REFINING FIA PLOT LOCATIONS USING LIDAR POINT CLOUDS

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Abstract—Forest Inventory and Analysis (FIA) plot location coordinate precision is often insufficient for use with high resolution remotely sensed data, thereby limiting the use of these plots for geospatial applications and reducing the validity of models that assume the locations are precise. A practical and efficient method is needed to improve coordinate precision. To address this need, the USDA Forest Service's Remote Sensing Steering Committee has funded an applied research project to evaluate alternative methods that capitalize on lidar data availability to improve plot location precision. We are exploring two methods to improve plot location precision—a manual interpretation technique and a 3D surface model matching routine using FIA tree data and lidar collected in northeastern Minnesota.

The Forest Inventory and Analysis (FIA) program of the USDA Forest Service maintains an extensive network of field plots. Data collected on these plots at regular time intervals are used to provide unbiased statistical estimates of forest resources across the USA and US territories. The established sample plot density was designed to produce estimates for county- or multi-county areas, and to support informed decision-making at the strategic level with prescribed levels of precision. Tactical decision-making by forest managers and ecological analyses by landscape scientists necessitate that plot-level data be combined with high-resolution ancillary data in support of small-area estimation techniques (e.g., Goerndt and others 2013). However, creating accurate linkages between plot-level data and high-resolution data requires precise plot locations, or, minimally, accurate co-registration between datasets.

FIA plot coordinates have been obtained using several methods depending upon the technology available at the time of the field visit and available funding. Methods have evolved over time, including location of plots by pin-pricking aerial photos and transferring to corresponding digital ortho quads, use of early GPS units with "Selective Availability" (intentional degradation of public GPS signals by the U.S. Department of Defense), and, lately, recreation grade and survey grade GPS units. These coordinates have been used primarily to efficiently relocate plots during return visits.

Recreational grade equipment has been deemed sufficient for navigational purposes to and from plots. GPS methods vary substantially in their horizontal (locational) precision and also vary with location, terrain, and canopy cover conditions. In many states (e.g., Minnesota), recreation grade GPS receivers are believed to produce horizontal accuracies within 8–10 m RMSE in medium to heavy canopy (USDA Forest Service 2015), which are inadequate for co-registration with high resolution imagery.

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In the absence of highly precise (i.e., survey grade GPS) coordinates, there is a need to enhance the precision of existing forest inventory plot location coordinates to better correlate with digital imagery and other geospatial data (Gobakken and Nasset 2009).

Although efforts are underway to upgrade plot coordinates to survey grade precision for selected states and special study areas, a nationwide implementation is not under consideration. Except for the Pacific Northwest FIA region, acquiring plot coordinates with survey- or even mapping-grade receivers has not been made a priority for the FIA program. To address the need for higher precision FIA plot locations, the Forest Service's Remote Sensing Steering Committee has funded an applied research project in which lidar (light detection and ranging) point clouds will be used in an attempt to enhance the precision of FIA plot locations in northeastern Minnesota.

The State of Minnesota has complete statewide lidar coverage with acquisition dates ranging from 2008 to 2012. The primary use of these data is terrain mapping with a focus on hydrologic applications. Considering that lidar point clouds have planar coordinate registration errors consistently below 1 m, the coordinates of landscape objects, such as dominant trees identified from the lidar data are more precise than those calculated by the aforementioned methods.

We are evaluating two methods for improving FIA plot location coordinate precision—a manual approach based on human cognition, and a 3D surface matching process developed by Gatziolis (2012)—using Minnesota's statewide low density (approximately 1 return per m^2) lidar data. Additionally we are testing these methods using a moderate density (approximately 4 returns per m^2) lidar dataset collected in support of the NASA Carbon Monitoring System (CMS; Cohen and others 2013).

METHODS

Our study area extends north of Duluth and is roughly coincident with the boundary of St. Louis County. This area was selected because it is also the lidar data acquisition area for the NASA CMS study. The methods are as follows:

1. Surface model matching method (Gatziolis 2012). This method was developed using FIA data and high density lidar data with a return density of approximately 9 returns per m^2 in forests of the Pacific Northwest, USA. This project will assess the feasibility of and results obtained from using FIA plot data and lower density lidar data in Minnesota, USA.
2. Manual interpretation of FIA plot stem maps and corresponding lidar point data. Brian Wing Research Forester, U.S. Forest Service Pacific Southwest Research Station) has developed a method of repositioning a plot's location by manually interpreting tree locations from the lidar point clouds and shifting the location of the plot to match the field stem map data.

The surface model matching method compares 3D canopy surface models derived from the lidar data and the FIA plot data (Fig. 1). The lidar surface model is held stationary while the FIA model is iteratively shifted in two horizontal dimensions. For each shift a weighted correlation between the two surfaces is calculated, with weight values determined dynamically from the vegetation structure present on the plot. A pronounced maximum in the correlation raster indicates that the actual plot location has been determined. Multiple weak correlation maxima suggest that the precise plot location remains elusive (Gatziolis 2012). The inputs required by the surface matching model include FIA-collected tree location and dimensionality (e.g., crown size and shape) data, either field-measured or model-derived, and lidar data and derivatives (Table 1).

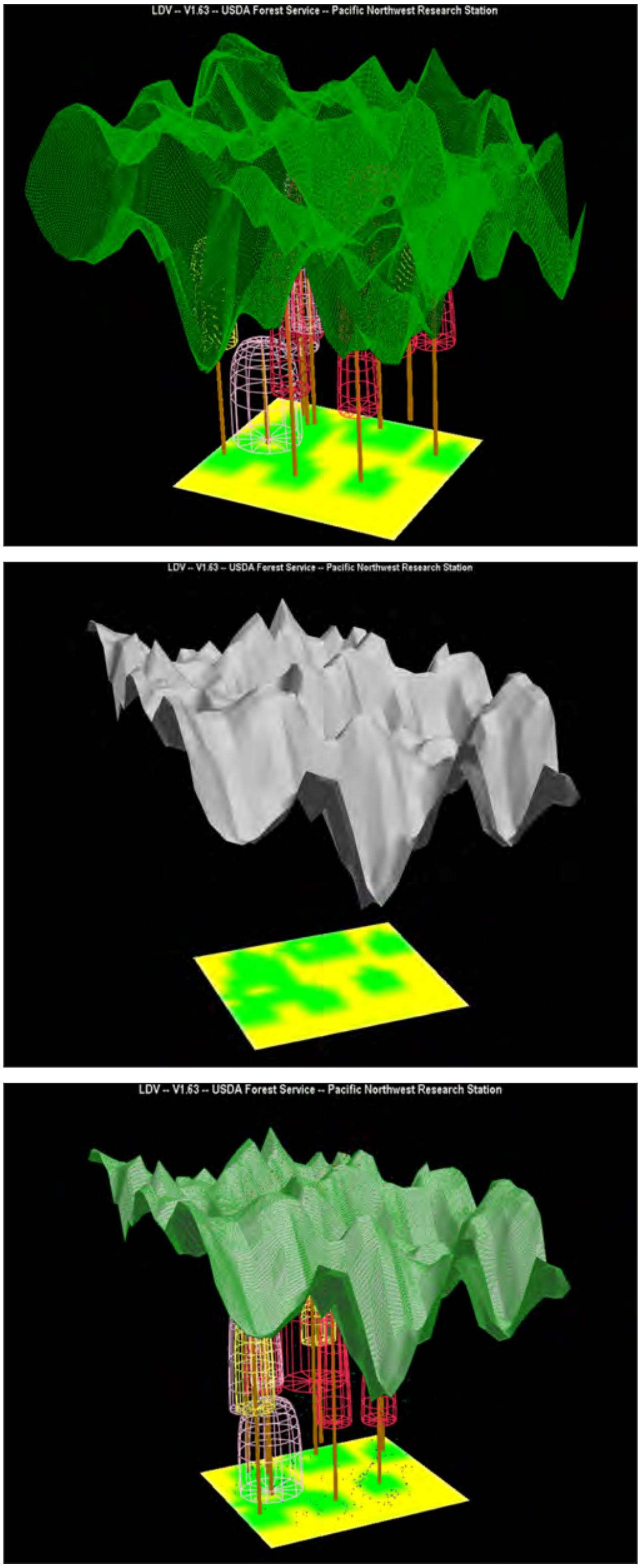
A
B
C


Figure 1—Conceptual representation of surface model matching method (Gatziolis 2012). A field-derived canopy height model (CHM) (1a) is iteratively shifted relative to a lidar-derived canopy surface height model (1b) until a satisfactory fit is achieved (1c). After fitting, new plot center coordinates are recorded from the shifted CHM.

Tree crowns that intersect a subplot but do not have a stem inside the subplot must be accounted for in the surface model matching method. This required delineation of tree crown boundaries in an area slightly larger than each subplot via a process called image segmentation. Using canopy height surface models derived from the lidar point cloud we compared segmentation results from eCognition software (Trimble Corporation; Sunnyvale, CA) and a tree crown segmentation program in FUSION (McGaughey and Carson 2003) called TreeSeg. TreeSeg is currently in development and is expected to be released in January 2016. The input canopy models were built using CanopyModel in FUSION with a 3x3 smoothing filter, with no preservation of minimum and maximum, at a 1 m cell output and with a normalized lidar LAS file as the input. The LAS files were normalized using the vendor-supplied digital elevation model (DEM). After several iterations of adjusting program settings to achieve suitable segments, both approaches produced comparable results and we elected to use segments produced by TreeSeg. The output from TreeSeg provides both a raster segmentation file and a maximum height point shapefile for each segment.

The manual interpretation method involves generating a tree stem map from the plot data using ArcMap v. 10.2.2 software (ESRI; Redlands, CA) and then overlaying the uncorrected position of the plot center with the lidar point cloud. Point clouds are visualized in the FUSION or other point cloud visualization software package. The interpreter then matches the tree stem map pattern with the trees identified in the lidar point cloud returns representing trees and shifts the plot location accordingly (Fig. 2). Manual interpretation focuses on visual cues such as the relative positioning of trees, tree heights, species-specific crown sizes and shapes, and the presence of snags.

This method was developed using a larger plot size (16.9 m radius) than the FIA subplots (7.3 m radius) and with all stems mapped, whereas in FIA subplots only trees larger than 12.7 cm d.b.h were tallied. Additionally this method has been used with higher density lidar (8–12 returns per m^2) than the data in this

Table 1—Inputs that are required by a program that attempts to match lidar point clouds to field-collected stem map data (Gatziolis 2012). An explanation of each input and how it was collected or derived is provided.

Data source	Input	Description and source
FIA tree data	Tree diameter	d.b.h. directly from FIA database
	Tree height	FIA variable 'actual height' which is a measure of a tree's length. The length and height differ depending on the amount of tree lean.
	Crown diameter	Modeled from tree diameter, crown ratio, and Hopkins Index using Forest Vegetation Simulator (FVS) Lakes States Variant equations (Dixon and Keyser 2008).
	x,y	Location of tree base relative to subplot center. Calculated from FIA measurements of distance and azimuth and corrected for declination using an online web application from NOAA's National Centers for Environmental Information.
	Crown shape	Shape on an ellipsoidal to conical gradient by tree species. Assignments of shapes were based on a majority opinion of three field-experienced foresters with regional knowledge.
	Crown base height	Height to bottom of crown. Approximated using Height – (Compacted Crown Ratio x Height). Uncompacted crown ratio would be a more appropriate choice, but it is only available on a subset of plots. As with tree heights, crown base will be impacted by tree lean.
Lidar/lidar derivatives	Lidar point cloud	LAS file containing lidar point data.
	Bare earth elevation	Vendor-delivered digital elevation model.
	Crown segments	2-D delineation of individual crown segments for each plot including some buffer space around the plot footprint. This is used to identify stems that fall outside the plot but that have crowns that would intersect the plot area. Segmentation rasters were produced by the TreeSeg function in FUSION software.

study (0.5–1 returns per m^2 for the statewide MN data, 4 returns per m^2 for the NASA CMS data). Identifying trees on this lower density data may be problematic. Using all FIA subplots in the interpretive process may compensate to a degree for the lower lidar data density.

Relative precision of plot location coordinates resulting from the two methods will be determined by comparing locations to survey- or mapping-grade GPS locations. In addition, we will evaluate the impact of refined locations on models of biomass created from FIA plot data and derivatives modeled from the lidar data. The goal is <=3 m RMSE horizontal precision for at least 80 percent of the sample plots assessed using survey-grade GPS data, and an improvement in biomass model fit using a plot-based response variable and lidar-derived predictor variables. We recognize that the success of these methods may be dependent on the canopy structure characteristics present in the plot. To help define the relationship between plot canopy structure and successful interpolation of new plot coordinates, precision metrics are being calculated for multiple plot stand structure and composition strata.

DISCUSSION

A number of challenges need to be overcome in order to generate required input data for the surface model matching program. Many tree inputs are not directly collected by FIA but can be derived from FIA data (Table 1). This requires a mix of approaches. For example, crown shapes were assigned to the species present in the study area by field foresters with regional knowledge using a combination of experience and consultation with silvicultural reference materials. FIA does not measure crown width or crown base height in the study area, but these were modeled using existing equations or by approximating from another FIA variable (e.g., using compacted crown ratio).

Statewide lidar collections are becoming more common (US IEI: http://coast.noaa.gov/inventory/#) but many are collected using pulse density that is

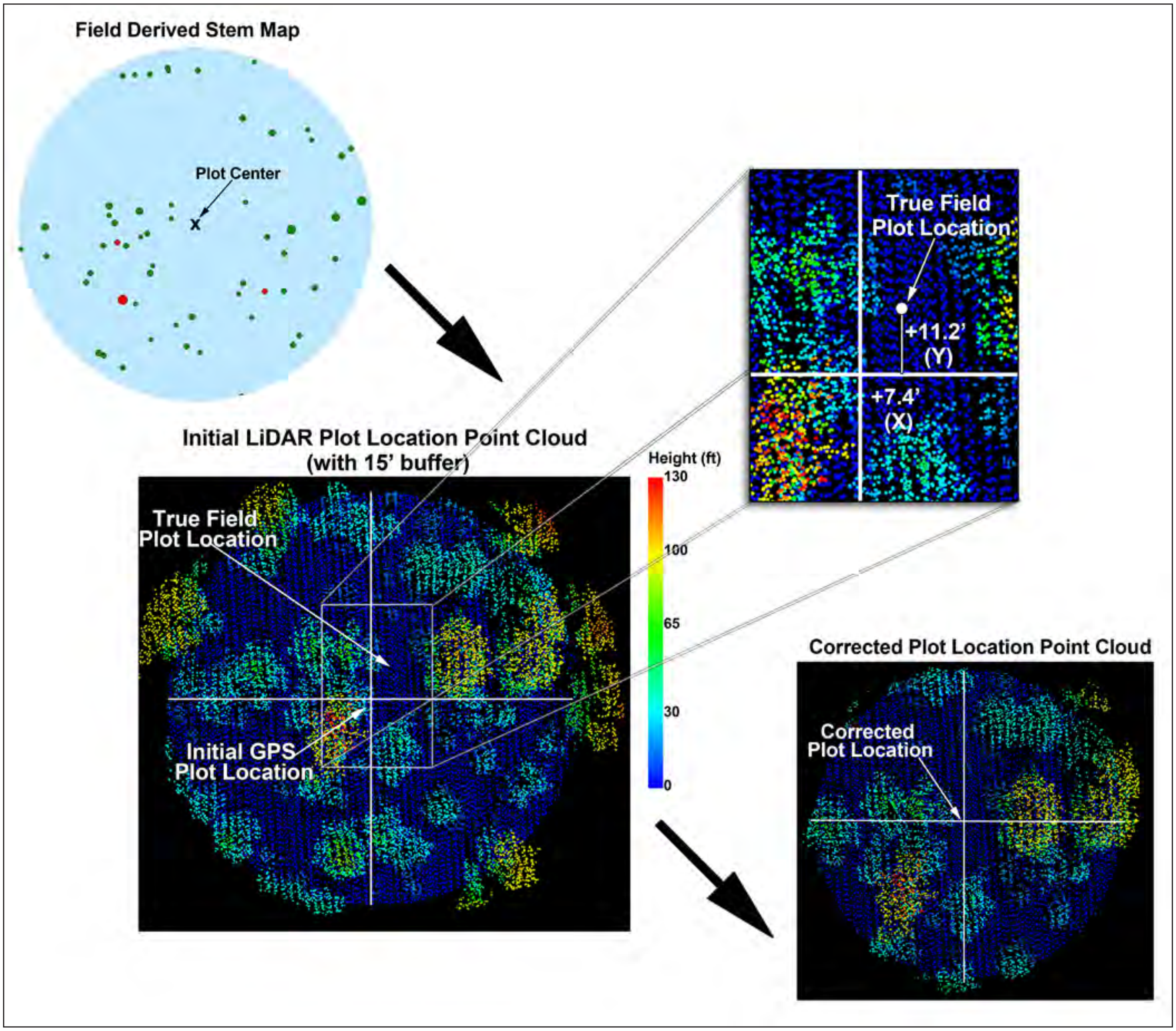


Figure 2—Methodology of repositioning plot center location using lidar point cloud data and a field derived plot stem map.

less than optimal for forestry applications (Gatziolis and Andersen 2008). This project seeks to determine whether lower pulse density lidar (i.e. 1-2 returns per m^2) has utility for improving coordinate precision of FIA plots. The lessons learned in working with lower pulse density lidar data have implications for future FIA projects that may require lidar coverage over broad-scale areas. In the case of the Minnesota statewide lidar collection, we discovered some additional challenges, such as highly variable pulse density and high variability in sidelap between adjacent flight lines. The implications of these irregularities for this project are still being explored.

The ability of these methods to improve plot locations will undoubtedly vary with canopy heterogeneity and perhaps composition. Improved precision on a subset of plots would still be valuable for remote sensing-based operation and analyses, especially if that subset is representative of the larger forest population or for plots with heterogeneous composition or structure for which improvement in location coordinates provides more benefit.

In summary, we are providing a status report on an applied project that is exploring one automated and one manual method for co-registering field plot locations with lidar data. Finding good matches between in situ and lidar data holds promise for improving the precision of field plot locations—if technical limitations can be overcome. In addition to testing two methods, we will be replicating the study with a higher-pulse density lidar collection and then validating the results against high-precision GPS coordinates and exploring the impact of improved co-registration on biophysical models. We aspire to provide recommendations for future lidar acquisitions and GPS coordinate data collection to improve the precision of FIA plot locations.

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FOREST INVENTORY WITH LIDAR AND STEREO DSM ON WASHINGTON DEPARTMENT OF NATURAL RESOURCES LANDS

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Abstract—DNR's forest inventory group has completed its first version of a new remote-sensing based forest inventory system covering 1.4 million acres of DNR forest lands. We use a combination of field plots, lidar, NAIP, and a NAIP-derived canopy surface DSM. Given that height drives many key inventory variables (e.g. height, volume, biomass, carbon), remote-sensing derived height information provides a powerful tool to make fine scale inference about height related forest attributes. Predictions can also be aggregated to sub-stand, stand, or strata levels. Remote-sensing derived forest attributes can also be used to automate stand delineation, a capability that we incorporated into our inventory system following object-oriented segmentation with eCognition software.

Our sampling design is closely related to the FIA plot design (paneled hexagonal grid), with slight modifications to the plot and grid layouts to accommodate remote sensing auxiliary variables, and to provide greater flexibility in adapting to changes in funding for field measurements. Modifications include (e.g.) using 1/5 acre fixed plots, survey-grade plot positioning with Javad GNNS units, and providing extra panels in each hex grid cell.

Our presentation will provide greater detail about our new inventory system, while describing key technical hurdles we overcame in moving a technology out of a (mostly) research mode and into an operational framework. Examples include merging a patchwork of remote sensing data, processing and managing tens of terabytes of point clouds, and distributing final products to our users. We also discuss hurdles that we have not yet overcome in an effort to motivate discussions which will benefit us and others who work to operationalize remote-sensing based methods.

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