

OPTIMUM NUMBER AND POSITIONS OF TERRESTRIAL LASER SCANNER TO DERIVE DTM AT FOREST PLOT LEVEL

S.K.P. Kushwaha^{* 1,3}, Arunima Singh², Kamal Jain¹, Martin Mokros^{2,3}

¹ Geomatics Group, Department of Civil Engineering, Indian Institute of Technology, Roorkee - 247667, Uttarakhand, India,
^{*}s.k.p.kushwaha92@gmail.com, kjainfce@iitr.ac.in

² Faculty of Forestry and Wood Sciences, Czech University of Life Sciences, Prague - 16500, Czech Republic,
singha@fld.czu.cz, mokros@fld.czu.cz

³ Department of Forest Harvesting, Logistics and Ameliorations, Faculty of Forestry, Technical University in Zvolen, Zvolen - 96001, Slovakia, martin.mokros@tuzvo.sk

Commission III, WG III/5

KEYWORDS: Forest, TLS, Point cloud, Ground Filtering, DTM

ABSTRACT:

Remote sensing of forest landscape is sometimes quite challenging, considering the rugged terrain, remote areas and presence of dense canopy. LiDAR is capable of generating dense three-dimensional (3D) structure of the forest. But when research is focused on a small area that needs dense information Terrestrial Laser Scanner (TLS) proves to be an efficient way of acquiring the information. TLS is an instrument used to acquire data from the ground surface level. Ground information and under canopy structure are acquired with more accuracy and precision with TLS when compared to aerial remote sensing techniques. When a TLS survey is done, scan positions and the number of scans are important parameters to consider to acquire datasets of forest plots. In this research, an analysis is carried out to determine the optimum number of TLS scans and positions that are needed to sufficiently generate the number of ground points to generate a Digital Terrain Model (DTM). The research considers two forest plots of 25m x 25m with different tree densities. Different TLS scanning combinations are used to determine the best scanning pattern for DTM generation at the forest plot level.

1. INTRODUCTION

Generating Digital Terrain Model (DTM) has always been an essential part of the survey for many years. As technology advances, many techniques have been emerged and developing rapidly. An advanced remote sensing technique is Light Detection and Ranging (LiDAR). Terrestrial Laser Scanner (TLS) is one instrument based on LiDAR technique that follows the time-of-flight principle (Kushwaha, 2018). TLS is used to generate an accurate dense three-dimensional (3D) model from the ground perspective. Its dataset is also used to produce high-resolution DTM along with other applications. It is a very effective tool in the forest under canopy data acquisition compared with Unmanned Aerial Vehicles (UAV) based photogrammetry or any other airborne remote sensing techniques which can help in forest inventory, forest management and planning.

In a forest, plot size is initially determined, and considering the size of the plot, a number of TLS scans and their positions are planned. (Ritter et al., 2020) tried to predict different plot sizes and scanner position layouts in multi scan settings for tree detection probability. Dense 3D point clouds are generated from each TLS scan position which are further

combined with all other TLS scans to produce a complete 3D point cloud dataset of the forest plot. Considering the high density of the points, the DTM generated from terrestrial LiDAR is considered to be very accurate.

Many factors can affect the quality of DTM produced in forest plots, such as the number of scans, positions of scans, tree densities, co-registration accuracy of individual scans, sensor coverage, etc. Similar research was carried out to study the parameters affecting the quality of DTM from Airborne Laser Scanning (ALS) (Hyypä et al., 2005). The high-quality DTM is required in the forestry even to use as a reference when integrating with other datasets. In forestry accurate DTM is also used to produce Canopy Height Model (CHM) which helps in providing forest metric parameters (Singh & Kushwaha, 2021).

In this research, we have tried to focus on the number and positions of TLS scans that can produce suitable DTM in two forest plots with different tree densities. Likewise, other research has been carried out stating that close range remote sensing techniques are capable of achieving higher accuracy when compared to Airborne Laser Scanning (ALS) and

* Corresponding Author

Digital Aerial Photogrammetry (DAP) (Jurjevic et al., 2021).

LiDAR is capable of getting points in highly vegetated areas. One such research highlights the process of DTM generation in detecting archaeological earthwork anomalies (Limongiello et al., 2020). Different algorithms and techniques were developed to improvise the accuracy of the DTM. The evaluation of the quality of ground surfaces generated from TLS is also important for the accuracy of DTM produced (Sun, 2019). The accuracy of DTM produced from different techniques like TLS, ALS, UAV-DAP were also tested using a different algorithm and the analysis is extensively explained (Crespo-Peremarch et al., 2020). The research was carried out to evaluate the DTM quality obtained from Airborne Laser Scanners (ALS) for two seasons (spring/summer) in a year and was validated with 95 checkpoints acquired from surveying methods (Sterenciak & Kozak, 2011). The form of terrain also plays an important role in DTM generation, So, high-resolution topography survey was carried out over an 8 km² with 81 different TLS scan positions to analyze the terrain variables, Aspect, Slope and hillshade in Keller Peninsula region (Schünemann et al., 2018). Not only in the vegetation areas LiDAR data derived DTM can also be used to improve the geometric data of hydraulic modeling, which helps in recognition of fluvial landforms and estimation of flood inundation extents (Hohenthal et al., 2011).

TLS is also used to generate quantitative structure models (QSMs). QSMs are very accurate in order to calculate forest above-ground biomass. To do so, the tree volume and wood density are measured (Demol et al., 2021). Later the Quality of DTM produced by TLS data is analyzed (Costantino & Angelini, 2013). TLS can also be effective in mapping tree stem in dense forest canopy cover (Tao et al., 2021).

Not only in forestry, TLS improves Digital Elevation Models (DEM) and can also help in topsoil pH modelling with a complex topography and dense vegetation (Baltensweiler et al., 2017). Hence, the most reliable way of generating DTM is needed. Defining the number of scans can minimize the workload in the field also save energy. The fixed scans with the different sets of plots can help to get an idea of the scan to cover the whole plot and all the trees. This also helps to minimize the occlusion effect in the plot.

2. STUDY AREA

In this research, two forest plots were chosen to test the hypothetic idea. The plots were considered with different tree densities plot 1 with 49 trees and plot 2 with 102 trees. Forest plots considered in this research are located in Zvolen,

the central part of Slovakia. The location of the study area is represented in Figure 1.

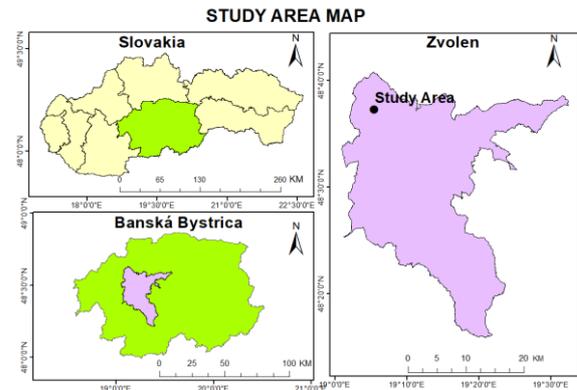


Figure 1: Study area map

3. DATASET USED

The dataset required for this research was acquired with TLS in pre-established plots. A total of 9 scans were done in each plot. Forest plots were considered with dimensions of 25 x 25 m, plots were scanned from nine scan positions. The pattern of all the nine scan positions in the forest plots is depicted in Figure 2.

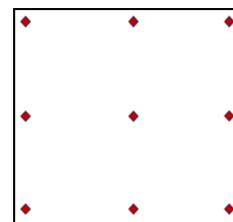


Figure 2. Sample forest plot (25m x 25m) showing the TLS scan positions used during data acquisition.

Spherical reflectors were used in the forest plots for co-registration of the individual scans. Ground markers were installed in all four corners of the plots for identification in the pointcloud datasets. After pre-processing the individual scans were used to produce the 3D point cloud dataset of the overall plots, respectively. Other six markers (Checkerboards) were also placed facing the centre scan position which was used to geo-reference the point clouds.

4. RESEARCH HYPOTHESIS

The research hypothesis is how many TLS scans and their spatial combination are sufficient to generate detailed and accurate DTM with less data absence and redundancy.

We came up with six possible combinations that can be considered in this research. The first combination is only with the Centre Scan (CS). The second combination is with all the Four Corner Scans (FCS). The third combination is with Four Corner with Centre Scans (FCwCS). The fourth combination is with Four Sides Centre Scans (FSCS). The fifth combination is with Four Sides Centre with Centre Scans (FSCwCS). Finally, the sixth combination is with All Nine Scans (ANS) in the forest plot which is also used as the reference scan combination dataset. Figure 3 represents all the scan combinations and the area of influence of each scan position. The red polygons depict the TLS scan positions in the forest plots. The circles/arch's depicts the region in which the TLS can produce more dense data with its position.

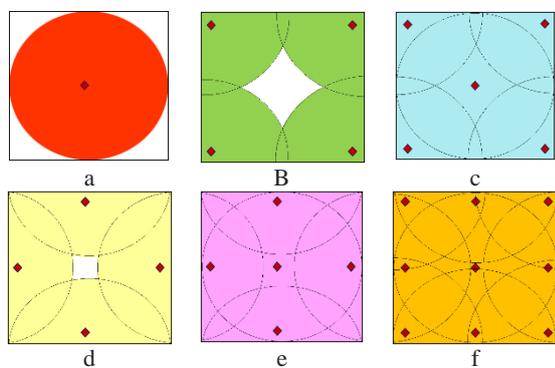


Figure 3. Shows the TLS Positions (red polygon) and its sphere of influence in different scan combinations a) Centre Scans (CS) b) Four Corners Scans (FCS) c) Four Corners with Centre Scans (FCwCS) d) Four Sides Centre Scans (FSCS) e) Four Sides Centre with Centre Scans (FSCwCS) f) All Nine Scans (ANS) - Reference

Case-I, When CS combination is considered, there are high chances that the areas near the corners may miss data either due to occlusion or due to less density of points as the distance increases radially from the TLS. Case-II, when the FCS combination is considered, there is a high probability of missing the plot's central area, but with more details in the corner regions. Case-III, when FCwCS is considered chances to cover the whole plot are increased. Case-IV, when FSCS is considered again there are high chances that the centre area data may get missed. Case-V, when FSCwCS is considered, then most parts of the whole plot are covered. Case-VI, when ANS is considered whole plots are covered like in case-III and case-V but with an increase in data and regions. As the number of scans is increased the region of coverage increases and density of points increases enormously and data redundancy also increases. The total number of sphere of influence of TLS scan positions are 1, 1, 2, 2, 3, 4 respectively in case – I, II, III, IV, V, VI

respectively. Case-III and case-V have an equal number of scans, but TLS scans position has a good advantage in case-V, as it has one extra sphere of influence with same number of scans. Theoretically, the authors would like to predict that case-V i.e., combination FSCwCS would be more suitable to generate a sufficient number of ground points to produce DTM of the forest plot.

5. RESEARCH METHODOLOGY

Initially, Forest plots were identified for the proposed research. TLS survey was carried out in both the plots identified in the forest with different tree densities.

Pre-processing of the TLS scans were done in FARO Scene software. Then the different scans were combined depending upon the possible scan pattern combinations as mentioned in Figure 3, ground points were filtered out from the point clouds obtained from all the six combinations using LAStools. Ground points were interpolated, and DTM was produced for all the possible combinations (for illustration refer Figure 5). DTM produced from the ANS combination is used as a reference and a DTM comparison is made with DTM's obtained from other scan combinations. The methodology is represented in the workflow in Figure 4.

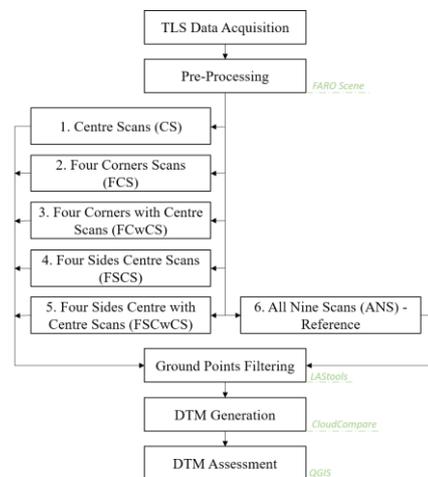


Figure 4. Methodology

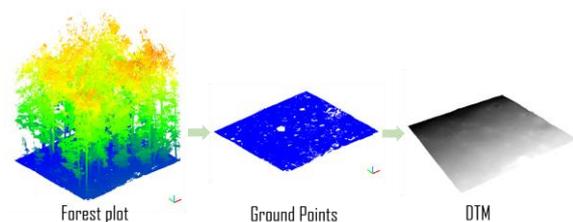


Figure 5. Illustration of forest plot 1 with filtered ground points and DTM generated

6. RESULTS

Ground points are filtered out from forest plot point clouds. The ground points are interpolated with the average elevation points wherever the data is missing in each scanning combination mentioned in earlier sections. The filtered ground points obtained in all the scan combinations are also shown in Figure 6, along with the percentage of ground coverage. The ground points are further used to produce DTM's, respectively. Among the DTM obtained in each scanning combination, it is challenging to inspect

which DTM produced is close to the reference DTM obtained from the ANS combination. So, the relative difference is calculated between all the scan combinations DTM's to the reference DTM. The results obtained are shown in Figure 7.

Hypothetically scan combination FCwCS and FSCwCS produce good results as both the combinations have five scan positions each. However, among both the combinations FSCwCS has produced the best results which is evident from Figure 7 and the histogram values obtained in Figure 8.

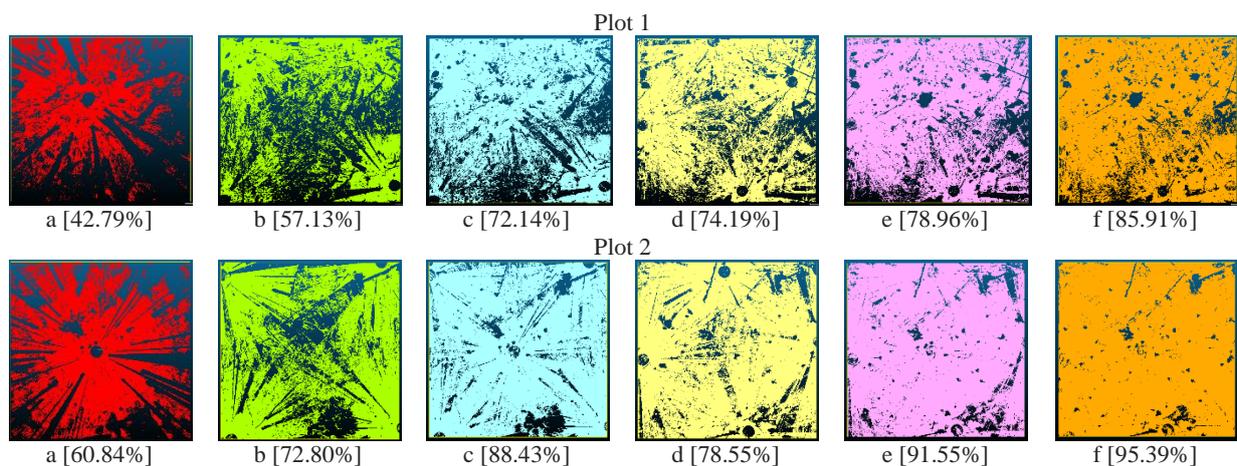


Figure 6. Shows ground points obtained in all the possible scan combinations for both plots, along with percentage of ground covered. a) Centre Scans (CS) b) Four Corners Scans (FCS) c) Four Corners with Centre Scans (FCwCS) d) Four Sides Centre Scans (FSCS) e) Four Sides Centre with Centre Scans (FSCwCS) f) All Nine Scans (ANS) - Reference

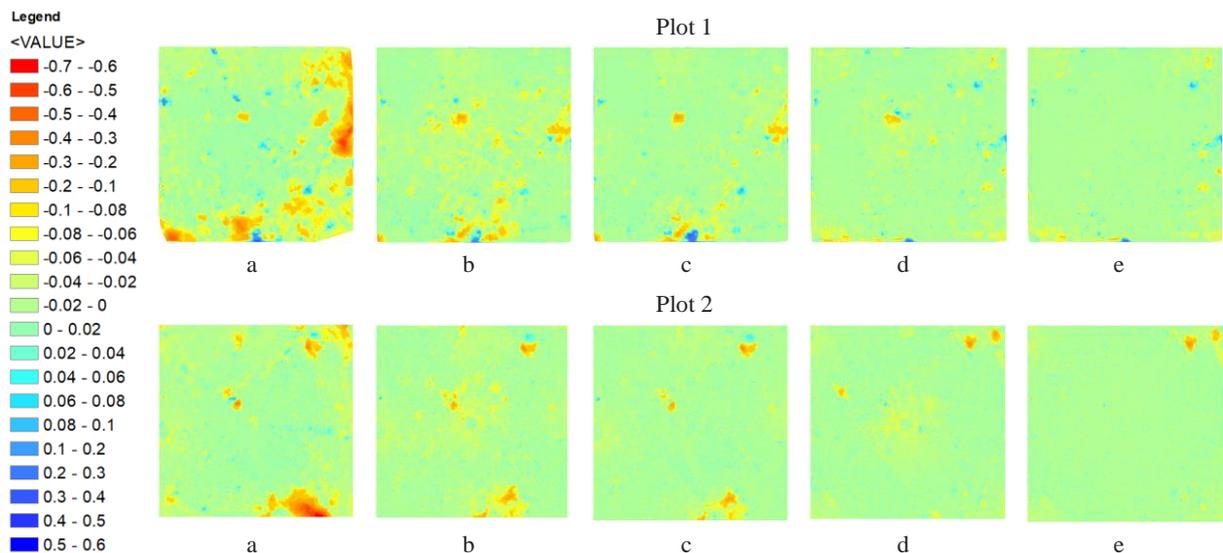


Figure 7. Shows the relative difference between DTM obtained with ANS - Reference combination and different scan combinations a) ANS-CS b) ANS-FCS c) ANS-FCwCS d) ANS-FSCS e) ANS-FSCwCS

7. DISCUSSIONS

7.1 Ground Coverage

The portion of ground covered in each scanning combination pattern is shown in Figure 6, and it is evident that with the increase in the number of scans, the percentage of ground cover has increased. Ground coverage is higher in plot 2 comparatively to plot 1 despite nearly double the number of trees. This is because the trees present in plot 2 are less thick than the trees in plot 1. FCS and FSCS both have four scans, but the position of scans has improved in FSCS, similarly, FCwCS and FSCwCS both have five scans, but the ground cover is more in FSCwCS. This is evident from Figure 6 for both plots 1 and 2, respectively.

7.2 Ground Filtering

We used lasground_new tool from LAStools plugin in QGIS software to filter out ground points from the overall point cloud of forest plots. The tool classifies the point cloud into the ground and non-ground classes.

7.3 DTM Generation

The ground points obtained in each scan combination do not have full coverage due tree stems, fallen logs, big stones, occlusions beyond the tree stems, etc. Therefore, the filtered ground points are used to interpolate and produce DTM.

7.4 DTM Assessment

In this research, we have considered the ANS scan combination as the reference scan combination as it has the highest number of scan positions and percentage of ground coverage. So, the DTM's obtained from all other scan combinations are comparatively analyzed with DTM obtained from ANS combination to find out the equal number of points which are common ground points. This can be further understood from the graph in Figure 8.

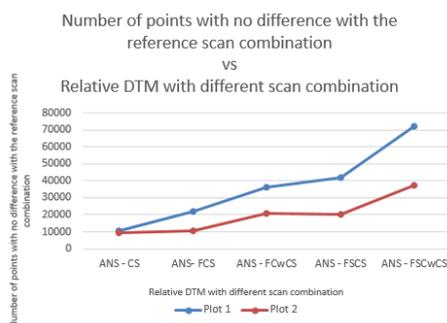


Figure 8. The graph represents the number of points with no difference with the reference scan combination Vs Relative DTM with different scan combination

8. CONCLUSIONS

We have presented the possibility of ground coverage in each scanning combination and DTM generated in two forest plots with different densities. From the results, obtained in both plots with different tree densities and as per the results obtained it is evident that among all the six scan combinations considered for this research Four Sides Centre with Centre Scans (FSCwCS) is the best suitable scan combination that can be used to generate DTM as close to All Nine Scans (ANS) combination without increasing more scans, data redundancy and size of the data.

The main advantages of minimizing the number of TLS scan positions are i) Reducing the data acquisition survey time. ii) Reduces the data redundancy; as we keep increasing the number of scan positions it is likely that we can cover the missing areas from other scans but it also highly increases the redundancy of points in the datasets by scanning the other same region many times. iii) As the number of scans is minimized the overall size of the dataset is also reduced which further helps in processing and handling the datasets.

The authors would like to recommend that if the forest plot is around 25 x 25 m and the aim is to produce DTM, then the FSCwCS scan pattern combination can be sufficient to fulfil the required objective effectively.

9. FUTURE SCOPE

Further, the authors would also like to investigate the effect of scanning pattern combinations and the number of scans on the under canopy information like stems, leaves, branches, etc., and also for individual tree detection and tree parameters retrieval.

ACKNOWLEDGEMENTS

This work was supported by grant No. CZ.02.1.01/0.0/0.0/16_019/0000803 (“Advanced research supporting the forestry and wood-processing sector’s adaptation to global change and the 4th industrial revolution”) financed by OP RDE, by the Scientific Grant Agency of the Ministry of Education, Science, Research, and Sport of the Slovak Republic and the Slovak Academy of Sciences [grant number VEGA 1/0335/20] and by the Slovak Research and Development Agency through Grants No. APVV-18-0305 and APVV-20-0391

REFERENCES

Baltensweiler, A., Walthert, L., Ginzler, C., Sutter, F., Purves, R. S., & Hanewinkel, M. (2017). Terrestrial laser scanning improves digital elevation models and topsoil pH

- modelling in regions with complex topography and dense vegetation. *Environmental Modelling and Software*, 95, 13–21. <https://doi.org/10.1016/j.envsoft.2017.05.009>
- CloudCompare (version 2.12) [GPL software]. (2022). Retrieved from <http://www.cloudcompare.org/>
- Costantino, D., & Angelini, M. G. (2013). Production of DTM quality by TLS data. *European Journal of Remote Sensing*, 46(1), 80–103. <https://doi.org/10.5721/EuJRS20134606>
- Crespo-Peremarch, P., Torralba, J., Carbonell-Rivera, J. P., & Ruiz, L. A. (2020). Comparing the generation of DTM in a forest ecosystem using TLS, ALS and UAV-DAP, and different software tools. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, 43(B3), 575–582. <https://doi.org/10.5194/isprs-archives-XLIII-B3-2020-575-2020>
- Demol, M., Calders, K., Verbeeck, H., & Gielen, B. (2021). Forest above-ground volume assessments with terrestrial laser scanning: A ground-truth validation experiment in temperate, managed forests. *Annals of Botany*, 128(6), 805–819. <https://doi.org/10.1093/aob/mcab110>
- Hohenthal, J., Alho, P., Hyyppä, J., & Hyyppä, H. (2011). Laser scanning applications in fluvial studies. *Progress in Physical Geography*, 35(6), 782–809. <https://doi.org/10.1177/0309133311414605>
- Hyyppä, H., Kaartinen, H., Yu, X., Hyyppä, J., Kaasalainen, S., Honkavaara, E., & Rönholm, P. (2005). Factors Affecting the Quality of DTM Generation in Forested Areas. ISPRS WG III/3, III/4, V/3 Workshop “Laser Scanning 2005”, Enschede, the Netherlands, September 12-14, 2005, 85–90. <https://www.researchgate.net/publication/228853407>
- Jurjevic, L., Gašparovic, M., Liang, X., & Balenovic, I. (2021). Assessment of close-range remote sensing methods for DTM estimation in a lowland deciduous forest. *Remote Sensing*, 13(11). <https://doi.org/10.3390/rs13112063>
- Kushwaha, S. K. P. (2018). 3D Documentation and Condition Assessment of Surface and Subsurface of Engineering Structures [Indian Institute of Remote Sensing]. <https://doi.org/10.13140/RG.2.2.10012.72328>
- Limongiello, M., Ronchi, D., & Albano, V. (2020). BLK2GO for DTM generation in highly vegetated area for detecting and documenting archaeological earthwork anomalies. IMEKO TC-4 International Conference on Metrology for Archaeology and Cultural Heritage Trento, Italy, October 22-24, 2020., 316–321.
- Martin Isenburg, LAStools - efficient tools for LiDAR processing. Version 111216, <http://lastools.org>.
- QGIS.org, 2022. QGIS Geographic Information System. QGIS Association. <http://www.qgis.org>
- Ritter, T., Gollob, C., & Nothdurft, A. (2020). Towards an optimization of sample plot size and scanner position layout for terrestrial laser scanning in multi-scan mode. *Forests*, 11(10), 1–23. <https://doi.org/10.3390/f11101099>
- Schünemann, A. L., Almeida, P. H. A., Thomazini, A., Fernandes Filho, E. I., Francelino, M. R., Schaefer, C. E. G. R., & Pereira, A. B. (2018). High-resolution topography for Digital Terrain Model (DTM) in keller peninsula, maritime antarctica. *Anais Da Academia Brasileira de Ciencias*, 90(2), 2001–2010. <https://doi.org/10.1590/0001-3765201820170296>
- Singh, A., & Kushwaha, S. K. P. (2021). Forest Degradation Assessment Using UAV Optical Photogrammetry and SAR Data. *Journal of the Indian Society of Remote Sensing*, 49(3), 559–567. <https://doi.org/10.1007/s12524-020-01232-2>
- Stereńczak, K., & Kozak, J. (2011). Evaluation of digital terrain models generated in forest conditions from airborne laser scanning data acquired in two seasons. *Scandinavian Journal of Forest Research*, 7581(26:4), 374–384. <https://doi.org/10.1080/02827581.2011.570781>
- Sun, Y. (2019). Evaluating the quality of ground surfaces generated from Terrestrial Laser Scanning (TLS) data [Virginia Polytechnic Institute and State University]. <https://vtechworks.lib.vt.edu/handle/10919/90577>
- Tao, S., Labrière, N., Calders, K., Fischer, F. J., Rau, E.-P., Plaisance, L., & Chave, J. (2021). Mapping tropical forest trees across large areas with lightweight cost-effective terrestrial laser scanning. *Annals of Forest Science*, 78(4). <https://doi.org/10.1007/s13595-021-01113-9>