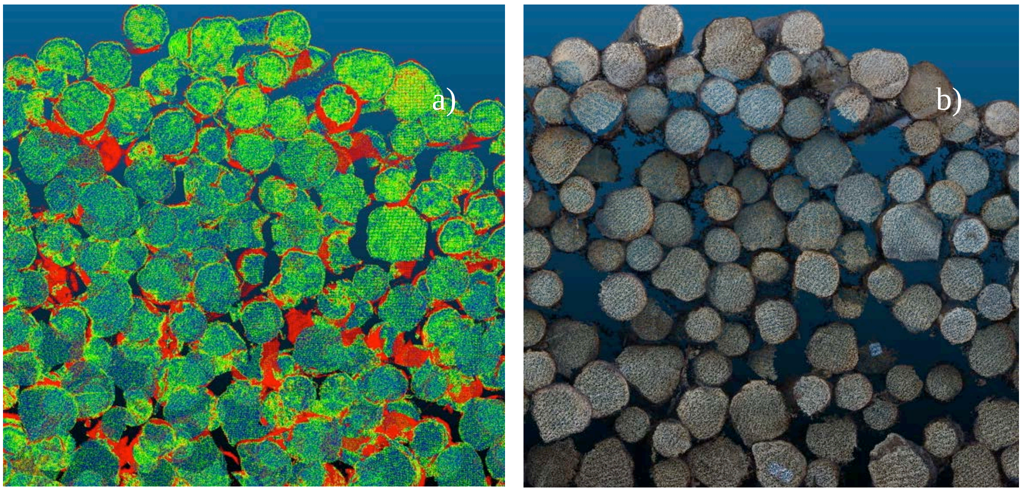

Figure 12. Magnified side view a) TLS point cloud Blue points < 1mm from reference, red points > 1cm from reference. Green and yellow points are a gradient between the low and high threshold. b) SfM point cloud

Mesh model generation

The matching algorithm of Photoscan failed to match and triangulate some of the pixels in the stockpile which generates areas without points. In Fig. 13 to Fig. 15 a couple of examples of problem areas are displayed as well as how the gap is filled in the “close holes” step of the mesh model generation. The problematic areas were never so severe that the mesh model was inapplicable for volumetric measurement.

As seen in Fig. 1-5 in Apendix 1 the top of every pile is reconstructed to a degree that should be satisfactory for volume assessment.

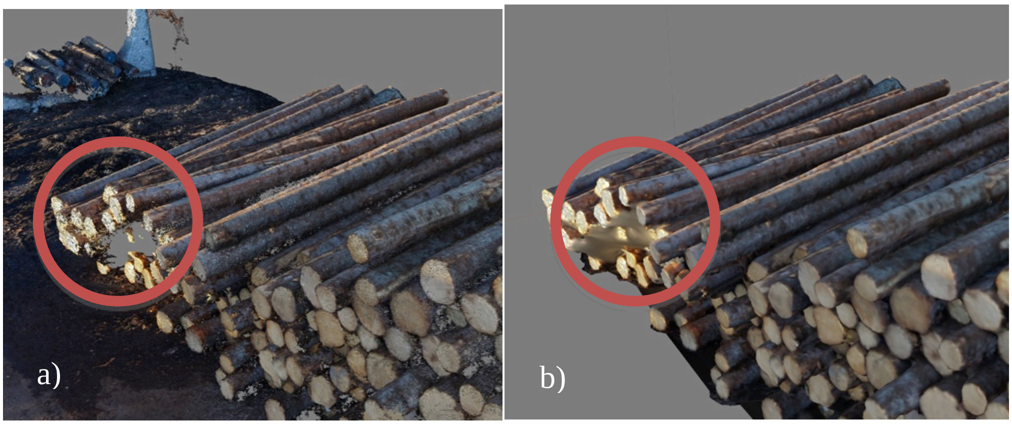

Figure 13. Spruce 1 a) problem area in the generated point cloud. b) result of mesh model generation of problem area.

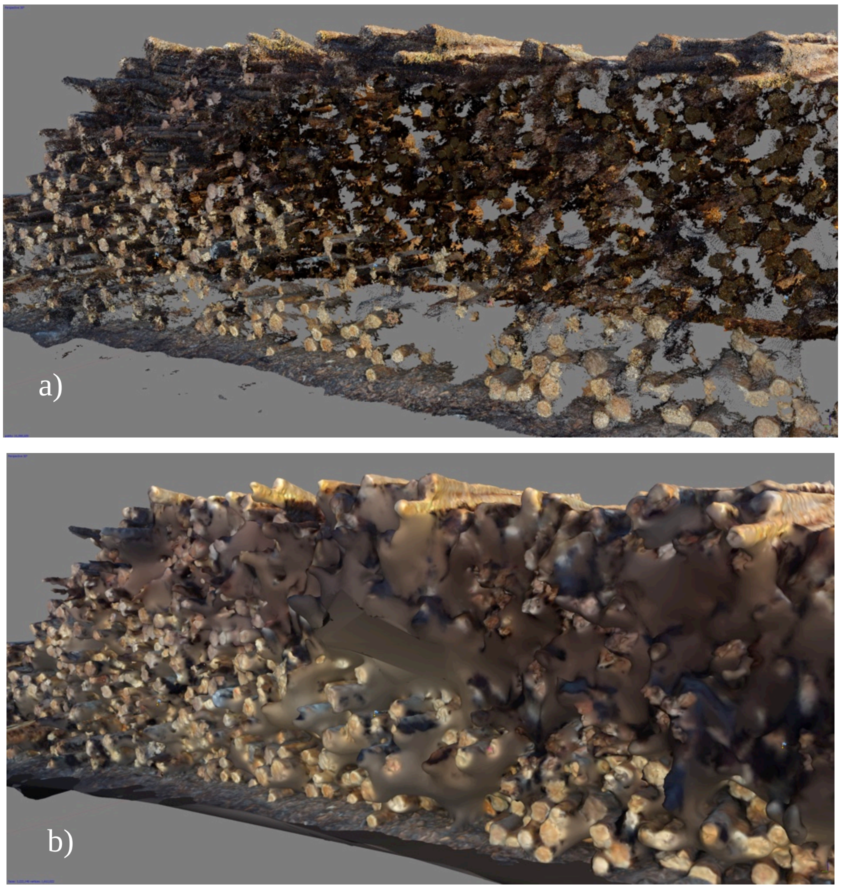

Figure 14. Pine 1 a) problem area in the generated point cloud. b) result of mesh model generation of problem area.

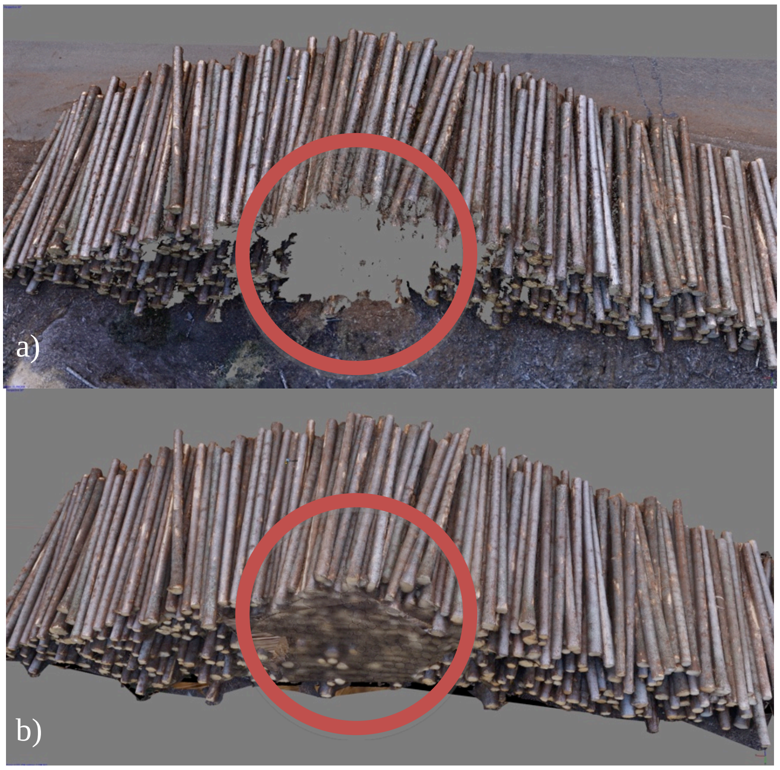

Figure 15. Spruce 2 a) Problem area in the generated point cloud. b) Result of mesh model generation of problem area.

Mantel volume estimation

In Table 4, the final mantle volume estimates are presented for the stockpiles at the two surveying dates.

Table 4 Mantle volume estimations for the stockpiles at different dates.

Stockpile	Volume (m^3)	Increase	Date
Spruce 1	595.466	N/A	2015-10-19
Pine 1	207.403	N/A	2015-10-19
Spruce 2	732.284	23.0%	2015-10-29
Pine 2	311.131	50.0%	2015-10-29

Wood proportion estimation

The result of the training process of the threshold model resulted in a value of 82.

The images themselves are of different sizes and dimensions; they also have a varying relation to their respective true wood proportion of the stockpiles. The accuracy of estimations made from single images range between 0.11 percentage points (pp) and 6.57 pp from the true wood proportion displayed in Table 5. The resulting binary images are presented in Fig 1 – 4 in Appendix 2.

Table 5. White pixel proportions of individual images

Stockpile	Image	Total pixel count (M pixels)	White pixel proportion (%)	Difference from theoretical wood proportion (pp)
Pine 1	1	2.13	56.23	-0.45
Pine 1	2	4.91	59.92	3.24
Pine 1	3	3.08	53.81	-2.87
Spruce 1	1	5.21	62.74	-0.36
Spruce 1	2	2.80	69.67	6.57
Spruce 1	3	4.40	63.21	0.11
Pine 2	1	1.61	57.65	1.01
Pine 2	2	1.14	58.31	1.67
Pine 2	3	3.71	56.30	-0.34
Spruce 2	1	0.91	65.54	0.34
Spruce 2	2	1.71	61.75	2.16
Spruce 2	3	3.95	63.57	2.75

Fig. 16 displays a scatterplot with image size compared to the achieved accuracy to the true wood proportion of the stockpile. In this small sample there is no evident relationship between the size of the image and the achieved accuracy.

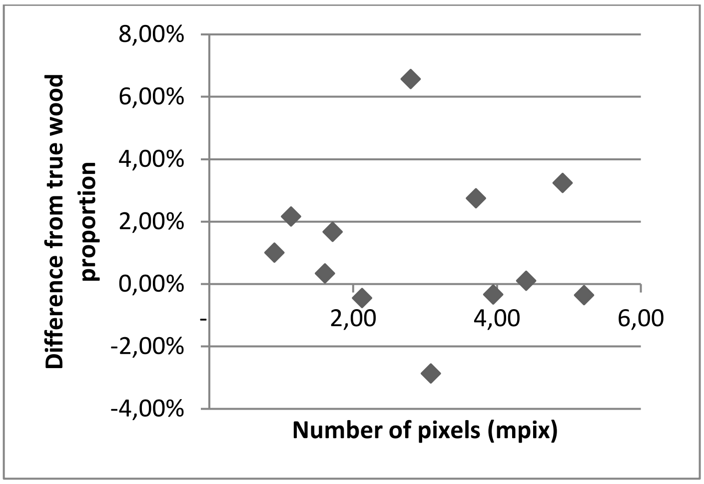

Figure 16. Pixel count in relation to accuracy

In Table 6 all three images are used to calculate an arithmetic mean value of the white pixel proportion for each model. As displayed in the third column the best accuracy was 0.03 pp from the true wood proportion while the worst was 2.10 pp. The worst accuracy in the table of means is at 2.10 pp whereas at its worst using a single image could result in a 6.57 pp overestimation, Table 5**.**

Table 6. Result of the threshold method of wood proportion estimation

Stockpile	Mean white pixel proportion (%)	Difference from theoretical wood proportion (pp)
Pine 1	56.65	-0.03
Spruce 1	65.21	2.10
Pine 2	57.42	1.75
Spruce 2	63.62	0.78

Volume estimation from traditional wood proportion assessment

Table 7 displays the volume assessment using the traditional method for wood proportion estimations. In all of the cases this approach made overestimations for every model. The overestimations for the pine stockpiles were higher compared to the spruce pile with a 25.92 % overestimation as the worst result. The Spruce piles overestimations were lower on both occasions with the best result, Spruce 1, with a 5.78 % difference from the reference volume.

Table 7 Volumes derived using traditional wood proportion estimation

Model	Volume (m^3_f)	Reference (m^3_f)	Difference from reference (%)
Pine 1	393.0	313.0	25.56
Spruce 1	131.7	124.5	5.78
Pine 2	484.3	384.6	25.92
Spruce 2	196.0	181.7	7.87

Volume estimation from image analysis wood proportion assessment

Table 8 shows the result of the volume estimations using the image analysis method for wood proportion estimations. The volume estimations from this method made overestimations in all but one case, Pine 1. Pine 1 was also the most accurate assessment where the difference was -0.04 %. The worst assessment was for the Spruce 2 pile with a 3.58% overestimation.

Table 8 Volume of threshold method wood proportion estimations

Modell	Estimated Volume (m^3_{fys})	Reference (m^3_{fys})	Difference from reference (%)
Pine 1	337.4	337.5	-0.04
Spruce 1	135.2	130.9	3.32
Pine 2	420.5	414.8	1.37
Spruce 2	197.9	191.1	3.58

Discussion

Mantel volume estimation

In the validation of the mantle model (Fig. 11) there were a lot of points with values above the above 1 cm (coloured red) from the closest laser point in between the log faces. The TLS points coloured red are actually points that are from within the stockpile itself, meaning that the laser beams are able to penetrate and measure parts of the logs where the images simply does not register information. This comes from photography being a passive technique, which only registers reflected sun light, while laser is an active sensor that emits light (Kraus 2007). Another reason for this is that because of the nature of SfM a detected feature needs to be matched into at least two pictures for the triangulation algorithm to assign it with a coordinate (Micheletti et al. 2015). The features in between logs are detectable only from a tight angle and therefore less likely to appear in two separate images.

There is no validation for the mantle volume besides the comparison between the TLS and photogrammetric point cloud. However, the development of the mantle volume of Table 4 can be compared to the development of the reference volume of Table 1. In this case the mantel volume of the Spruce pile has increased at the same rate as the reference volume in the time period between the two field surveys. For the pine assortment the SfM mantle volume has increased 5 pp more than the reference. This indicates that either the mantle volume is not accurate or that the new stockpile's stacking properties has been altered thus changing its wood proportion between the two dates.

In the validation of the mantle model (Figure 9 and 10) the difference between the SfM point cloud and the TLS point cloud is low. In both figures it is evident that the mantel model has high accuracy, the vast majority of points in the TLS point cloud is less than 1 cm from their neighbouring SfM-point. This is a superior description of the mantle surface compared to the result of the process in Figure 1.

A better utilization of the photogrammetric software would most probably result in a better and more accurate mesh model. The study however was conducted by treating the four stockpiles as similar as possible so that the SfM-workflow had as little manual input as possible. This was to review the method as if it would be part of a totally autonomous process. That is why some piles were better modelled than others: the process was not repeated because a single pile resulted in a poor model. All generated models, one for each pile, was made with the same settings and included in the study.

The problem mentioned above is a cause for concern regarding the ability of the models to base volumetric estimations on. The models however describe the tops of the stockpiles well and therefore should generate a mantel volume that is satisfactory for stockpile inventory, especially for inventories made at terminal lumber yards.

Wood proportion estimations

The images analysed was subjectively cropped so that the result would be an image with the logs facing the viewpoint. If the images were cropped so that the sides, the bark, of the logs would make out more of the image the result would probably be skewed towards an overestimation of the wood proportion. Although the images were cropped for the reason above this does introduce subjective part to the method where the operator can influence the final result. Ideally the image selection and cropping should be an automatic process as well. Perhaps a process where an algorithm chooses which images should make good candidates for the method by analysing the position and direction of the camera attained from the image alignment step of Agisoft Photoscan or other software used for bundle adjustment (Triggs et al. 1999). The algorithm would then chose images with an angle perpendicular to the surface, where the centre of the image is close to the imagined nadir point of the stockpile, that the faces of the logs creates and crop to a given degree. Another idea would be to create an image of orthogonal projection so that the result would picture the logs facing the viewpoint throughout the image (Rau et al. 2002). The orthogonal projection would then make an image where the actual proportion of wood in the stockpile is accounted for, in comparison to the described image analysis of this study that utilizes a sampling of the wood proportion.

The wood proportion for each stockpile was derived as a mean value of three images which seems to give more stable result than the using single images. The most evident example is Spruce 1 where the there is a 6.93 percent point difference between the extremes (Spruce 1 -1 and Spruce 1 -2).

Using a threshold filter is a very basic method of image segmentation. The method used in this study can be compared to what is referred to as “global thresholding” in the medical field (Bankman 2008). Thresholding has been used to automate mammography to aid the detection of breast cancer (Bick and Giger 1995) as well as isolating individual bones from X-ray computed tomography (Zhang et al. 2010). Studies using image analysis where feature detection recognizes the log faces as circular objects in an orthogonal projection, enabling calculations of the amount of logs in a stockpile, have been proven effective (Knyaz and Maksimov 2014). This or other more advanced methods of image analysis would be a welcome development of wood proportion estimation. However since the early results using a simple global threshold seemed to make assessments of the solid wood proportion that made satisfactory volumetric estimations, more rigorous methods was not examined.

When looking at the result of the image analysis (Fig 1 - Fig 4 in appendix 2) it becomes evident that other parts than the faces logs that has become white as well as some logs, those stuck in the shadow, have become black pixels. This has two possible effects – either the corrupt black and white pixels cancel each other out when the study area becomes big enough or the faulty pixels makes the result skewed to one side or the other rendering the method to struggle with making the right estimations of the solid wood proportion.

Using an average from the three images resulted in an estimation that was more accurate than the worst cases within the sample, i.e., the average of three images was better than using the worst example of a single image.

Final volume estimations

The difference between estimated volume and reference volume is higher for the stockpiles with the traditional wood proportion estimation compared to the image analysis. It is especially evident for pine assortment stockpiles. The image analysis method was within 2.5 % of the reference volume in comparison to the traditional method that resulted in a high overestimation of the stockpile volume. Thus only two of the stockpiles had volume estimations within the tolerance of 10 % (Anon 2008a).Volumes for all four stockpiles that had the solid wood proportion estimated using the image analysis method were within acceptable accuracy of stock pile inventory of today. This suggests that a wood proportion estimation using image analysis is applicable for such estimations.

It is important to keep in mind that this is not a comparison to how the whole method of inventory is made today. The traditional method only concerns the solid wood proportion-estimations of the stockpile, which are then applied to the mantle volume from the same 3D model.

Using the image analysis method for wood proportion estimations, the results are along the line of Yakar et al (2013) who assessed volume of stockpiles in the mining industry with 95 % accuracy. The accuracy of the four stockpiles presented in this thesis was as high as 96.42 to 99.96 % although log stockpiles are more difficult to measure compared to homogenous stockpiles of mining material.

This study has focused on making volume estimations of single stockpiles that are accessible from all sides which makes the wood proportion estimations from image analysis possible for the whole stockpile. The ambition to conduct inventory of stock kept at terminal faces challenges concerning the wood proportion estimation that have not been discussed in this study. However the possibility to assess the mantle volume with high accuracy is directly transferable from the small stockpiles to the terminals. The SfM approach should offer superior quality of measurement compared to the subjective approach of traditional inventory.

Development of the field survey

This study has been conducted with the same basic layout as traditional stockpile inventories. This can be considered as a strength when trying to apply new technology to already established workflows, instead of having to replace the established method of conducting inventory, merely new tools are supplied to achieve better accuracy of the results.

The evident development of this kind of technology is of course that human input and labour is kept to a minimum. One way of developing the workflow is for the drone is to make the entire photo survey autonomous. There are products developed to enable for UAS platforms to initiate, execute and communicate autonomous photographic missions on a set schedule or as a reaction to an external event (H3 dynamics group 2015). These kinds of platforms are likely to be deployed in the field to a larger extent than imagined today (Sand 2015). This enables the material for inventory to be automatically generated thus rendering manual input in the field to a minimum.

Another alternative is to develop a system that utilizes the natural conditions of the lumberyard to create the data used for inventory, i.e. using lamp posts, industrial vehicles, workers performing other operations. Photogrammetric calculations have been made with the implementation of surveillance cameras to isolate and determine the height of a human body (Lee, J. et al. 2008).The same principle should be applicable to lumberyards. Mounting cameras around the lumberyard to be able to create inventory data without any moving vehicles would be the ideal since it creates fewer situations that might fail during the inventory process. Since finding the sheer amount of mounting points for the cameras to cover the object to a satisfactory degree might be an overwhelming task. Utilizing the moving trucks that already patrol the lumberyard and handle the stockpiles as mounting points for several cameras might be a solution to this problem. Since the trucks reach higher than the stock piles they might have mounting points that elevates the camera enough to “see” over the stockpiles (Svetruck 2015). Studies using cars as mobile platforms for mapping tree height has been evaluated with -1.6 cm bias and a standard deviation of 5.4 cm when measuring pole like objects (Jaakkola, Anttoni et al. 2010). Measurements have also been made from other moving vehicles: a moving train was used register clearance data of the train tracks (Blug et al. 2007). Measurements were successful in velocities up to 100 km/h.

Conclusion

For each one of the four samples the result from using SfM and wood proportion estimation from image analysis was found to be well within the requirements of today’s methods: 10 %. Using only SfM and the manual approach to wood proportion estimation the result was within the requirements for two of the four stockpiles.

This study indicates that the SfM method could provide a viable option for stockpile inventory of logs. Especially the image analysis assisted volume estimations were made with high accuracy. One of the strength of this inventory approach is that it has the potential of being entirely objective.

One of the most apparent drawbacks of the method is that it’s fairly time consuming. The method needs a lot of computation time. Although this process is more or less automatic the process time makes the method suffer from long lead times for the result.

One weakness with the study is that the sample size is too small to make any kind of quantified statistical analysis. Therefore it is impossible to draw any conclusions regarding the actual precision and potential bias of the volume estimations, i.e., the study is not able to say how often the result is within the requirements of stockpile inventory. Further studies with bigger sample sizes are necessary before any final recommendations can be given.

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Appendix 1

Generated mesh models

The resulting mesh models on which the mantle volume was calculated.

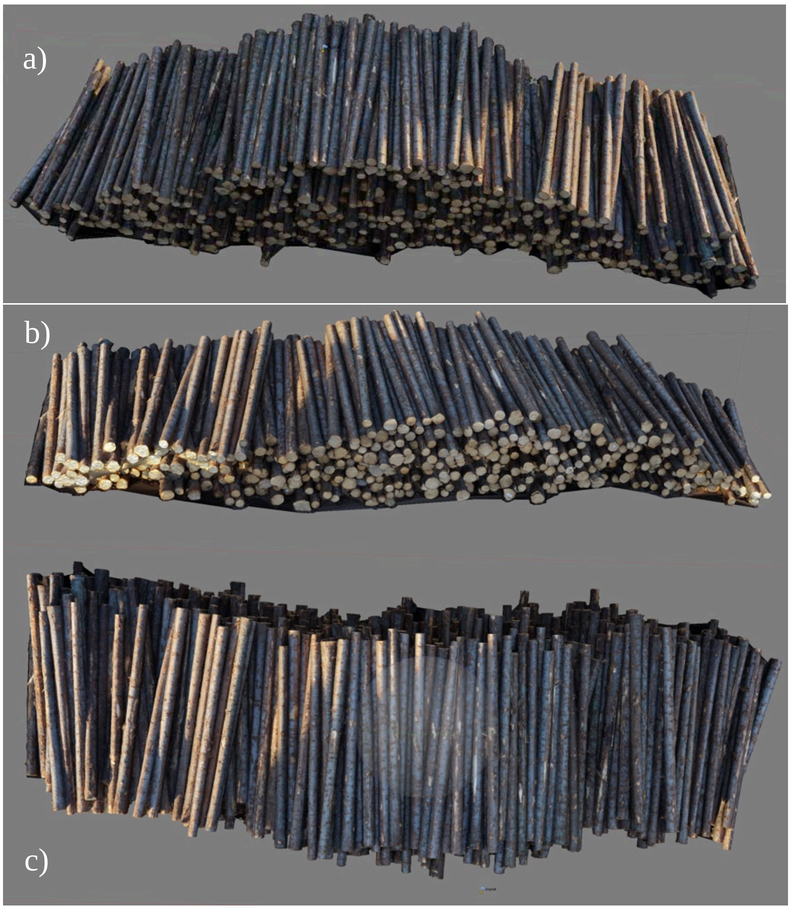

Figure 1. Mesh model of the stockpile Spruce 1 a) Side view 1 b) Side view 2 c) top view

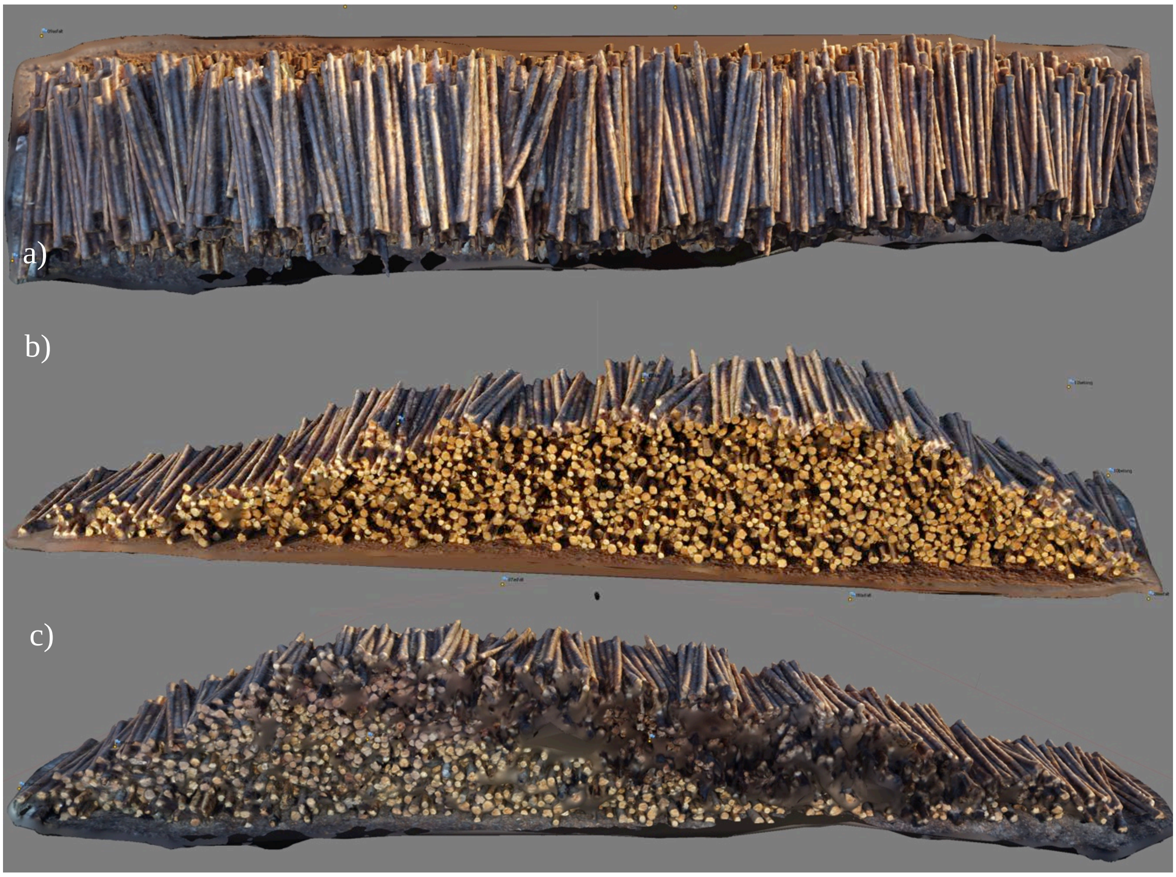

Figure 2. Mesh model of the stockpile Pine 1 a) top view b) Side view 1 c) Side view 2

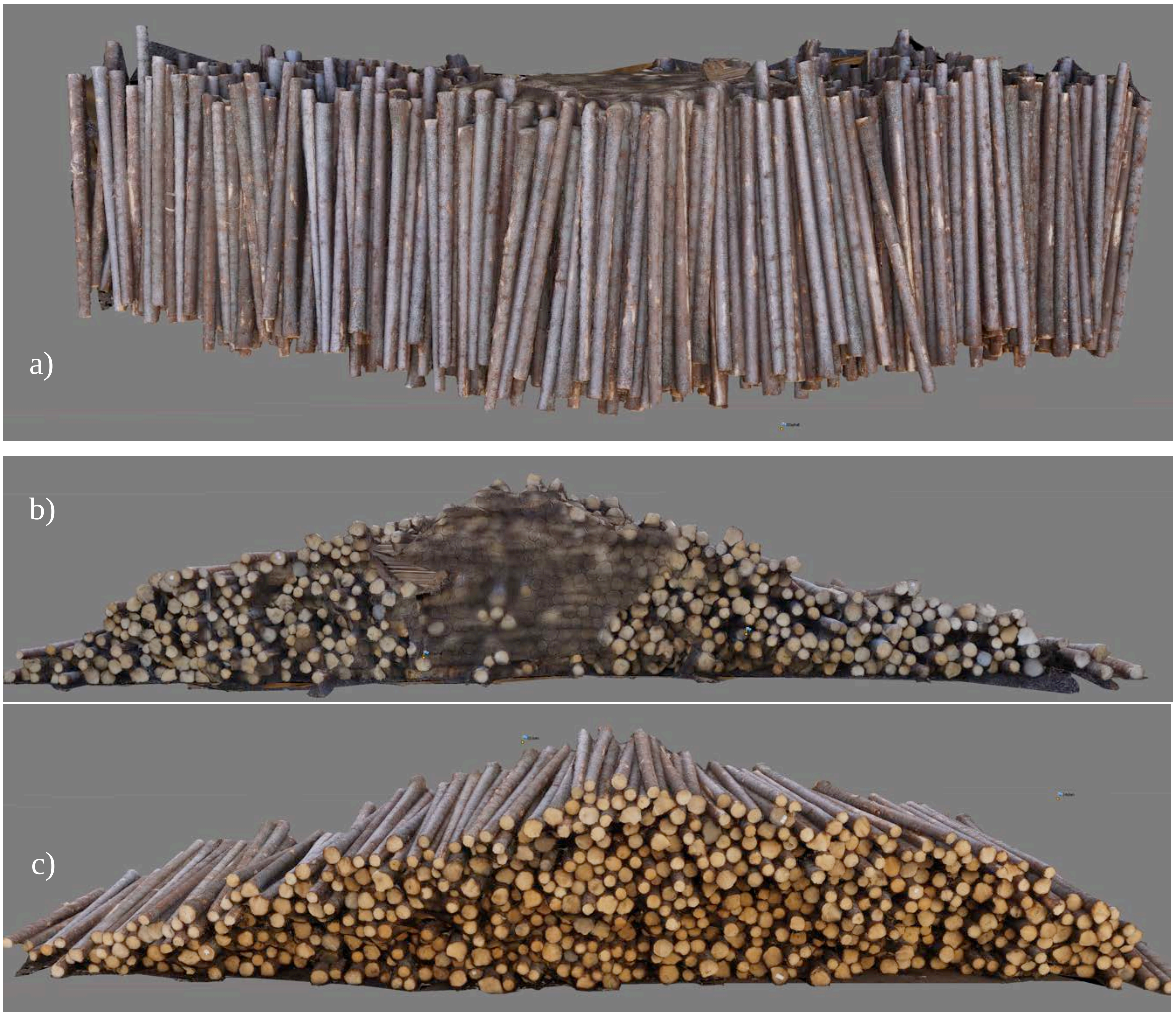

Figure 3. Mesh model of Spruce 2 a) top view b) Side view 1 c) Side view 2

Figure 4. Mesh model of the stockpile Pine 2 a) top view b) Side view 1 c) Side view 2

Appendix 2

Result of the threshold filter

Fig 1 – 4 displays the three individual images after the threshold filter. On these images the wood proportion was calculated.

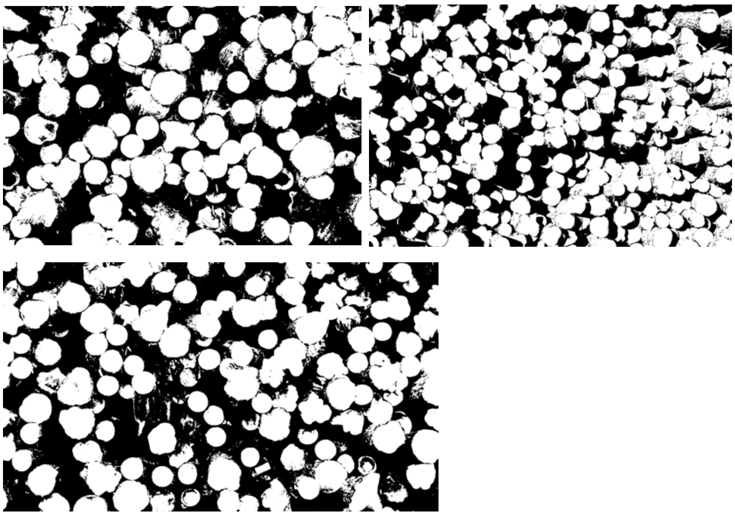

Figure 1. Pine 1 threshold filter result. White pixels are considered as wood, black are considered as cavities in stockpile.

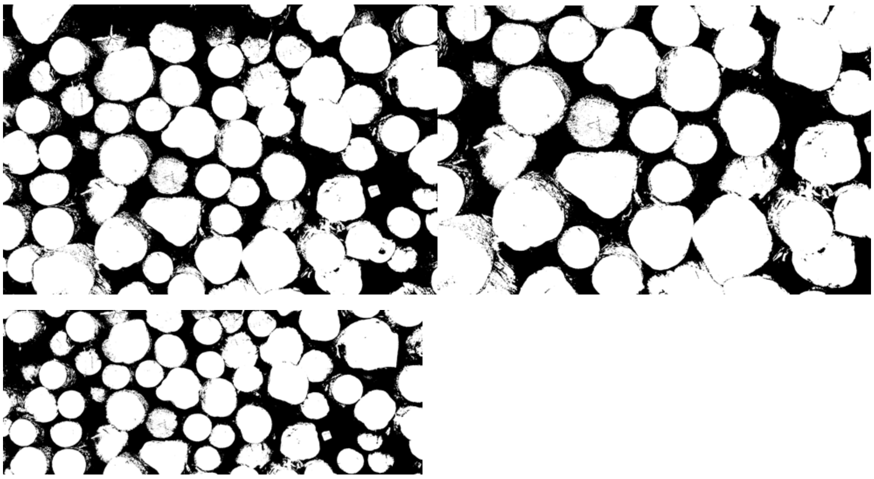

Figure 2. Spruce 1 threshold filter result. White pixels are considered as wood, black are considered as cavities in stockpile..

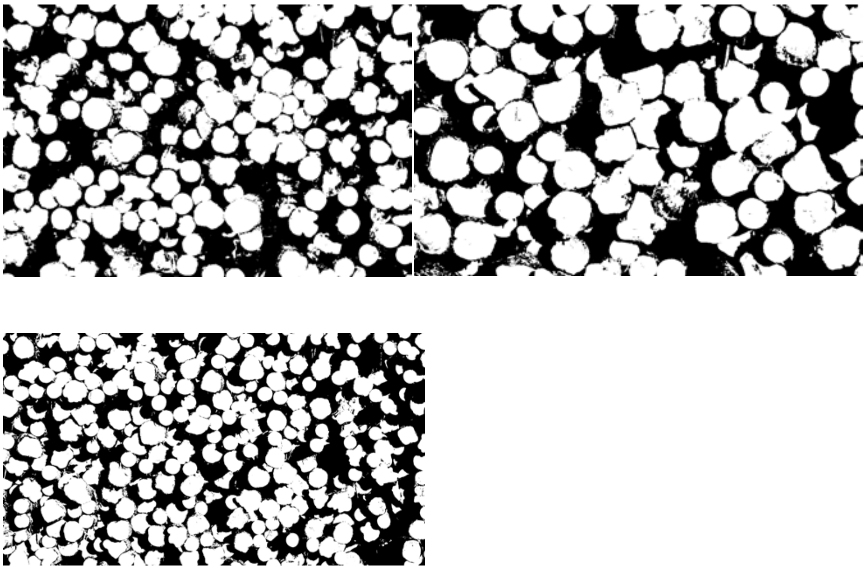

Figure 3. Pine 2 threshold filter result. White pixels are considered as wood, black are considered as cavities in stockpile.

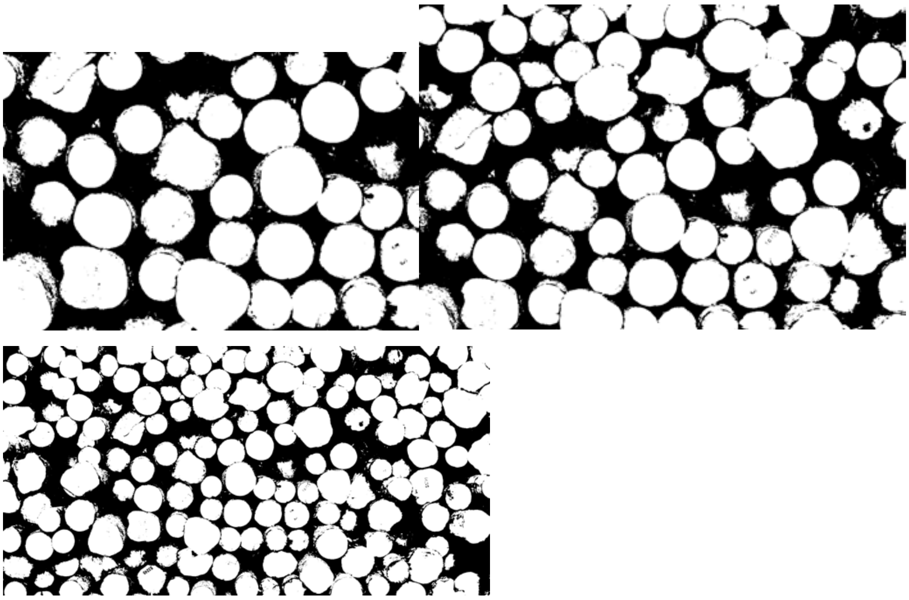

Figure 4. Spruce 2 threshold filter result. White pixels are considered as wood, black are considered as cavities in stockpile.