# Tree-stem Volume Calculation from SfM-MVS to Improve Estimates in the Timber Industry in Indonesia

**Christopher Gomez, Aditya Saputra, Hiroki Matsui**

***Abstract*****:** ***Spatial Analysis is often thought through the cartographic two dimensions of space, with eventually a 3D component and any form of data associated to it. This concept inherited from eras from data mapping on paper has been driving recent computational development in spatial analysis, however spatial analysis can free itself from this virtual plane, we human evolve on and use any space vertical, reversed, spherical, tubular to investigates all sorts of issues, like the production of timber from trees for instance. As Indonesia is a forestry nation, being able to effectively assess the usable amount of timber available. In the present contribution we aimed to show the loss that can be miscalculated using DBH traditional measurement, and to do so we used a photographic based Structure from Motion method combined with Wavelet Decomposition Analysis. The data shows that the DBH method is correct between 60 to 80%, when considering large-scale variations between DBH and SfM-obtained data, showing that the estimates for the timber industry could be improved, even without the use of expensive laser-based equipment.***

***Keywords*** **:** ***Structure from Motion; Multiple-View-Stereo-photogrammetry; Photogrammetry; Geographical Information System; Tree stem measurement; Wavelet decomposition.***

## I. INTRODUCTION

For forestry researchers and practitioners, tree stem measurement is an essential source of proxies and a key component in complex analysis. Notably, stem data has been used worldwide in allometric relationships from tropical environment (e.g. Feldpausch et al. 2011) to temperate (e.g. Osada 2012; Wang et al. 2010; Özer et al, 2018) and boreal forests (e.g. Urban et al. 2013). The tree-stem measures based data can in turn be used to estimate carbon storage (Chave et al. 2005) or to acquire stem's key-data, traditional methods have been recently completed thanks to the development of remote sensing and laser techniques. For wide-area surveys, satellite imagery is the favoured method to derive different types of estimates (e.g. Greenberg et al. 2005), but at a smaller scale recent advances in laser technologies provide the best results using either airborne laser: LiDAR – Light Detection and Ranging - (Edson and Wing 2011) or the ground-based equivalent: TLS – Terrestrial Laser Scanner – (Henning and Radtke 2006; Kato et al. 2013), eventually enhancing measurements taken with more traditional techniques (Liang et al. 2014).

Although bringing an unprecedented level of precision, TLS and LiDAR are still expensive techniques that require specialist equipment and important logistic. An alternative method, which provides similar level of accuracy, is SfM-MVS (Structure-from-Motion and Multiple-view Stereophotogrammetry). SfM-MVS has recently crossed over from computer-vision engineering to bio-geosciences (James and Robson 2012; Westoby et al. 2012; Gomez 2012), highlighting the possibilities of numerous photographic platforms ranging from personal digital cameras (e.g. Fonstad et al. 2013, Saputra et al. 2018) to aerial photographs used in a diachronic manner for the 3D reconstruction of evolving 3D-scenes (Gomez 2013, Gomez et al. submitted). Although most of the research has mainly concerned topographical features, preliminary tests of the method on different trees have also shown its potential for the measurement of entire structures (Morgenroth and Gomez 2014; Millanei et al, 2016).

SfM-MVS is a compound of two processes. The first one (SfM) consists in the reconstruction of a 3D point cloud based on a series of overlapping 2D photographs, a common problem in computer vision. The specificity of SfM is its ability to simultaneously estimate the 3D geometry of a scene, while it also determines the pose of the camera. The computation of SfM only relies on image correspondences (Lowe 2004; Ranjbari et al, 2015). Therefore, using solely overlapping photographs, the algorithm recognises objects into the photographed scene, and then perform calculation based on the locations of the identified object. The computational process starts with (1) the retrieval of the position of each camera

Revised Manuscript Received on September 25, 2019

* Correspondence Author

**Christopher Gomez ***, Kobe University, Graduate School of Maritime Science, Japan. christophergomez@bear.kobe-u.ac.jp

**Aditya Saputra**, Faculty of Geography, Universitas Muhammadiyah Surakarta, Indonesia.

**Hiroki Matsui**, Kobe University, Graduate School of Maritime Science, Japan

(in a non-referenced and unscaled 3D space), (2) the positioning in 3D of the identified features in the scene and (3) a bundle adjustment, which improves the relative positioning of the 3D-points (Lourakis and Argyros 2009). This results in a 3D constrained space, but without a scale related to the reality and without a proper orientation. To resolve these two issues, it is possible to either enter position values in the 3D scene, taken from tie-points – such as recorded DGPS point entered in the 3D scene – or from GPS/DGPS data linked to the camera. The GPS position of each photograph has the advantage of increasing the speed of data processing as it reduces the time necessary for step-1 but it is necessary to use a high-quality GPS or DGPS when working on scenes of small sizes. The second step concerns the reconstruction of a 3D mesh (vertices and polygons). Although it is possible to use the point cloud created by means of SfM to directly create an interpolated mesh, MVS uses traditional photogrammetric technique adapted to multiple photographs to calculate a higher number of 3D points using the points calculated by SfM as the equivalent of tie-points. The bundle of the two techniques allows the development of multiple photographs photogrammetry without the necessity of having numerous tie-points in the field. This appears as a clear advantage for working in areas that are hardly accessible – providing that tie-points can be collected in accessible areas, on the margins for instance; it also extends the possibilities of 3D reconstructions for areas that have changed and for which aerial or series of overlapping land-based photographs exist. Historical photographs, aerial photographs and the large amount of photographs taken by tourists and uploaded over the Internet are an eventual source of 3D geomorphological data, which haven't been explored as yet.

## II. RESEARCH METHOD

The present contribution is based on the measure of 7 sampled white oaks in Japan. The trees have been chosen because they are expensive pieces of timber and for which calculation errors in the available timber can modify the benefit margin of the producer.

The method is based on the Structure from Motion method compared with manual "belt-based" measurement (Fig. 1). The data was collected using a commercial Canon SLR camera with a standard optic set on auto-focus, with 54 to 138 frames per tree taken successively while rotating around the tree. In order to compare the results from SfM to the one given by the dial-belt located at breast height, height at which the photographs were taken. For processing, the data was transferred into a PC computing system running a 64bit 2 GHz IE7 processor and 2 GB RAM. The data processing was conducted using the commercial software Photoscanpro 1.0 created by Agisoft®, which, in a streamlined fashion, align the photographs, create a pointcloud and then a dense point cloud that was exported into Matlab. The point cloud located 5 to 10 cm above the belt was then projected on a plane parallel to the measuring belt, in order to retrieve the circumference and shape of the trees. Using this dataset, measurements of tree diameter circumference and horizontal area were computed for each tree.

Because, the interest of the present study in the tree-stem geometric variation is not concerned with the micro variation of the tree bark or any local overgrowth, the second step has been to extract from the row-SfM-morphometric data, a set of scaled information, that can show variations above or below given thresholds (Gomez 2018, Gomez 2012, Gomez et al. 2017). To do so effectively and objectively, the data was thus filtered using wavelet decomposition, using the dmey (discrete meyer) wavelet set at 4 level, separating the original signal into a set of 4 different scaled data all representing the morphometric variations at a given scale, the most important one being "d1", which includes variations at the several 10s of centimetre scale, and which would consequently have significant impacts on the timber volume.

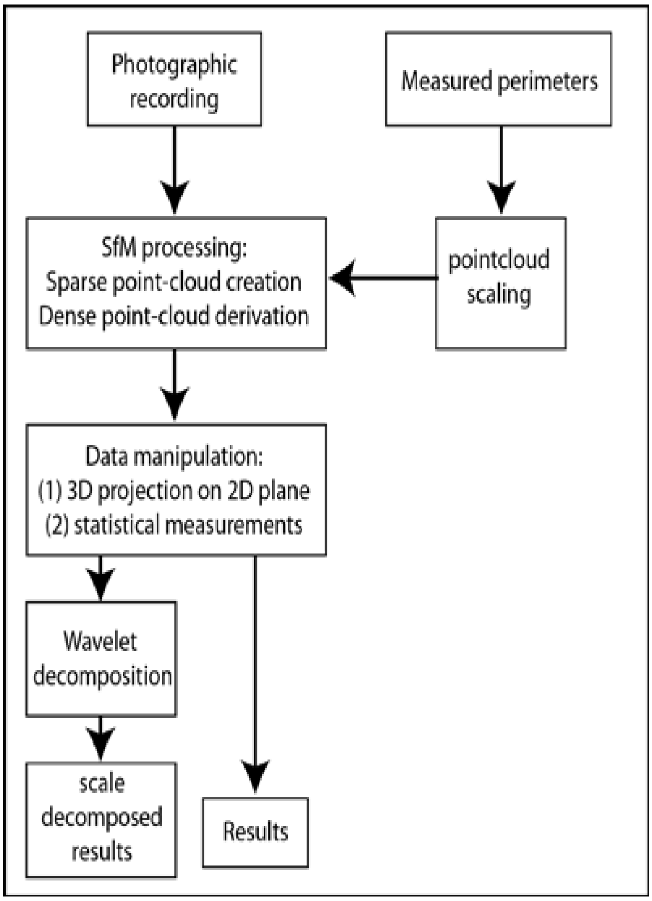

Figure. 1 Flow chart of the method from 2D photographs to 3D scale-filtered and decomposed results.
Source: Gomez et al. 2019

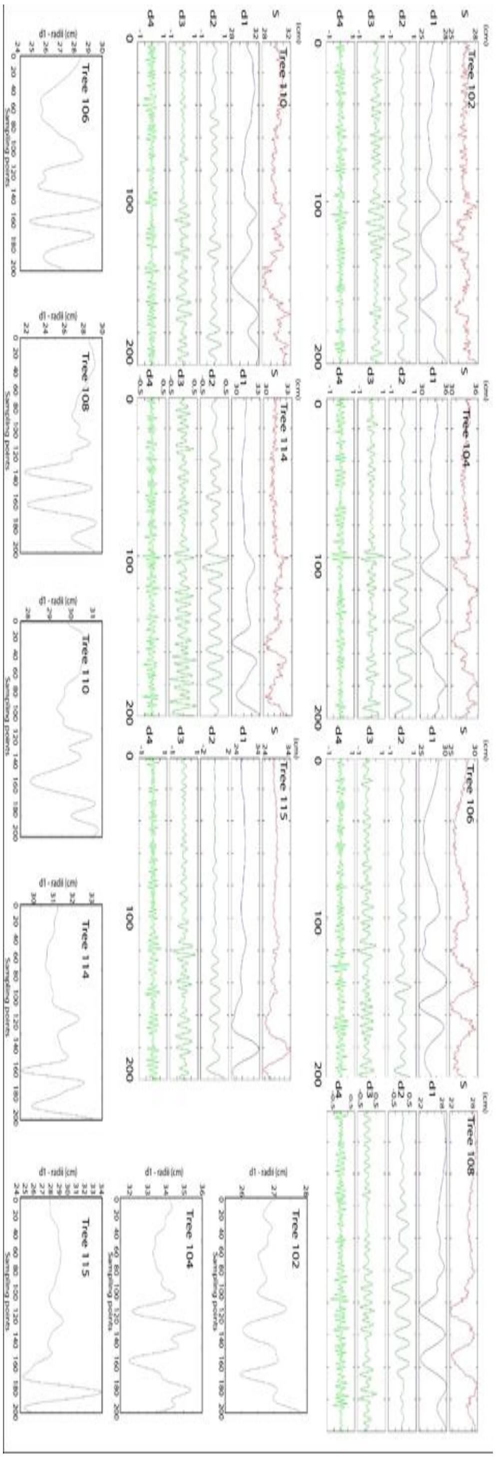

Figure. 2 Decomposition of the radii data to extract the major variations and reduce the impacts of micro-variations due to the tree bark, source: Gomez et al. 2019

## III. RESULTS AND DISCUSSION

The 7 white-oak tree-stems used in this study all range between ~168 to ~213 cm diameter according to the measuring belt, and from ~171 to ~220 cm according to the SfM method (Table. 1).

Table 1: Derived attributes from the sample using SfM and a perfect circle defined by the belt

| Sample | Tree-code | Data Acquisition | Mean radius | Standard deviation of radius | min. radius | max. radius | Per. (cm) | Area (cm2) |
|---|---|---|---|---|---|---|---|---|
| *1* | 102 | Perfect circle | | 0 | NA | NA | 168 | 2245 |
| *1* | 102 | SfM | 26.76 | 0.5 | 25 | 28 | 173 | 2250 |
| *2* | 104 | Perfect circle | | 0 | NA | NA | 213 | 3589 |
| *2* | 104 | SfM | 33.87 | 1 | 31 | 36 | 220 | 3614 |
| *3* | 106 | Perfect circle | | 0 | NA | NA | 171 | 2309 |
| *3* | 106 | SfM | 27.08 | 1.4 | 24 | 31 | 177 | 2295 |
| *4* | 108 | Perfect circle | | 0 | NA | NA | 177 | 2483 |
| *4* | 108 | SfM | 27.21 | 2 | 21 | 30 | 174 | 2169 |
| *5* | 110 | Perfect circle | | 0 | NA | NA | 189 | 2833 |
| *5* | 110 | SfM | 30.05 | 0.9 | 27 | 32 | 193 | 2833 |
| *6* | 114 | Perfect circle | | 0 | NA | NA | 195 | 3024 |
| *6* | 114 | SfM | 31.23 | 0.7 | 29 | 34 | 203 | 3113 |
| *7* | 115 | Perfect circle | | 0 | NA | NA | 178 | 2526 |
| *7* | 115 | SfM | 28.08 | 1.8 | 23 | 35 | 187 | 2407 |

Source: Gomez et al. 2019

The irregularity of the shapes of the tree-stem at breast height have been decomposed using 200 radii measurement with the very heart of the tree as the origin point of the radii (Fig. 3). The result shows contrast between areas of relative regularity, with a constant distance to the centre, varying less than half of a centimetre and bulge and overgrowth spot (Fig. 3). This pattern as observed for tree 102, 104, 114 along a rotation angle of ~180° (i.e. half of the tree diameter was very regular) but not the second half. The other trees also present part of their perimeter with relative regularity, but they either slowly bulge or curve in. It is the case for tree 108, 110, and to a larger extend with tree 106 that present a very long-wave deep depression of ~3 cm (Fig. 3). The standard deviation of the diameter of the measured trees varies from 1 cm (tree 102) to 4 cm (tree 108). The same results are conserved, even when the short variations have been denoised using the *dmey* level 3 wavelet decomposition: 0.8 cm for tree 102 and 3.89 for tree 108. This result shows that an external measurement from a belt can only give an approximation of radii and diameter to a precision of 1-4 cm.

The variations of diameter between the belt method and the SfM (tab. 1) are difficult to compare and can't be considered significant, as the tree bark can be considered as a fractal, introducing variations in the measured results depending on the scale used. For this reason, the authors have denoised the data from the short-range variations induced by the bark using wavelet decomposition as explained in the method (Fig. 4). The denoised data was aligned so that all the trees are oriented in the same direction, and interestingly all the trees seem to show a modification of the tree stem geometry in the same direction, it is therefore very likely that the location site play an important role in controlling the growth direction of the trees.

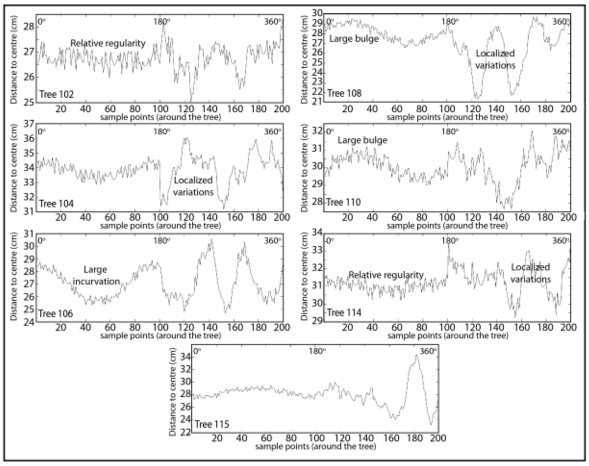

Figure. 3 Calculated radii from 200 sample points on each tree stem at breast height, source: Gomez et al. 2019

Extracted from the wavelet decomposition, the radii variations for all the tree-stem can be compared without the effects of the tree-bark rugosity (Fig. 4). It appears very clearly that the trees have all a perimeter governed for 65% to 80% by a relatively regular shape, with a constant distance to the centre and a shorter part of the perimeter presenting strong irregularities.

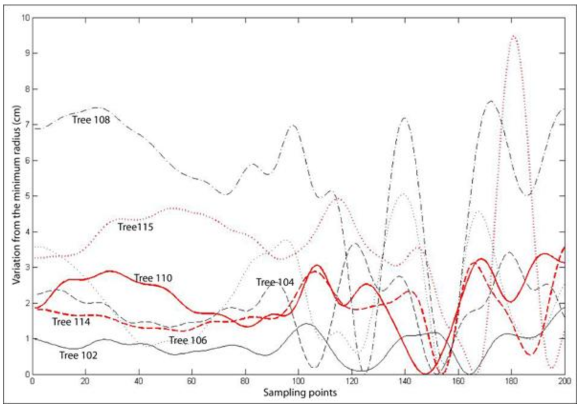

Figure. 4 Radii variations to the smallest calculated radius.

This graphic shows the high variability of the tree truncs that can vary up to a maximum of 10 cm. Rapid variations are unaccounted for by the belt system as the later doesn't follow the small-range incurvation of the tree-stem., source: Gomez et al. 2019

## IV. CONCLUSION

Structure from Motion is an appropriate and low-cost tool that can detect variations of tree stem shapes and provide data that cannot be accounted for by the DBH tape and measurement belts on trees. For the used sample, it was shown that the traditional method can account for 60% to 80% of the available timber but consequently overestimate the existing timber by the corresponding 20 to 40%, which can have an important effect on economic projection. Because SfM is a very low-cost method, one should encourage its development in forestry.

## ACKNOWLEDGEMENT

The research team would like to thank Hokkaido University, which allowed access to forested areas own by the university and to the reviewing and editorial team for their help and handling.

## REFERENCES

1. Chave, J., C. Andalo, S. Brown, M.A. Cairns, J.Q. Chambers, D. Eamus, H. Folster, F. Fromard, N. Higuchi, T. Kira, J-P. Lescure, B.W. Nelson, H. Ogawa, H. Puig, B. Riera, T. Yamakra. 2005. "Tree Allometry and Improved Estimation of Carbon Stocks and Balance in Tropical Forests". *Oecologia* 145: 87-99.
2. Edson, C., and M.G. Wing. 2011. "Airborne Light Detection and Ranging (LiDAR) for Individual Tree Stem Location, Height, and Biomass Measurements". *Remote Sensing* 3: 2494-2528.
3. Feldpausch, T. R., L. Banin, O.L. Phillips, et al. 2011. "Height-diameter allometry of tropical forest trees". *Biogeosciences* 8: 1081-1106.
4. Fonstad, M. A., J.T. Dietrich, C.B. Courville, J.L. Jensen, P.E. Carbonneau. 2013. "Topographic structure from motion: a new development in photogrammetric measurement". *Earth Surface Processes and Landforms* 38: 421-430.
5. Greenberg, J. A., S.Z. Dobrowski, S.L. Ustin. 2005. "Shadow allometry: Estimating tree structural parameters using hyperspectral image analysis". *Remote Sensing of Environment* 97: 15-25.
6. Gomez, C. 2018. "Understanding Volcanic Geomorphology from Derivatives and Wavelet Analysis: case study at Miyakejima Volcano, Izu Islands, Japan". *Journal of Volcanology and Geothermal Research* 354: 57-66.
7. Gomez, C. 2013. "Tamagawa hanrangen ni okeru tochi hifuku no hensen to jishin no yure no kankei (The role of landcover change for earthquake impacts – in Japanese) Tokyo, Japan". *Centre for Spatial Information Science (CSIS) Days 2013, 22,23 Nov 2013 proceedings* A11: 17.
8. Gomez, C. 2012. "Multi-scale analysis of Merbabu and Merapi volcanoes using wavelet decomposition". *Environmental Earth Sciences* 67:1423-1430.
9. Gomez, C., K. Kataoka, A. Saputra, P. Wassmer, A. Urabe, J. Morgenroth, A. Kato. 2017. "Photogrammetry-based Texture Analysis of a Volcaniclastic Outcrop-peel : Low-cost Alternative to TLS and Automation Potentialities using Haar Wavelet and Spatial-Analysis Algorithms". *Forum Geografi* 31: 16-27.
10. Gomez, C., Y. Hayakawa, H. Obanawa. 2015. "A study of Japanese landscapes using structure from motion derived DSMs and DEMs based on historical aerial photographs: New opportunities for vegetation monitoring and diachronic geomorphology". *Geomorphology* 242: 11-20.
11. Henning, J. G., P.J. Radtke. 2006. "Detailed Stem Measurements of Standing Trees from Ground-Based Scanning Lidar". *Forest Science* 52: 67-80.
12. James, M. R., and S. Robson. 2012. "Straightforward reconstruction of 3D surfaces and topography with a camera: Accuracy and geoscience application". *Journal of Geophysical Research* 117: F03017.
13. Kato, A., J. Morgenroth, D. Kelbe, C. Gomez, J. van Aardt. 2013. *"Ground Truth Measurement of Trees Using Terrestrial Laser for Satellite Remote Sensing"*. Melbourne, Australia: IEEE International Geoscience and Remote Sensing Symposium (IGARSS) proceedings.

14. Liang, X., V. Kankare, X. Yu, J. Hyppa, M. Holopainen. 2014. "Automated Stem Curve Measurement Using Terrestrial Laser Scanning". *IEEE Transactions On Geoscience and Remote Sensing* 52(3): 1739-1748.
15. Lourakis, M.I.A. and A.A. Argyros. 2009. "SBA: A software package for generic sparse bundle adjustment". ACM Trans. Math. Softw. 36 (1). Doi: 10.1145/1486525.1486527.
16. Lowe, D.G. 2004. "Distinctive image features from scale-invariant key-points". *International Journal of Computer Vision* 60: 91-110.
17. Millanei, A., Dorafshan, S. M. H. G., & Bayrami, A. (2016). Sunnite Religious View about Jurisprudence Nature of Istisna Contract. *UCT Journal of Social Sciences and Humanities Research, 4*(1), 25-27.
18. Morgenroth, J., and C. Gomez. 2014. "Assessment of tree structure using a 3D image analysis technique – a proof of concept". *Urban Forestry and Urban Greening*, 13: 198-203.
19. Osada, N. 2012. "Crown exposure to light and tree allometry of 11 tree species in a snowy cool-temperate forest in Japan". *Plant Ecology* 213: 783-794.
20. Özer, G., Ergün, U., & İnan, L. E. (2018). Headache in Multiple Sclerosis from A Different Perspective: A Prospective Study. *Journal of Clinical and Experimental Investigations*, *9*(1), 9-13.
21. Ranjbari, M. H., Shaheri, A., Dalili, R., & Soroush, R. (2015). Optimal allocation of distributed generation using an analytical method with consideration of technical and economic parameters. *UCT Journal of Research in Science, Engineering and Technology, 3*(1), 9-17.
22. Saputra, A., C. Gomez, I. Delikostidis, P. Zawar-Reza, D.S. Hadmoko, J. Sartohadi, M.A. Setiawan. 2018. "Determining earthquake susceptible areas southeast of Yogyakarta, Indonesia-Outcrop analysis from structure from motion (SfM) and geographic information system (GIS). *Geosciences* 8: 132.
23. Urban, J., K. Holusova, L. Mensik, J. Cermak, P. Kantor. 2013. "Tree allometry of Douglas fir and Norway spruce on a nutrient-poor and a nutrient-rich site". *Trees* 1: 97-110.
24. Wang, X., C. Wang, Q. Zhang, X. Quan. 2010. "Heartwood and sapwood allometry of seven Chinese temperate tree species". *Annals of Forest Science* 67(410): 1-10.
25. Westoby, M. J., J. Brasington, N.F. Glasser, M.J. Hambrey, J.M. Reynolds. 2012. "Structure-from-Motion photogrammetry: A low-cost, effective tool for geosciences applications". *Geomorphology* 179: 300-314..

## AUTHORS PROFILE

**Christopher Gomez*:*** Associate Professor and head of VoRAS Laboratory, Kobe University, Graduate School of Maritime Science, Japan.

**Aditya Saputra*:*** Lecturer, Faculty of Geography, Universitas Muhammadiyah Surakarta, Indonesia

**Hiroki Matsui*:*** *researchers in* VoRAS Laboratory, Kobe University, Graduate School of Maritime Science, Japan.