Airborne LiDAR based forest inventory in Bangladesh for REDD plus MRV: scope and potentiality

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Abstract
Nowadays, the accurate measurements of carbon stock for carbon trading in REDD plus (Reducing Emissions from Deforestation and Forest Degradation in Developing Countries) countries are going highly demanding. IPCC (Intergovernmental Panel on Climate Change) Tier 3 level accuracy for estimation of emissions from deforestation and forest degradation requires detailed national inventory of key carbon stocks, repeated measurements and modeling. Present study has been carried out to know scope and potentiality of the airborne LiDAR based forest inventory in Bangladesh for REDD plus MRV (monitoring, reporting and verification). Here we supposed a hybrid method where the integration of airborne LiDAR data with satellite imagery and ground truth data based forest inventory in Bangladesh. As the forest of Bangladesh is highly dynamic and inaccessible due to hilly and mountainous area, this method will give an accountable and transparent report of carbon stock. We also highlighted the limitation of this approach in a developing country like Bangladesh due to poor economic and technical condition. Till now there is no record of application of airborne LiDAR system for forest inventory in Bangladesh. Finally, we recommended that the Forest Department of Bangladesh with financial and technical help from international organization can do a pilot project in Sundarban Mangrove Forest.

Keywords: LiDAR, REDD, remote sensing, Bangladesh, Forest inventory

1. Principle of airborne laser scanning (ALS) system
Airborne laser scanning, LiDAR (Light Detection and Ranging) is an optical remote sensing technology which measures the properties of scattered light radiating from of a distant target. An airplane or helicopter-mounted sensor sends laser pulses towards ground and records the elapsed time between beam launch and return signal registration. A typical LiDAR system consists of three main components: a Global Positioning System (GPS) to provide position information, an Inertial Navigation System (INS) for attitude determination and a laser scanner to provide the range from the laser-beam firing point to its footprint (Bang et al. 2008). Some of the LiDAR pulses are reflected from tree canopy, trunks, branches, leaves or lower vegetation, but they also penetrate through the canopy layer reaching the ground, thereby profiling a three-dimensional point cloud image of the forest (Gautam and Kandel 2010). In addition, by varying the wavelength of the light transmitted, pulse frequency and duration, and other factors, LiDAR can be used in a variety of applications to detect numerous substances.

There are two main categories of airborne LiDAR systems: small-footprint discrete-return LiDAR and large-footprint, waveform-recording LiDAR. Small-footprint discrete-return LiDAR devices measure either one (single-return systems) or a small number (multiple-return systems) of heights by identifying, in the return signal, major peaks that represent discrete objects in the path of the laser illumination. Large-footprint waveform-recording devices record the time-varying intensity of the returned energy from each laser pulse, providing a record of the height distribution of the surfaces illuminated by the laser pulse (Li 2009). Slender than 1 meter is usually categorized as small footprint and suitable for estimation of forest attributes at stand or single tree level, whereas large footprint reaching dozens of meters are normally designed for topographical survey of planet.
Airborne LiDAR based forest inventory is two types such as Individual Tree Detection (ITD) and Area Based method. The area based method is considered the more cost-efficient approach due to its lower pulse density (<1/m²), although it needs large amounts of expensive fieldwork, compared with the individual tree detection (pulse density >5/m²) to perform accurately. Area based method also called as distribution-based method that uses the canopy height or vertical distribution of laser echoes for estimating area-based forest inventory parameters (e.g. mean height, stem number, basal area, and volume) by statistical means (Naesset 2004).

2. LiDAR technology for REDD plus Monitoring, Reporting and Verification

REDD, Reducing Emissions from Deforestation and Forest Degradation in Developing Countries, refers to “an effort to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development” (UNREDD 2010). The reason for including REDD in the carbon market is to allow developing countries to earn money simply by conserving their forests. The participating developing countries will receive a dual benefit from REDD. They can reduce their own country-specific emissions on the one hand, as well as earn money on the other by selling credits thus achieved to rich countries, helping the latter meet their own emission-reduction targets. Within the mechanism of REDD, rich countries are allowed to pay for protecting tropical forests as a cost-effective alternative to cutting their own GHG. Developed nations can buy credits from developing nations that are backed by reliably measured carbon stored in tree growth, thereby offsetting the higher cost of achieving corresponding reductions by cutting their own emissions.

The significance of estimation of accurate carbon stock in the tropical forest has been growing radically. However, due to topographical complexity with lack of up-to-date data has been a challenging task to get a cost-effective, efficient and equitable approach to meet the carbon monitoring, reporting and verification. In addition, the conventional remote sensing technique with incorrect field measurement has made it difficult to gain accurate estimations of the biomass of tropical forests. Therefore, a hybrid approach, wherein airborne laser scanning is used with satellite image and sample field measurement, is a viable solution that can increase accuracy as well as reduce cost. Such an approach is feasible because wall-to-wall LiDAR meets even higher accuracy standards that are needed in operational forest management. When followed by adaptive statistical estimation, LiDAR is able to “teach” automatic satellite data interpretation to achieve almost the same level of accuracy, even when the area covered by LiDAR is just ten percent of the total.

LiDAR, an emerging remote sensing technology, can improve the assessment of forests and make determinations of the amount of carbon stocks in a particular forest much more reliable. In addition, LiDAR technology is especially well-suited for use in the tropics, as it is less sensitive to weather conditions and sun angles than satellite imaging technology. The IPCC has proposed different levels of methodology for estimating greenhouse gas (GHG) emissions. These options are specified at different Tiers, which relate to methodological complexity. Moving from Tier 1 to Tier 3, the estimation of eligible forest carbon content requires steadily increasing accuracy, whereas the feasibility of estimation methods increases in the opposite direction. At Tier 3, higher accuracy—if it can be verified—is rewarded by a much higher compensation level per ton of carbon, due to better reliability of the assessed amount of carbon captured in forests. As well, Tier 3 estimates can be achieved and verified by adopting a LiDAR-based biomass and carbon assessment method. LiDAR-based forest inventory has become the method of choice in operational forest management.

In August 2010, Bangladesh joined in UN-REDD (The UN-REDD Programme is the United Nations Collaborative initiative on Reducing Emissions from Deforestation and forest Degradation in developing countries) as a partner country. Bangladesh Forest Department has been furnished a carbon stock inventory project for Sundarban Mangrove Forest and Eight Protected Areas. In addition, 'Sundarbans Forest Carbon Inventory-2009' conducted by Forest Department (FD) of Bangladesh under assistance from USDA Forest Service, USAID and other collaborators. The 16th UNFCCC Conference of Parties (2009) in Mexico emphasizes on the integration of indigenous
knowledge (IK) and collaboration of indigenous people to the role of conservation, sustainable management of forest and enhancement of forest carbon stock. For the successful implementation of REDD plus mechanism relies on the accurate estimation of forest carbon stock that requires that there is an effective monitoring, reporting and verification system in operation. According to the Intergovernmental Panel on Climate Change (IPCC), moving from Tier 1 to Tier 3 requires higher accuracy and Tier 3 will be rewarded by a much higher compensation level per ton of carbon, due to better reliability of the assessed amount of carbon captured in forests.

3. An overview of Bangladesh Forest

Bangladesh occupies a unique geographic location (20°34’N – 26°38’N latitude to 88°01’E – 92°41’E longitude) – spanning a relatively short stretch of land between the mighty Himalayan mountain chain and open ocean. According to Forest Department and some other sources (Rana et al. 2009) forest cover is nearly about 2.53 million ha representing approximately 17.5% of the country’s total surface area (Figure 1, Table 1). Officially, Bangladesh Forest Department manages 1.53 million hectares of forest land of the country. Besides, 0.73 million ha of unclassed state forests (USF) are under the jurisdiction of district administration (Roy 2005). The annual deforestation rate in Bangladesh is 3.3% which is highest among the south-east Asian countries (Poffenberger 2000). Contribution of the forestry sector to Bangladesh GDP is 3.3% at current prices and about 2% of the country’s labor forces are employed in this sector (Siddiqi 2001).

<table>
<thead>
<tr>
<th>Forest type</th>
<th>Location</th>
<th>Area (million ha)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hill forest</td>
<td>Managed reserved forest (evergreen to semi-evergreen) &lt;br&gt;Eastern part of the country (Chittagong, Chittagong Hill Tracts and Sylhet)</td>
<td>0.67</td>
<td>Highly degraded and managed by the Forest Department.</td>
</tr>
<tr>
<td></td>
<td>Unclassed state forest (USF) &lt;br&gt;Chittagong Hill Tracts</td>
<td>0.73</td>
<td>Under the control of district administration and denuded mainly due to faulty management and shifting cultivation. Mainly scrub forest.</td>
</tr>
<tr>
<td>Plain land forest</td>
<td>Tropical moist deciduous Forest &lt;br&gt;Central and north-western region (Dhaka, Mymensingh, Tangail etc.)</td>
<td>0.12</td>
<td>Mainly Sal forest but now converting to exotic short rotation plantations. Managed by the Forest Department.</td>
</tr>
<tr>
<td>Mangrove</td>
<td>Sundarbans &lt;br&gt;Southwest (Khulna, Satkhira)</td>
<td>0.57</td>
<td>World’s largest continuous mangrove forest and including 0.17 million ha of water.</td>
</tr>
<tr>
<td></td>
<td>Coastal forest &lt;br&gt;Along the shoreline of twelve districts</td>
<td>0.10</td>
<td>Mangrove plantations along the shoreline of 12 districts. Managed by Forest Department.</td>
</tr>
<tr>
<td>Village forest</td>
<td>Homestead Forests all over the Country</td>
<td>0.27</td>
<td>Diversified productive system. Fulfill majority of country’s domestic timber, fuelwood and bamboo requirements.</td>
</tr>
<tr>
<td>Plantation in tea and rubber gardens</td>
<td>Chittagong Hill Tracts and</td>
<td>0.07</td>
<td>Plantations of various short rotation species (mainly</td>
</tr>
</tbody>
</table>

Table 1 Forest types and areas in Bangladesh
5. Sampling design followed for forest inventory in Bangladesh

The last National Forest Inventory (NFI) in Bangladesh has been carried out in 2005-2007 by following systemic sampling method with technical suggestion from FAO Forest Resources Development Service (FOMR). “Tract” was regarded as a sampling unit for ground truth data measurement. 299 tracts or samples site was the result for field measurement after following systematically distribution of sample sites with an interval of 15 minutes latitude and 10 minutes longitude where the sample coordinates represent the South-West corner of the tracts (NFTRA 2007). Each tract represents a square of 1km*1km (1km²) contains 4 plots (the dimension of 20m*20m or 0.5ha). The plot orientation in each tract was such as Plot # 1 North-ward, Plot # 2 East-ward, Plot # 3 South-ward and Plot # 4 West-ward. If the plots are in the land use class of “Forest”, circular subplots was established to collect data on tree regeneration. As tree diversity is very high with respect to wide variety of size, age and species composition, it was recommended that Concentric Circular Sample Plots (CCSPS) are used to tallying trees (NFTRA 2007; van Laar and Akcal 1997). A circular plot that was regarded as subplot with radii of 3.99 m (50m²) that was placed with their center at 5m, 125m and 245m from the plot starting point along the plot central axis (see Figure 2). In addition, the CCSP is easy to locate in a rugged and fragile topography like in Bangladesh and it has less edge effect as compared to square/rectangular plot. All the living trees above the diameter of 5cm was tallied and measured within the radius of the circular plot.
4. Sundarban Mangrove Forest, a priority area for LiDAR based forest inventory
The Sundarbans is the single largest continuous mangrove forest of the world with an area of about 6,01,700 hectare which is 4.07% of total land mass of the country and 40% of total forest land. Sundarban harbours 334 species of trees, shrubs and ephyphites and 269 species of wild animals. The forest inventory of 1998 exhibits that there are 12.26 million cubic meter timber is available from the species of Sundri (Heritiera fomes), Gewa (Excoecaria agallocha), Keora (Sonneratia apetala), Raen (Avecennia officinalis), Dhundul (Xylocarpus granatum), Passur (Xylocarpus mekongensis) etc with 15cm and above diameter (NFTRA 2007). Sundri is the most important tree species in the Sundarban which is distributed over 73% of the reserve. Extent of Sundri is followed by Gewa (Excoecaria agallocha), Raen (Avecinnia offecinialis), Passur (Xylocarpur mekongensis), Keora (Sonneratia apetala) etc. There are some other non-wood forest products like Golpata (Nypa fruticans), honey,
wax, fish, crab etc which are also of high value. Considering the importance of preserving biodiversity of the Sundarbans, the UNESCO had on December 6, 1997, declared the forest as the 798th ‘World Heritage Site’. It is also one of the two RAMSAR sites of the country.

However, mangrove forest is facing severe problem including over exploitation of forest resources, conversion of forest stand to shrimp pond. In addition, nowadays, salinity intrusion due to declining fresh water flows is also going a big issue. Furthermore, tree mortality especially top dying of Sundri tree makes an uncertain future of mangrove forest. Poor forest management strategy with weak law enforcement reducing the productivity of mangrove forest.

A good forest management plan is necessary for Sundarban mangrove forest which is ecologically suitable, economically feasible, and socially acceptable that achieves the core objectives of sustainable forest management. Till now there is no record of application of airborne LiDAR system for forest inventory in Bangladesh. Therefore, an integrated approach like as LiDAR mapping in this forest is recommended. A area based LiDAR inventory is recommended in Sundarban mangrove forest for accurate carbon estimation for REDD plus monitoring, reporting and verification. The strength of area based method lies in their robustness, relative simplicity, lower computational requirements and proven ability to generate unbiased estimates of dynamic and inaccessible Sundarban mangrove forest attributes including, carbon stock, basal area, volume, mean diameter and mean height.

6. Potentiality and advantage of LiDAR application for forest inventory in Bangladesh

Forest inventory in tropical countries like Bangladesh is quite difficult and challenging. Due to heterogeneous characteristics of forest, it takes long time and more costly for measurement of forest resources. In addition, the access to the forest area is also difficult due to steep terrain and hilly area. Remote sensing technique is an important way to measure the forest resources without entering the forest. However, conventional remote sensing technique is not efficient for measurement of forest resources in hill forest of Bangladesh. Airborne laser scanning is an active remote sensing technique that permits observation of the vertical structure of forest. LiDAR data has a great advantage compared to conventional optical remote sensing data/imagery, which suffers from saturation and only shows the topmost layer of the vegetation, while laser pulses penetrate through even a dense canopy.

LiDAR is able to meet the demanding accuracy requirements of operations planning better than any previous technology, also in large-scale forest inventory. As species diversity is very high in Bangladesh, the accurate measurements of carbon stock in each type of forests are very necessary. Therefore, the greatest advantage and potentiality of LiDAR is that it is highly capable of monitoring three-dimensional forest structure. Forest carbon content can be measured very accurately from LiDAR pulse with describing estimated tree height, above-ground biomass, timber volume and crown parameters. LiDAR can also measure forest biomass from individual trees to vegetation on a local, regional and national level.

LiDAR technology will be well-suited for forest inventory in Bangladesh as it is less sensitive to weather conditions and sun angles than satellite imaging technology. In addition, the integration of Airborne Laser Scanning (LiDAR), satellite image and field measurement with advanced statistical models on sample plots, it becomes most powerful tool for sustainable forest resource management. Finally it is already proved that the LiDAR based carbon stock measurement is more reliable in tropical, temporal and other regions (Figure 3) (Næsset 2009)
Some of advantages of LiDAR technology are given below
1. LiDAR based forest inventory reduces the costs for large areas
2. LiDAR gives very high resolution digital elevation information for large forest areas than conventional Digital Elevation Models (DEMs)
3. LiDAR pulse can penetrate very dense forest vegetation
4. LiDAR data can collected during day or night under clean weather condition and less suffer from saturation problem
5. Nowadays, integration of LiDAR data with aerial images and field measurement are the best way of forest resource management.
6. The interpreted LiDAR data layers are easy to integrate with other form of data in GIS analysis.
7. LiDAR data helps pinpoint locations where filed data will be useful

7. Limitation of LiDAR application for forest inventory in Bangladesh
1. High costly technique on a per-acre basis than aerial photography considering Bangladesh perspective
2. Require skilled manpower and software for processing and analyzing LiDAR data sets
3. Although the growing use of LiDAR technology for forest resource management or forest inventory, all the parameters cannot measured by using LiDAR data and the models are not always understood well enough to generalize final findings from local studies.
4. In the tropical forest like forest of Bangladesh where density of vegetation is so high that dense undergrowth may be confused with bare ground.
5. From the previous studies, it was found that vegetation height calculated from LiDAR data is less than the height obtained through aerial images and field measurement.
6. Poor economic condition of Bangladesh
7. Logistic problem
8. Political and bureaucratic problem

8. Concluding remarks
Above all, the LiDAR technology with satellite imagery and field measurement based forest inventory for accurate carbon stock measurement and robust benefit sharing with collaboration of local and
indigenous people has significant prospect in Bangladesh. The Forest Department and Government of Bangladesh with financial or technical help from international organization can make a prosperous and effective management of forest resources. For Tier 3 level REDD plus monitoring, reporting and verification of forest resources, this hybrid method (LiDAR with satellite imagery and ground truth data) will be very effective in Bangladesh. This integrated system will be able to produce consistent reports and a source of verification for any geographic area in Bangladesh.

9. Reference