

A GIS-BASED TOOL FOR ESTIMATING TREE CANOPY COVER ON FIXED-RADIUS PLOTS USING HIGH-RESOLUTION AERIAL IMAGERY

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Abstract.—Recent changes to the Forest Inventory and Analysis (FIA) Program’s definition of forest land precipitated the development of a geographic information system (GIS)-based tool for efficiently estimating tree canopy cover for all FIA plots. The FIA definition of forest land has shifted from a density-related criterion based on stocking to a 10 percent tree canopy cover threshold. This definitional change required a consistent method of estimating tree canopy cover, which is now a core FIA variable, using a combination of field-based and image-based assessments. In order to accomplish the image-interpretation task for thousands of plots annually, the FIA program, working in collaboration with the Remote Sensing Applications Center, developed a GIS-based canopy cover tool. Design considerations for the tool include the following: desired precision of the tree canopy cover estimate, seamless use across regions, compatibility with the existing Forest Service streaming image technology, and ease-of-use for image interpreters. Data from this image interpretation effort will not only serve the needs of FIA, but will also be used to update the National Land Cover Dataset tree canopy cover data layer.

INTRODUCTION

With the release of Forest Inventory and Analysis (FIA) Field Guide 5.0, the FIA program began collecting canopy cover information (specifically, percent canopy cover) on all plots. To complement the new field-based canopy cover protocols, the national prefield task team designed an image-based canopy cover protocol for plots that are withheld from field visits via the prefield process (i.e., plots that are obviously nonforest). The prefield canopy cover assessment protocol is applied at tens of thousands of plots annually and involves dozens of image

interpreters. Therefore, it was necessary to develop a user-friendly, geographic information system (GIS)-based tool that facilitates efficient image-based interpretation and documentation of percent canopy cover. During inventory year 2012, the canopy cover tool was used to assign a percent canopy cover at all FIA plots in support of an update of the National Land Cover Dataset (NLCD) canopy cover data. This paper presents the development history, design considerations, and practical advantages of the canopy cover tool.

METHODS

Collaboration

FIA’s national prefield task team, which includes members from the four FIA regions, identified the need for a GIS-based canopy cover tool and prepared a functional needs assessment. Subsequent tool development was supported by the Techniques Research Band in collaboration with the Forest

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Service's Remote Sensing Applications Center (RSAC). The RSAC and the FIA program have had a longstanding partnership applying remote sensing technology to the national forest inventory of the United States. In addition, RSAC has expertise and experience developing software tools to assist with image interpretation, such as Digital Mylar (Clark et al. 2004). The project team, which consisted of a programmer and a project manager from RSAC and the national prefield team from FIA, collaboratively developed a specification document based on FIA's needs assessment. A number of additional FIA personnel served as software testers. The project followed a rapid application development paradigm with iterative versions of the software prepared by RSAC and promptly tested by FIA staff. One of the agreements in this partnership was the delivery of the tool's source code to the FIA program, which will provide flexibility to adapt the tool to other resource settings or dot grid designs.

Design Considerations

Multiple image-based methodologies were considered and tested (see Goeking and Liknes 2009), and a dot grid approach was selected due to favorable repeatability performance and minimal training requirements. The question of dot grid sample size was investigated using statistical methods, and it was determined that 100 dots would provide a suitable compromise between precision and interpretation time. Dots were to be fit within a circle of 43.9-m radius, which contains all four subplots in the FIA plot design. Additionally, the dot grid was to be rotated clockwise 15 degrees in order to reduce alignment with cultural features. The final dot arrangement uses an integer spacing (8 m) between dots, resulting in 109 dots in the 43.9-m circle (Fig. 1).

Software Development

Because all FIA image interpreter personnel have experience using ArcGIS® products (e.g., ArcMap™)

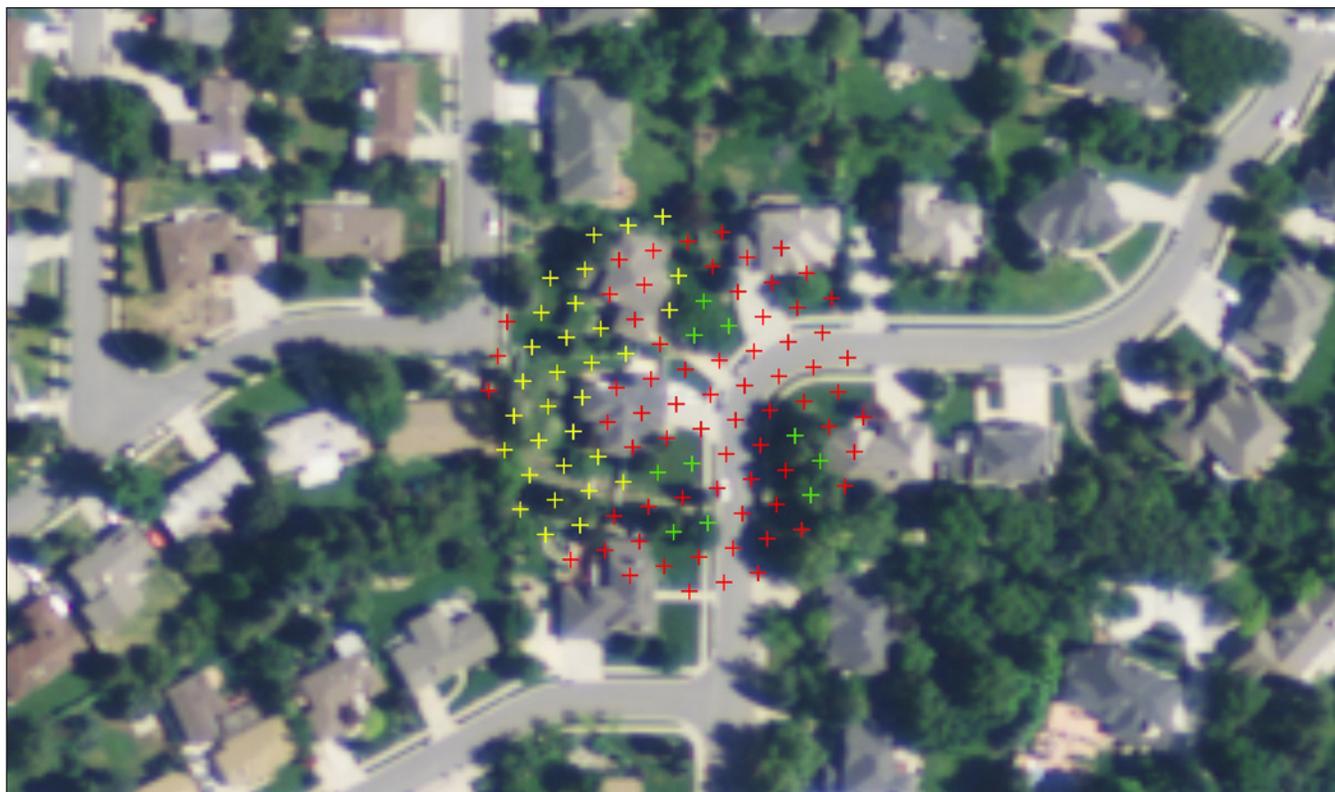
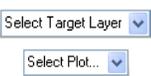


Figure 1.— Screen capture of dot grid overlain on NAIP imagery using the FIA canopy cover tool. Red crosshairs indicate non-tree dots, green indicate tree dots, and yellow indicate dots that have not yet been classified. This example illustrates a situation where the plot does not meet the FIA definition of forest land yet includes a substantial amount of tree canopy cover.

and the software can seamlessly utilize imagery from RSAC's ImageServer (Vines 2007), the canopy tool was developed as an ArcMap™ add-in using C# and ArcObjects® in ArcGIS® 10. The add-in can be hosted at a network location, and users therefore automatically use the latest version of the software each time they restart the ArcMap™ application. This reduces the technical support effort required to ensure all users have the same version of software and enables the use of the software tool at the Forest Service's Enterprise Data Center.

Working from the basic functionality outlined in a specification document, a prototype of the tool was developed. Image interpreters from all four FIA regions tested several iterations of the tool, working toward consensus while still meeting the workflow requirements in each region. Particular attention was paid to optimizing efficiency of the interpretation process. A summary of the tool's components appears in Table 1.

Table 1.—Summary of functions within the canopy cover tool. Note that the options function permits flexibility in defining parameters that may vary across FIA regions or resource applications.

Icon	Utility	Functionality
	Select layer/ Select plot	Dropdown menus that specify the plot layer and individual plot to which other operations will be applied.
	Generate dots	Creates the 109-dot grid for the currently selected plot.
	All no tree	Single click operation that assigns all no tree attributes to the current plot's dot grid.
	Select based on location	Out-of-the-box ArcMap tools used to select dots; default tools included are select by polygon (left) and select by lasso/freehand (right).
	Attribute dots	Assign either tree (left) or not tree (middle) to currently selected dots. Another option allows users to distinguish between tally trees (left) and non-tally trees (right).
	Select based on attributes: Invert select/ select null	Custom selection tools; either selects all dots not currently selected and makes all currently selected dots not selected (left) or selects all dots that have not yet been assigned a tree/not tree value (right).
	Undo	Removes the last assigned tree/not tree attribute. Successive clicks of this button step through older attribute assignments and remove them.
	Confidence	Dropdown box that allows user to indicate how confident they are in the percent canopy for the current plot. Options are high (default) and low; a low confidence value prompts the user for a low confidence reason (e.g., clouds).
	Done	User can indicate they have completed work on a plot. Saves attribute information for the currently selected plot and zooms to the next plot in the plot dropdown list.
	Percent canopy	Calculates and reports the percent canopy cover based on dots that have been attributed. Also reports the number of dots that have not yet been attributed.
	Options	Launches a dialog that allows the user to specify the following parameters: <i>Plot key:</i> Specifies an attribute field in the plot layer used to uniquely identify plots (e.g., CN, or a concatenation of state, county, plot). The values of this key populate the "Select plot" dropdown list. <i>Data frame reprojection:</i> Specifies behavior of data frame in the event imagery or plots are in different projections. <i>Dot layer projection:</i> Specifies the output projection of dot grids. <i>Zoom level:</i> Defines the display scale when application moves to a new plot; default is 1:1000. <i>Attribute levels:</i> Option to turn off distinction between tally and non-tally trees. <i>Symbology:</i> Option to load custom symbology. <i>Canopy cover button:</i> Option to disable the informational Percent Canopy Cover button. <i>Big undo:</i> Option to delete all dot files in the directory of the currently active layer and to reset the associated plot file to its original state by deleting the canopy cover attributes. <i>Dot output folder:</i> User-specified location for storage of dot layers. <i>Current data frame:</i> Specifies to which data frame tool operations apply.

Practical Advantages and Applicability

There are several practical advantages of both the tool's user-friendly design and the simplicity of the dot grid protocol. First, the ability to host the tool at a network location is critical for minimizing software support and troubleshooting. Second, the tool requires only minimal GIS experience and technical training, which is a significant advantage over object-oriented image segmentation methods. Third, no field data are required. While some assessments of tree canopy cover rely on mapped-plot data including tree size and location (see Toney et al. 2009), this approach requires only high-resolution imagery along with either a point shapefile or comma-separated value file of plot locations. As with any photo-interpreted evaluation of tree cover, however, photo interpretation skills and familiarity with regional vegetation are required for accurate and repeatable percent canopy cover values.

A fourth advantage is the ability to assess repeatability and sampling error. The tool's visible output includes a new shapefile, which contains each of the 109 dots in each plot's dot grid, as well as the tree/no tree attribute for each dot. Therefore, multiple interpreters can evaluate quality control plots using consistent dot locations and imagery. Further, the existence of dot grids allows straightforward calculation of sampling error. In contrast, while census-based approaches (e.g., image segmentation, which produces polygons) have no sampling error, they do have misclassification and boundary errors that are difficult to quantify. Finally, datasets representing dot grids are relatively small in size, parallel in structure given that each plot always contains the same number of dots and attributes, and generally easier to manage than polygon outputs produced by image segmentation.

The straightforward design of the canopy cover tool lends itself to applications in other projects and resource settings. The tool's principal requirement is a point shapefile or comma-separated values (CSV) file, wherein each point or record represents one plot and contains a unique identifier in the attribute table.

Based on user-assigned dot grid values, canopy cover is calculated for each sample plot and stored in this attribute table. RSAC has made available an adaptable version of the tool called Image Sampler, which is part of the Digital Mylar toolkit (USDA FS 2012). This version of the tool allows the user to specify whether the dots should be randomly or systematically arranged within an area of interest, and also allows for a user-defined classification scheme.

DISCUSSION

A new GIS-based tool facilitates the determination of percent canopy cover, which is a critical component in FIA's new definition of forest land, using a dot grid and high-resolution imagery. A partnership between RSAC and FIA successfully led to delivery of a functional tool within a few months' time.

The canopy cover tool was used to assign percent canopy cover to tens of thousands of FIA plots for the 2012 inventory year. The resulting data will not only populate the canopy cover variable for non-visit plots in the national FIA database, but will also be used in the update of the NLCD percent canopy cover layer, which is currently under development as a collaboration among several national agencies. In future inventory years, percent canopy cover will continue to be assigned at all non-visited FIA plots using this method. The determination of percent canopy cover at all FIA plots will allow FIA to align with international cover-based definitions of forest land and also monitor trends in tree cover on nonforest lands.

ACKNOWLEDGMENTS

Along with the previous and current members of the national prefield team and Remote Sensing Application Center collaborators, the authors thank the FIA Techniques Research Band for supporting development of the canopy cover tool and all of the FIA staff involved in testing the tool during the rapid development process.

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