D5.3 Evaluation of the MLS-derived point cloud inside the forest using IMU, GPS, and SLAM

**Advanced_SAR**
Advanced Techniques for Forest Biomass and Biomass Change Mapping Using Novel Combination of Active Remote Sensing Sensors

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<td>Partner in lead</td>
<td>FGI</td>
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<tr>
<td>Authors</td>
<td>Xinlian Liang, Antero Kukko, Juha Hyvppä</td>
</tr>
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<td>Reviewed by Coordinator</td>
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- PU = Public
- PP = Restricted to other programme participants (including the Commission Services)
- RE = Restricted to a group specified by the consortium (including the Commission Services)
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Executive Summary (public)

Mobile laser scanning (MLS) systems have shown great potential in the collection of large forest plots. Preliminary research has demonstrated MLS can provide accurate information for basic tree attributes estimation. However, it is not clear what the performance of MLS in the estimating advanced tree attributes, such as stem curves. This topic is studied in this work package. In order to understand the MLS performance in the context of state-of-the-art techniques, the MLS performance is evaluated in comparison with statistic TLS performance where TLS is understood as the best possible data source in terms of accuracy.
1. Summary

Reference data collected from sample plots are fundamental parameters for forest environment monitoring and studies. Conventionally, reference tree attributes are collected on permanent sample plots, e.g. a circular area with a radius of approximately 10-15 m. Sample plots are typically small in size because it is very demanding and mostly impractical for forest inventories to collect reference data on circular plots with radii larger than 10 to 12 m using conventional measurement methods, especially if the stem count per hectare is high. In addition, the number of sample plots is often limited due to the labor-intensity, time-consuming and expensive field measurement. In areas there is not enough references, the coefficient of determination of e.g. the National Forest Inventory data, based on Landsat, has been close to zero. In reality, large numbers of sample plots and plots in larger size are desirable because such ground references not only provide a more accurate and comprehensive understanding of the forest environment but also make the registration of ground references and airborne remote sensing data easier.

The automated measurement of tree parameters using point-cloud technology has been a research focus for a decade. Terrestrial Laser Scanning (TLS), also known as ground-based LiDAR, has been shown to be a promising technique for forest field inventories at the plot level [1], [2].

The main advantage of using TLS in forest field inventories lies in its capacity to document the forest in detail. Research has shown that TLS can automatically provide accurate tree attributes that are measurable utilizing conventional tools (e.g., calipers and measuring tapes), such as tree locations and diameter-at-breast-height (DBH) [3]–[7], and tree attributes that are not measurable non-invasively utilizing conventional tools, such as stem volume [8] and biomass [9]. In addition, TLS data also permit automated time series analyses [10].

The limitation of applying TLS in mapping large forest plots lies in its limited mobility. TLS is placed on a tripod during scanning. Operator needs to carry and move all equipment between scanning locations, which can be very physical demanding in forest environment. The other restriction of TLS is the limited operational range. Most of off-the-shelf TLS hardware has a maximum measuring range from 70 to 150 m, up to 300 m. However, in typical forest conditions, the effective measuring distance is about 20-30 m because of occlusion effects. Point cloud data become sparse at places beyond that range and the tree parameter estimation become consequently very difficult. To compensate this limitation, several scan positions are needed and the registration of several scans using artificial targets becomes necessary, which increases the cost and reduces the speed in field measurements.

Laser scanning has recently been put on moving platforms to build MLS systems and is being studied for forest mapping applications. The platform is usually a car in the urban environment and an all-terrain-vehicle (ATV) in forest environment. The positioning and navigation system typically includes a Global Positioning System (GPS) receiver and an inertial measurement unit (IMU).

The main advantage of applying MLS for forest measurements lies in its rapid data collection. Within an equal time frame, the area that can be investigated by utilizing MLS is significantly larger than the area investigated with TLS. It was estimated that an area covered by MLS in 15 min would take a whole day for statistic TLS to measure [11]. In addition, the MLS has an multi-view geometry [11], where the viewing angle between a target and the MLS constantly changes since the MLS is moving all the time. This theoretically compensates the problem of occlusion effects in the single-scan TLS.

The data collected by MLS systems is less precise in comparison with TLS because positioning errors from GNSS and IMU systems propagate in the MLS point cloud. In this task, the point cloud from MLS in forest environment was collected in test areas, and the application of MLS in the estimation of tree attributes are
studied and evaluated. The objective of this task is to understand the performance of MLS in real forest conditions and to point out further research topics.

2. Study area and data acquisition

2.1. Study area

The study area is located in our test field, Evo, Hämeenlinna, Finland (61°13’ N, 25°6’ E). The area belongs to the southern Boreal Forest Zone and comprises approximately 2000 ha of managed forest (test site covers an area of 4 km x 6 km). The elevation of the area varies from 125 m to 185 m above sea level. Scots pine (Pinus sylvestris, L.) and Norway spruce (Picea Abies, L.) are the dominant tree species in the study area, contributing 44.7% and 33.5% of the total volume, respectively. The percentage of deciduous trees is 21.8% of the total volume.

In the task, several field experiment areas were established. The terrain is most flat. The main tree species growing in the test area is Scots pine (Pinus sylvestris). A few Norway spruce (Picea abies) and Silver and Downy birch (Betula sp.) are also present.

The other test area is a 50-by-50 meter square forest, dominated by pine trees. The plot has slightly hilly terrain.

2.2. Data acquisition

Test area was divided into two sub-sets. In the test area I, only MLS data were collected. In the area II, both MLS and TLS data were collected.

2.2.1. MLS and TLS data acquisition

Test I – Data collection was carried out using Roamer system with the following scanning parameters: 122 kHz PRF, 49 Hz scan frequency, and vertical scanning. The system was mounted on a 6-wheel all-terrain vehicle (ATV), and the laser operation wavelength was 785 nm. The test area was covered by driving through it multiple times from different directions. The full data set consists of 72 blocks of data, 3000 profiles in each. The angular resolution within a profile was 10000pts/360°, (0.6 mrad) meaning 6.2 mm point distance at 10 m range from the scanner. The data collection took about 45 minutes. Figure # shows the Roamer system used for the data collection in Test I, and Figure 1 illustrates part of the point cloud data collected. The point cloud is colored by the point elevation.
Figure 1. System and Data point cloud from the test I MLS collection. Point cloud is colored by the point elevation. Tree trunks are clearly detectable for accurate stem model estimation. Roamer system on top of an ATV was used for data acquisition. The scanner was operated in vertical position to capture the tree tops at approximately 15 mm point spacing. (Photo by H. Kaartinen)

Test II – consists of a somewhat hilly terrain with mature pine forest which has a size 0.4 ha. Data collection was carried out using RoamerR2 system mounted on a 6-wheel ATV. The used laser wavelength was 905 nm. The achieved angular resolution within a profile was 0.77 mrad yielding point separation of 7.7 mm at 10 m range from the scanner. The data collection comprises in total of 32 block files, and the data acquisition took less than 30 minutes.

TLS measurements were performed using Faro Focus3D X 330 (Faro, USA). The scanner has with 13 scans around the plot (Figure 2). The scanner used was, wave length 1550 nm and beam divergence 0.19 mrad. Artificial reference targets (spheres) were used to register scans.

Figure 2. TLS measurements in test sit II
3. Data processing
MLS data are automated processed to estimate stem curve of individual standing trees. The reference data are stem curve manually measured from the static TLS point cloud. The MLS-derived curves are compared with the reference data and are evaluated.

3.1. Reference data measurement
Stem curves of standing trees are measured from statistic TLS. Ground points were first classified in TerraScan software (Terrasolid Ltd., Finland). The algorithm is based on triangulated irregular network (TIN) approach that in short uses local low points as initial points and starts growing a network of triangles according to the given parameters. (For more details, see Axelsson 2000). In this study, the parameters were optimized to produce a surface model that is sufficiently dense and follows also the smaller variations of terrain, yet excludes extreme noise.

Every individual tree was cut out of the point cloud and the stem curve was measured by fitting a circle to cross-sections on every given heights, i.e., 1 meter interval. The circles were fitted manually using visual interpretation. The measuring continued up the stem as long as there were a sufficient amount of points to be recognized as a stem cross section. Figure 3 shows an example of the stem curve measurement.

![Figure 3. The stem cross measurement](image)

3.2. MLS data processing
MLS data sets we post-processed for trajectory (X, Y, Z, Roll, Pitch, Heading, time) based on the observations stored by the positioning systems in the MLS, and GNSS base station data. The laser data was georeferenced to point clouds, and filtered for noise (small clusters of points and ranging errors), and classified to extract ground surface. MLS point clouds were further processed using robust stem modelling methods [11] and stem curves were automated estimated.

3.3. Evaluation
The stem curves of standing trees are manually measured from the multi-scan TLS data. This is the most accurate measurement could be achieved without felling trees down, and this is the only option at this moment since the permission to cut the trees down is not available. This process is still going on.

When the reference data are ready (in the second half of 2015), the stem curve automated measured from MLS will be compared with the manual curve measurements at the tree level. The accuracy of the estimations will be evaluated in terms of the bias and root mean squared error (RMSE). The accuracy of
MLS-derived stem curve will be studied using these evaluation parameters. These results will give a more clear understand of the performance of professional MLS under forest canopies.

4. Further development

The stem curves of individual trees have been automated extracted from mobile laser scanning data. The reference stem curves are now being extracted from static TLS which is the most accurate measurement without cutting trees into pieces. The quality of MLS data will be evaluated by comparing automated estimates and manual measurements.

5. Reference