Estimation of above ground biomass in boreal forest using ground-based Lidar

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Abstract. Assessing above ground biomass of forest is important for carbon storage monitoring in boreal forest. In this study, a new model is developed to estimate the above ground biomass using ground based Lidar data. 21 trees were measured and scanned across the plot area study in boreal forests of Alberta, Canada. The study area was scanned in the summer season 2014 to quantify the green biomass. The average of total crown biomass and green biomass in this study was 377 kg (standard deviation, S.D. = 243 kg) and 6.42 kg (S.D. = 2.69 m), respectively.

1. Introduction
Forest ecosystems deliver many viable goods and services, invaluable for human life [1], [2]. Forests provide ecological services such as regulation of water regime, preservation of soil quality, prevention of soil erosion, regulation of climate, protection of habitats for other species and conservation of biodiversity [3]. Forests are also the basis of industries such as timber, processed wood and paper, rubber, and fruits. They also help ecotourism by offering scenic and landscape services [3]. The proper assessment of forest benefits requires accurate calculation of forest structure that is described by parameters such as total leaf area and biomass. The amount of total leaf area defines functions such as radiation absorption, precipitation interception, photosynthesis [4] and the exchange processes between the atmosphere and the land surface [5]. Estimation of above ground biomass (AGB) at local, provincial and worldwide scales is basic for assessing global carbon storage and evaluating ecosystem reaction to environmental change and anthropogenic interferences [6], [7]. The study of the interrelation of biomass and leaf area is a strong tool for development of forest growth model [8], [9]. Due to the quantity of vegetation material in the forests retrieving the detail from structural elements by direct measurements is impractical. Remote sensing technologies such as LiDAR enable automatic collection of a detailed database on the forest structure and calculation of parameters such as leaf area and biomass [10]-[13]. Small-footprint discrete return ground based Lidar systems provide a high precision since data at individual tree level can be described [14], [15]. This paper studies the interrelation between biomass and leaf area in Canadian boreal forest using ground based LiDAR.

2. Study area
The study area in this project is a 50 m × 50 m plot located in northwestern Alberta, Canada (latitude: 56° 44' 24" N; longitude: 118° 20' 24" W; altitude: 871 m) at the Peace River Environmental Monitoring Super Site (PR-EMSS) which consist of an old-growth stand of Trembling Aspen (Populus tremuloides) with a broad leaf deciduous canopy. The supersite is situated in the joint industry-research forestry region for Ecosystem Management Emulating Natural Disturbance (EMEND) for large-scale variable preservation boreal forest harvest experimentation. Figure1 shows
the location map. At the study area, we measured 21 trees manually and scanned by ground Lidar. The mean value of tree heights by Lidar was 25.48 m (standard deviation, S.D. = 1.59 m) and mean value of diameter at breast height (DBH) was 38.6 cm  (S.D. = 7.31 cm).

3. Material and methods
In this study, the point cloud data were collected from a high-elevation aspen stand using the terrestrial laser scanner Leica Scan Station C10. The plot scanning is shown in figure 2a. To avoid the shadowing effect and collect a complete point cloud, the site was scanned from five locations with 4.5 mm sampling spacing at 50 m. Meanwhile, five targets were set as reference points to align the five scans. The targets’ locations were made observable in most of the scans. The experiment layout for locations is shown in figure 2b. The black signs represent the scan locations of Leica device. The characteristics of C10 are summarized in Table 1. Scanner locations are indicated alphabetically in the order of gaining. T1 to T5 shows the location of reference targets with a black dot. In this plot, north is shown. The distance between the points is marked in the figure. All five scans from the plot study were co-registered together using four standing targets. The collection, registration, and processing of the TLS point cloud data were performed in the Cyclone 8.1 software and MATLAB R2013b. The study area was scanned in summer 2014.

![Location of study area in Boreal Forest NW Alberta.](image)

**Figure 1.** Location of study area in Boreal Forest NW Alberta.

![Plot scanning with Leica C10 (a) and Schematic TLS field setup for plot study (b).](image)

**Figure 2.** Plot scanning with Leica C10 (a) and Schematic TLS field setup for plot study (b).

| **Table 1.** Leica Scan Station C10 scanner settings for data acquisition. |
|--------------------------------------------------|
| Beam divergence     | 0.1mrad |
| **Range**           | 0.1-300m |
| **Azimuth range**   | 0–360° |
| **Max Zenith range** | 270 |
| **Acquisition time** | 6 min 45 s |
| **Data acquisition rate** | 50000 Samples/sec |

In this study plant area (PA) of individual trees was estimated in a developed algorithm in MATLAB. Leaf area (LA) is defined as the amount of live leaf material in trees with the unit of m² [16], [17]. The algorithm is applied on co-registered TLS return from five scanning stations based on contact frequency method.
In this study the tree height and DBH were also measured in the field manually, using laser Rangefinder Model and DBH measuring tape respectively (figure 3). Illustration of LiDAR measurements from one of the tree is shown in figure 4.

![Field measurement devices](image1)

(a) Laser Rangefinder
(b) DBH measuring tape

**Figure 3.** Field measurement devices: a) laser Rangefinder and, b) DBH measuring tape.

![LiDAR measurements](image2)

(a) Projected plant area of individual tree top view
(b) Side view

**Figure 4.** LiDAR measurements: Projected plant area of individual tree top view (a), side view (b).

4. Results and discussion
The relationship between Lidar data and field data is shown in figure 5. There is a strong correlation ($r = 0.98$, $p<0.001$, $N=21$) between DBH calculated by Lidar and DBH calculated by field measurement while this correlation in tree height data is lower ($r = 0.80$).
Total biomass calculated for individual trees in plot study is related nonlinearly to DBH and height in figure 6.

As figure 6a shows there is a strong correlation (r = 0.98, p<0.001, N=21) between total biomass and DBH. The correlation between total biomass and tree height is r = 0.77. Adding tree height as a predicting parameter to calculate biomass resulted in a slight decrease of the regression coefficients $R^2$.

Crown biomass (branches and leaves) and leaf area are related to DBH and height in figure 7. Leaf area is calculated for each single tree in developed algorithm in MATLAB.
The results in the figure 7 shows leaf area and crown biomass are strongly linearly related (r= 0.82, p<0.001, N=21) for both models.

5. Conclusion
This paper presented a new method for estimation of above-ground biomass which was applied to a point cloud data from ground LiDAR. The terrestrial data was collected from a boreal forest at Peace River, Alberta, Canada during summer in 2014.

6. References
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