Long Range High-Speed Personal Laser Scanner (PLS) applied to Simultaneous Localisation and Mapping (SLAM) Technology in Roundwood Measurement

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1. Introduction

The use of technologies such as Terrestrial Laser Scanning (TLS) has increased the efficiency and quality of forest inventories compared to traditional methods. Despite large innovations TLS is still considered labour-intensive and ineffective for large scale data acquisition. However, many of these shortcomings can be mitigated by applying a Personal Laser Scanner (PLS), a device applied to Simultaneous Localisation and Mapping (SLAM) technology. Gollob et al. (2020) examined this kind of device to estimate tree position and diameter and demonstrated its accuracy. However, to our knowledge the PLS has not yet been applied to the measurement of felled industrial roundwood. The log scaling process involves measuring the length of the logs and midpoint-diameters, the top-diameter or the diameters at both ends and then applying a determined formula (Edwards, 1998). This lengthy process does not ensure any reliable estimation of the log's volume, since the estimated volume is derived from empirical formulas based on analogue and manual measurements. The accumulated measured volume error when acquiring roundwood can lead to considerable economic losses for the roundwood purchaser since as stated by Fonseca (2005), approximately 60 - 85% of costs of producing wood products can lie in this initial purchase. Therefore, accuracy in the log scaling process is critically important. Likewise, process transparency and stakeholder trust in the roundwood supply chain can be keys to sustainable commercial success. This can be achieved since when using the PLS, the files containing the point clouds of the scanned roundwood are saved and can become accessible immediately allowing all stakeholders to access records of the roundwood purchased and recalculate its volume at any time. In this paper both methods, the PLS measurement of roundwood and its digitized procurement and transparent supply chain, are presented. The present study aims to examine the accuracy of the use of the PLS applied to SLAM technology in measuring log volume, to assess its reliability when measuring roundwood volume during the roundwood acquisition stage.

2. Data and Methods

In this study, fifty logs of Norway Spruce (*Picea abies* L.) were scanned and analysed. The logs were felled in the forestry district of Chorin (52° 53' 22'' N, 13° 52' 06'' E), located in Brandenburg, Germany. These logs belonged to the assortment industrial wood, with an average length of 2.53 m, ranging from 2.46 m to 2.65 m, and with an average midpoint diameter of 19.97 cm, ranging from 14.45 cm to 28.55 cm. Firstly, the logs were numbered with forest crayons then top, butt and midpoint diameters as well as the length of the log were measured manually, using the method explained by de Miguel-Diez et al. (2021). This step was carried out to recognise the logs later once the data were processed, and the logs were reproduced as point clouds. Afterwards, the volume of every log was measured using a xylometer and the resulting volumes were taken as reference values. Finally, each log was scanned digitally using a GeoSLAM ZEB HORIZON personal mobile laser scanner. The technical characteristics of this device are comprehensively presented by Gollob et al. (2020). After scanning, the files were converted into a point cloud with a *.LAZ format using the software GeoSLAM HUB 6.0.0.. These LAZ files were analysed using the software Cloud Compare (version 2.10.2., Cloud Compare, 2021). Here, the logs were segmented manually using the segmentation tool in Cloud Compare. The noise was removed using the low pass filter of Cloud Compare's "Filter noise" tool. In doing so, six neighbours around each point were extracted inputting a relative maximum error of 1.0 and removing all isolated points. Subsequently, the normals were computed using a plane local surface mode, as recommended for noisy samples by Girardeau-Montaut, in 2015 with a minimum spanning tree, considering twenty nearest neighbours to build the tree. Afterwards a mesh was generated using the

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“Poisson” surface reconstruction method, which is suitable for surface reconstruction of noise affected samples (Kazdhan et al., 2006) and provided as plugin in Cloud Compare (see Figure 1). Twenty neighbouring sample points per node were considered for the log reconstruction with a centre point weight of 2. The Neumann constraint was chosen as boundary condition, as it is proven robust to missing data, e.g., on the bottom side of the logs (Kazdhan and Hoppe, 2013). Instead of using an octree depth, the target resolution was defined with 0.1 m. Once all the volumes were calculated, they were compared with each other by fitting a linear regression with the volumes measured using the xylometer and the volumes calculated in Cloud Compare from the PLS sample. In addition, paired t-tests were conducted in order to prove if the difference between the samples was statistically significant. The results were analysed using the programme RStudio (version 1.3.1093, RStudio Team, 2021). For the visualisation of the simulation results the R package *ggplot 2* was used (Wickham, 2009).

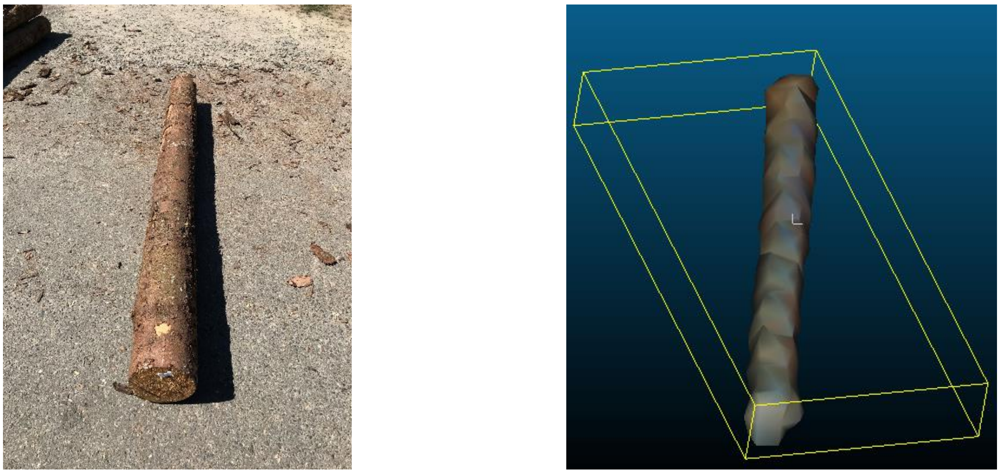

Figure 1: Real log (left) and mesh generated virtually from the PLS sample (right).

3. Results and discussion

The mean volume of all measured logs with xylometer was 81.4 dm^3, ranging from 47.3 dm^3 to 167.3 dm^3, and the mean volume calculated in Cloud Compare resulted in 81.5 dm^3, ranging from 46.7 dm^3 to 166.2 dm^3. When comparing the results using both methods, the adjusted R^2 obtained was very close to 1 (see figure 2). This can be interpreted as a marginal deviation from a linear relation.

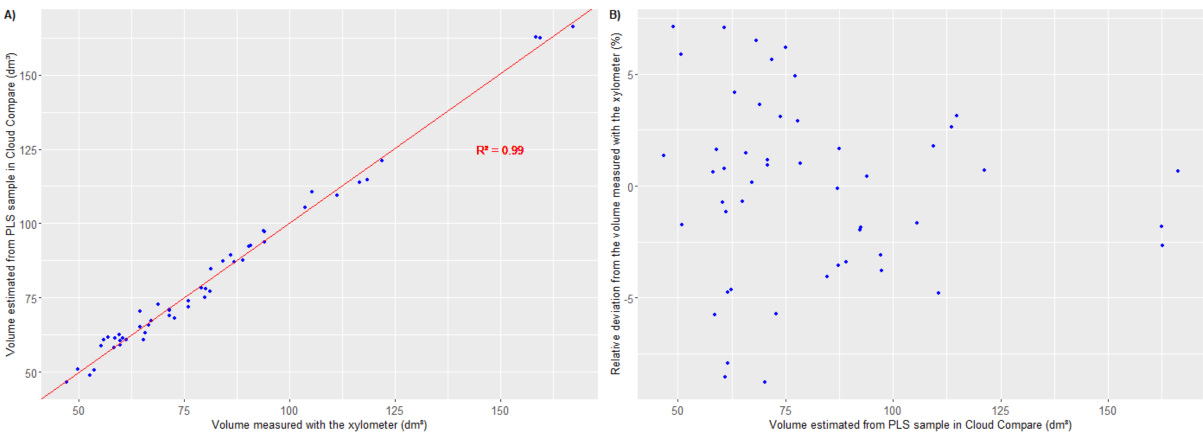

Figure 2: Linear regression concerning both measurement methods (A) and relative deviation of the volume estimated in Cloud Compare from the volume measured with the xylometer (%) (B).

The difference between all samples is normally distributed (Shapiro-Wilks, Sig = 0.134). The mean difference of the samples of 0.107 dm^3 (or 0.13%) (Std. Dev 2.913 dm^3, 95%-Confidence Interval [- 0.720 dm^3; 0.935 dm^3]) is not statistically significant (paired t-test; $t(49) = 0.260$, Sig(2 - tailed) = 0.796). In addition, as depicted in Figure 2B the relative deviation (Dev%) becomes smaller when the log's volume increases which means that the estimation is more accurate for bigger logs (Dev% (Vol < 75 dm³) = ± 8%; Dev% (Vol > 150 dm) ≤ 3%).

According to the device´s product specifications the operational temperature ranges from 0 to 50 ° C (GeoSLAM Ltd., 2018). In addition, the product specifications indicates that the device´s protection class is IP 54 (GeoSLAM Ltd., 2018). This implies that the use of this device is constrained by weather conditions, eg., heavy precipitations or freezing temperatures. Another important limitation of PLS in forest applications and timber-logging measurements is its susceptibility to airborne dust. In this study, the logs were scanned near to a sandy terrain in which the air was quite dusty, which was later observable in the point cloud. In particular, the dust in the air created salt-and-pepper noise which requires additional filtering prior to the digital measurement process. Under such conditions the samples result in unsharp surfaces of the scanned object which hinders object extraction, log modelling and any further analyses. Nevertheless, the Cloud Compare software provides several tools such as the "local surface model" or "number of samples per node" to solve this problem in most cases, allowing for log volume to be estimated accurately.

4. Conclusions

Concluding the analyses and results of this study, the use of PLS applied to SLAM technology provides accurate results when estimating the volume of the logs under realistic timber logging conditions. Errors in the point cloud, resulting from dusty air when taking the samples can be solved using filters and robust algorithms to reconstruct the log surfaces virtually.

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