Forest visualization at multiple scales for management and planning

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Abstract In this study forests were visualized at various scales by placing individual trees into a forest with realistic sizes and densities. Tree images were used from two sources: high quality field photos and images created using graphic design software. The terrain, species composition, and tree sizes and density from forest inventory were all represented in GIS data format. In addition, non-tree objects and features that are essential for close-to-reality visualization were combined with the tree images in a 3-D visualization software package. We further portrayed stand level effects by animating a simulated fly-through of a forest. To visualize temporal change, a case study of four different forest patches was animated. The advantages of this approach comparing to other visualization approaches are: (1) it represents the forests with realistic individual tree images; and (2) it maintains both visual and informational realism in a forest viewable from within-stand to landscape scales. Thus, this approach is realistic in two aspects. First, it is almost as realistic as a photograph, and secondly, its information content is actual forest composition, density, and height.

Keywords: 3-D, visualization, forest, landscape, multiple scales.

It has become possible to use computer-animated pictures and movies to represent the real world in three dimensions¹¹–⁶. This visualization provides additional insight to results displayed only as text or graphics⁷. It is impractical to experiment with many management strategies in the field, since many effects will occur over decades or more, and the corresponding environmental changes may be irreversible⁴. The use of a virtual forest, however, provides the possibility of assessing some potential consequences of alternatives before they are implemented. Management alternatives can be combined
with models that simulate long-term forest dynamics to visualize forest recovery\textsuperscript{[3,4]}. Short-term and long-term visualizations may be used to increase public involvement in natural resource management decisions. When presenting management proposals to the public or other governmental officials, the dynamic, graphical nature of this approach provides tremendous advantages over more traditional table and graph-based presentations\textsuperscript{[4]}. This facilitates communication of alternative management scenarios and assists in the development of the best possible management plans.

In this study we visualized forests across multiple scales and different forest management practices by combining realistic field pictures with a forest inventory database to create realistic 3-D virtual forests and landscapes that may be seen from within-stand scales to landscape scales. Topographic information from digital elevation models (DEM\textemdashs) and vector boundaries of land cover polygons provide the basic spatial input for visualizing environmental data, with realistic tree images to be inserted into specific forest\textemdash\textemdashecosystems. This approach is not scale\textemdashspecific; it can be used from fine scales to broad scales. It is unique in that it maintains both visual and informational realism in a forest viewable at various scales.

1 Methods

1.1 Study approach

Realistic tree images were generated from two sources: (1) field photographs that were edited using advanced computer photo-editing techniques; and (2) tree images designed in graphics software. Most of the individual tree images in this study were photos taken in northern Wisconsin, then scanned and edited using Photoshop 6.0, Mask 2.1, and Paintshop 5.0. In addition, a small number of individual tree images were designed using TreeProfessional\textsuperscript{[8]}. To mimic complex forests and landscapes, several high quality tree images for each species were collected to ensure the representation of various ages and forms within a species. Note that to accurately represent natural forest ecosystems the tree images chosen should be the ones growing under closed canopies.

Following information was also needed in 3-D visualizations, i.e., tree species, sizes, density, and composition from forest inventory sources; topography of landscapes; and different forest/land cover types. The DEM provided topographical data for creating the landform features. The GIS forest/land cover information provided the locations for the cover types to be overlaid on the DEM. The tree composition data provided the information for various trees of different species to place within those cover types.

Visual Nature Studio\textsuperscript{[9]} was used to integrate all information and generate a 3-D virtual forest. The flexibility of this software allowed us to visualize forests from within-stand to landscape levels (Fig. 1d, e, f). The ecosystem design capability in VNS allowed the terrain to be covered with rock, soil, and foliage based on the natural sequence of ground, understory, and overstory layers. Different ecosystems were assigned according to site-specific tree species composition, sizes and densities for both understory and overstory vegetation. To make the forest visualization realistic, we also included non-tree objects such as snags, logs, woody debris, roads, and water bodies.
We combined real images of trees and ecosystem information with management practices to create realistic visual scenarios of forest management. Changes in stands due to management included spatial, forest compositional, and density effects. These effects were shown spatially and temporally as movies. A case study was conducted to view the temporal changes of four forest patches at the near-landscape scale, based on estimated density and height dynamics curves. A harvesting event was incorporated into one patch.

1.2 Study area

The study area is the Northern Highland-American Legion (NHAL) State Forest in northern Wisconsin, USA. The NHAL is approximately 89,031 ha, of which over 75 percent is covered by forested vegetation. It is largely a pitted outwash plain, with a maximum elevation differential of about 250 meters. The weather in the area is characterized by long, cold winters with snow cover from November to April, short, mild summers, and 850 mm of annual precipitation. Mean temperatures are \(-10^\circ C\) for January and \(18^\circ C\) for July. Currently, aspen forest is the most widespread cover type (33.7%), in which the dominant species include quaking and bigtooth aspens (\textit{Populus tremuloides} and \textit{P. grandidentata}), and white birch (\textit{Betula papyrifera}); with other land cover types of marsh (9.9%); northern hardwood (8.6%), in which the dominant species include Balsam fir (\textit{Abies balsamea}), black ash (\textit{Fraxinus nigra}), and spruces (\textit{Picea glauca} and \textit{P. mariana}); pine (8.0%), in which the dominant species include white and red pines (\textit{Pinus strobus} and \textit{P. resinosa}), and Jack pine (\textit{Pinus banksiana}); and oak forests (7.2%) in which the dominant species include Bur, white, and black oaks (\textit{Quercus macrocarpa}, \textit{Q. alba}, and \textit{Q. velutina}). Within the NHAL, an area of 53.0 hectare (ha, 100 m \times 100 m) was chosen to include a diverse landscape of dominant forest types with different ages (Fig. 1e).

1.3 Data sets

The DEM data from US Geological Survey (USGS) had a resolution of 75 m \times 75 m. Forest and land cover data from the Wisconsin Initiative for Statewide Cooperation on Landscape Analysis and Data and a Landsat TM satellite land cover classification at 30 m resolution were used for 3-D visualizations at the landscape scale. Forest inventory information from the Forest Compartment Reconnaissance was used for near-landscape and stand scales. In this compartment database, each cover type reflected only the dominant vegetation in forest stands. Within any of these cover types, individual stands had different structures and compositions with different management potentials.

2 Results

Realistic virtual forests were created at three different scales (Fig. 1). At the regional landscape scale, an area of 90,000 ha over three counties in northern Wisconsin (Fig. 1a), was visualized (Fig. 1d). At this scale, it was difficult to differentiate tree species, but the patchiness of different land cover types was noticeable (Fig. 1d). At near-landscape scale, a rectangular area of 53 ha (Fig. 1b) consisting of diverse forest types of various ages,
was also visualized (Fig. 1e). At this scale, different tree crown forms, densities, and sizes were obvious (Fig. 1e). At within-stand scale, the composition and structure of forests were portrayed (Fig. 1f). An example of an aspen stand was chosen (Fig. 1c) based on compartment data from northern Wisconsin. At this scale, the shrubs, herbaceous vegetation, and snags were visible, and different tree species with different sizes were clearly visualized (Fig. 1f). As an understory layer of each ecosystem, the shrub and herbaceous layers were added to make the visualization more realistic, and the composition and the density of these understory layers change corresponding to the specific ecosystems in VNS.

Fig. 1. Visualization at different scales: a, the land cover map of the townships around Northern Highland American Legion State Forest (NHAIL) in the northern Wisconsin; b, a rectangular area of about 53 ha with diverse cover types; c, aspen stand with dominant tree height of 8.2 m; d, landscape scale visualization, a small section of the center of Fig. 1a; e, near landscape scale visualization of the rectangular area in Fig. 1b; and f, within-stand scale visualization, a scene of the aspen forest of Fig. 1c.

At the stand scale the user can view the ground level within a forest and virtually walk between trees. Some of the scenes were animated, allowing for a truly interactive view of the forest. An example was shown of a camera moving through (e.g., a bird flying through) a virtual forest at the stand scale (Fig. 2a to d). In this case, the camera gradually approaches Tree A. Along the camera route, the spatial characteristics of forest composition and structure were unveiled to the viewer.

The effects of forest management were visualized. "Intermediate thinning" in red pine forest was visualized: "before thinning" (Fig. 3a) and "after thinning" (Fig. 3b).

We successfully animated the changes of four forest patches. In this visualization, the camera remained stationary as the landscape changed as the forest aged (Fig. 4). The tree density in Patch Aspen 1 started with 2706.0 trees per ha at Year 0, and dropped to 104.0
per ha at Year 60. The tree height of the dominant species aspen in Patch Aspen 1 started at 0.58 m (Fig. 4a) as seedlings and reached 17.1 m at the end (Fig. 4d). The Patch Jack Pine 2 was completely harvested after 22 years (Fig. 4b) and was re-established after clear-cutting (Fig. 4d).
Fig. 4. Near-landscape scale animation: the temporal changes of four different forest patches Aspen 1, Aspen 2, Jack pine 1, and Jack pine 2 at a: Year 0; b: Year 22, when Patch Jack pine 2 was harvested; c: Year 40; and d: Year 60. The density and tree height changes over the 60 years in four forest patches, and for Patch Jack pine 2, there was a clear cut at Year 22, but re-established afterwards, and Patch Jack pine 1’s density gradually decreased over the years until this patch was totally gone at Year 60.

At Year 0, Patch Aspen 1 and Aspen 2 were distinctively different (Fig. 4a) with different densities and tree sizes. Over time they gradually became indistinguishable (Fig. 4d). At Year 0, Patch Jack pine 1 and Jack pine 2 blended with each other (Fig. 4a). At Year 22, Patch Jack Pine 2 was completely harvested, so the front of the view was covered only by ground vegetation (Fig. 4b). However, since there was re-establishment after the clearcut for this patch, there were small trees gradually growing back (Fig. 4d). The tree densities in Patch Jack pine 1 continued to decrease and finally reached zero (Fig. 4d).

3 Discussion

The approach used in this study can produce pictures and movies similar to the ones taken in the field, with several significant advantages: (1) It is flexible. Pictures can be taken from virtually any angle or altitude on a computer and can be designed for any time of month/day/time with different sun angles. (2) It can display the effects of various management strategies or the results from modeling simulations. (3) The pictures and movies produced in this approach have a strong linkage with quantitative ecological information, such as the composition, density, and tree sizes of a forest. (4) It is economical and efficient, especially for long-term prediction and overlarge spatial extents.

There are some tradeoffs for this highly realistic forest visualization approach. One of the critical factors is the quality of tree images used. To capture high quality tree images it requires consistent lighting, shadow, and color range and a variety of individual trees
and ages. Once the fieldwork is complete, it can be time-consuming to edit the photographs. Another challenge is to design diverse ecosystems with different ages and diverse environments. Once the libraries of individual tree species and ecosystems are established, this tool is easy to use. Currently, trees are located by random assignment based on the site-specific density. If spatial locations are available, VNS can draw trees based on their real spatial locations.

The approach outlined in this study gives a close-to-reality representation and it accurately visualizes and animates forests/landscapes with realistic forest structures, composition, and corresponding geographic locations. It is a truly georeferenced rendering system, using accurate latitude and longitude coordinates and forest structure and composition information from forest inventory data. If needed, stands and trees can be classified by being highlighted with different user-defined color-codes. This approach allows the visualization of forests at multiple scales ranging from within-stand to landscape scales. Different management effects can also be portrayed at multiple scales. Many important non-tree features in forests and landscapes, which are necessary to mimic reality but usually not portrayed by other approaches, can be incorporated. Temporal and spatial changes of forests at different scales can also be visualized. Preliminary work on visualizing the temporal changes of different forest patches based on estimated density and height curves demonstrate the potential to incorporate visualization with modeling.

The animation capability allows the spatial arrangement of forests and landscapes to be explored, which is helpful when comparing the consequences of various management practices. It can also be very useful for evaluation of long-term changes or alternative long-term management plans, facilitating discussion of management alternatives, and promoting better understanding of natural and human disturbances. Assessing forest change and long-term forest management effects will require building linkages between visualization tools and forest models. In the future, forest changes at the stand level can be animated based on the output of dynamic simulation models. Long-term changes of entire landscapes can also be animated based on landscape model simulation, including forest change due to fire, windthrow, succession, seed dispersal and forest harvesting\textsuperscript{[12,13]}

4 Conclusion

The approach outlined in this study is the most close-to-reality representation so far that can accurately visualize and animate forests/landscapes with realistic forest structures, composition, and corresponding geographic locations. This approach allows the visualization of forests at multiple scales ranging from within-stand to landscape scales. Different management effects can also be portrayed at different scales. Many important non-tree features in forests and landscapes, which are necessary to mimic reality but usually not portrayed by other approaches, can be incorporated. With 2-D spatial information, realistic 3-D effects, and the capability of animation, this study suggests that this approach is feasible for creating high-quality forest visualizations, and it provides the best tool so far in presenting a harvest plan or other forest/landscape changes in public review
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