Enhanced Visualisation Capability for Forest Management Optimisation Results

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Abstract: Despite the adoption of heuristic search algorithms for optimising large-scale spatial harvesting mainly constrained for socio-economic and environmental concerns, visualisation of landscape outcomes is still in the domain of 2-D GIS maps. Issues on visual impact due to harvesting, or forest structure for habitat niches, may not necessarily become obvious from a basic 2-D GIS map, making 3-D visualisation highly desirable. This paper looks at the potential use of airborne scanning lidar for visualisation that can be used to view modelled spatial harvesting scenarios from optimisation models and thus provide decision-makers with a capability to qualitatively improve on any optimisation scenario. Two case studies are looked at in this paper, to verify the visualisation capabilities of airborne scanning lidar.

Keywords: Airborne scanning lidar, Spatial harvesting, 3-D visualisation

1. INTRODUCTION

In the last ten to fifteen years, forest analysts have made progress in modelling the forest ecosystem in tandem with the changing views and concerns raised by the public, governments and other private bodies in regards to the sustainability of forest management practices. Not only are forests managed for timber, but also for a myriad other entities that in themselves contribute equally in defining the complete forest ecosystem. Today we talk of 'ecosystem management', a terminology widely used in the United States, or 'sustainable forest management', which all mean the utilisation of forest resources in a manner that would not lead to depletion of any of the components that makeup the ecosystem in question. Such a situation would cripple the forest ecosystem in such a way that it looses its capability to self-repair in the event of anthropogenic or natural disturbances.

In terms of modelling the forest ecosystem, there has been a gradual shift from basic wood or timber models integrated with linear programming for scheduling harvesting over a prescribed time horizon, to more complex ways of accounting for spatial harvesting such that non-timber values are catered for. Because of the limitations of linear programming in its inability to solve problems of 0-1 integer type (combinatorial) for resolving land use or management action of neighbouring land parcels, other linear programming variants have been put to test, however, fraught with size problems. Mixed-integer linear programming comes to mind and handles these kinds of problems well, but only for small problems. Also when constraints are tight, the problem can be difficult to formulate, making the search hard to find an optimal solution. The Boise Cascade Corporation has tackled the problem in another way by linking a linear programming formulation, using FORPLAN [Barber and Rodman, 1990] and a GIS package, ARC/INFO [ESRI, 2001] to produce an application called Spatial Feasibility Test (SFT). A linear programming formulation is resolved using FORPLAN and the solution is 'disaggregated' by a process that attempts to resolve adjacency violations of neighbouring polygon stands [Carroll et al., 1995]. The method is interactive, and FORPLAN is run many a time and at each run altering the constraints until such a time when the spatial constraints are satisfied. Given that SFT is deterministic and depends on the order of the list of polygon stands, each FORPLAN solution is tested against different lists, making the process time-consuming.

A quicker way to resolve these problems has been the use of heuristic search algorithms that are well known for their robustness in resolving large-scale combinatorial problems, although they are much harder to verify optimality. Since they are to be applied in situations where direct methods (such as linear programming) or enumerative methods (such as dynamic programming for exhaustive search) are difficult to apply, the goal becomes one of finding a solution that will improve the status quo rather than striving for optimality [Goldberg, 1989]. Some recent work has shown that heuristic search algorithms are now being applied although it will take years of monitoring the outcomes of implemented strategies derived from these models, to see whether they are indeed improving the status quo [Chikumbo et al., 2000; Lockwood and Moore, 1993; Van Deusen, 1999].

To aid spatial modelling, visualisation is an important part of this kind of modelling. Most of the work so far has been to link optimisation results to GIS layers such that the overall spatial impact can be seen. For example, the new FORPLAN version, SPECTRUM, can now be linked seamlessly to a GIS visualisation capability called SPECTRAVISION, which is an ESRI ArcView extension [Chikumbo et al., 1999]. That means at each time step in the optimisation, one can visualise the area extent that is harvested. Although this is quite essential, it is still inadequate for visualising forest stand structures which help to inform on habitat quality for fauna, identifying impact on recreational areas, visual impact of the forests and so on. The basic 2-D GIS maps would not suffice here, and 'enhanced 3-D visualisation' will go a long way in satisfying our needs.

This paper explores the capability of enhanced 3-D visualisation using airborne scanning lidar, as a potential tool for visualising optimisation results, such that further improvements are made to the spatial solution by qualitative means. This may also aid in reformulation of an optimisation problem. These days, forest analysts perform 3-D visualisation in commercial GIS packages by draping remotely sensed images over digital elevation models (DEMs). The information gleaned from this is only good for assessing visual impact from a myriad of forest management practices. However, the ability to visualise stand structure that would be invaluable for assessing animal habitat areas and enhance visual impact is not realised, as more information is required for this level of assessment. A more realistic representation of many elements within the 3-D landscape, for example trees and forests, becomes essential, hence the combination of remotely sensed data and the airborne scanning lidar.

2. STUDY AREAS AND DATA CAPTURE

Two study areas were considered here, in the states of Queensland and New South Wales (NSW) of Australia. The primary study area covers 220,000 hectares of private and public land near Injune in central Queensland. Due to past and present agricultural and forestry management practices a wide range of regeneration and degradation stages exist, creating woodland communities that vary structurally. An associated study site covers two coastal forest compartments totalling nearly 400 hectares in the southern Hunter Region, New South Wales. Here State Forests of NSW have established a series of research sites located in native regrowth forest and hardwood plantation production forests with complex structural heterogeneity.

Airborne scanning lidar data were captured at the Injune and Hunter study sites on the week starting August 24th 2000 and May 28th 2001, respectively. Specific detail of the data capture can be found in Tickle et al., [2001]. Data were provided as ASCII text files, pre-processed into ground and vegetation returns, with an average sampling interval of <1m. At Injune, field data were gathered in 33 ground plots of 0.25ha. Within each plot, each tree over 10cm in diameter at breast height (DBH) was located and mapped, including various structural (canopy and trunk) components.

3. METHOD

Since the GIS programs store their information in databases, an optimisation solution can be integrated in a database, showing when, where and how much timber will be harvested, which areas will be preserved for fauna and flora conservation and so on. This information may then be displayed like a movie over a time-series in a GIS program as in SPECTRAVISION [Chikumbo et al., 1999], making it possible for the user to study the spatial effects of the solution in a visual manner. Combining this with a DEM and airborne scanning lidar would provide an enhanced 3-D visualisation, that would lead to an improved understanding of optimisation results, with the added advantage of further refining the solution qualitatively, such that it better suits the wildlife and visual impact issues.

The data preparation process for the enhanced 3-D visualisation is described below, based on the two study areas. This process basically involved visualising the lidar and other remotely sensed data, by using a combination of tools that included

ESRI ArcView, ARC/INFO, ArcGIS [ESRI 2000], ERDAS Imagine [ERDAS 2001] and ENVI & IDL products [Research Systems, 2001]. The DEMs used in the visualisation were generated in an involved way, that was automated by using a scripting language called AML in ARC/INFO and the steps in the process were as follows:

- The raw ASCII data (lidar) were converted to point data and first and last ground returns combined;
- A ground TIN (Triangulated Irregular Network) was generated with a 2m proximal tolerance;
- For each vegetation point, a height above the ground TIN surface was calculated. Ground points were assigned a height-above-ground value of zero;
- First return vegetation data were combined with ground data, and a combined TIN canopy/ground surface created with a 1m proximal tolerance; and
- Bare earth and canopy TINs were converted to 1m raster DEMs for analysis with other raster datasets. Vector contours were derived from raster DEMs.

During testing of the routines the TINs were visually checked to confirm correct classification of ground and vegetation returns. Estimates of canopy cover were generated by calculating the proportion of vegetation to ground hits within a specified cell size, and height range. ARC/INFO topogrid analysis routines were tested in the Hunter study area and they seemed to produce smoother terrain models, however quantitative assessment of the different processing methods is still to be carried out.

4. RESULTS AND DISCUSSION

Visualisation of spatial harvesting results from an optimisation problem maybe carried out at different scales depending on the information requirements of the analyst. Issues on harvesting block sizes of a management area within specified upper and lower limits for each successive period over a planning horizon, can be visualised using 2-D maps. However, issues on access and stand structure are better handled using enhanced 3-D visualisation. This section describes visualisation at different scales using data from the two study areas, Injune and the Hunter Region.

The three scales are as follows;

- Tree level,
- Stand level (group of trees),
- Compartment level (group of stands).

4.1 Tree Level Scale

An initial attempt was made to visualise at one time-step, tree species, which would represent simulated harvested area, from a typical spatial harvesting optimisation problem. Stand Visualisation Software package (SVS), developed by the US Forest Service [McGaughly, 1997] was used to reconstruct field plot data for 3-D visualisation and assessment. Opportunities to identify and correct errors were realised, allowing for better interpretation of how the various sensors reported different canopy components and relative stand densities of the study plots. A lesson learnt here was that if we are to interpret spatial harvesting solutions in 3-D visualisation, carefully measured training areas from stands that have been previously prescribed similar management strategies, would be invaluable. Such information would then make it possible to simulate 3-D visualisation for the rest of the management area in question.

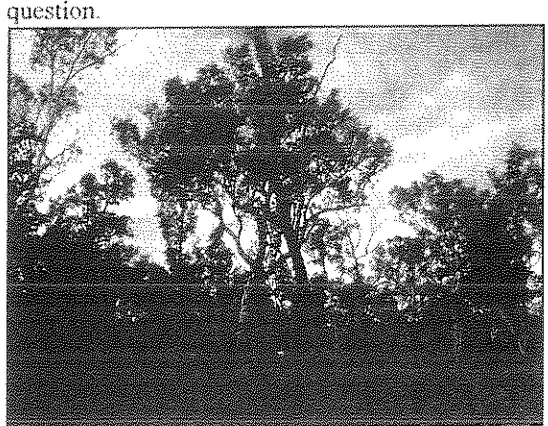

Figure 1: Digital photo of actual field plot portrayed in Figure 2. The view is from south-west looking north-east.

While SVS is useful for visualising stand-based data, it does not provide true representation of the Australian woodland forest. This is because the program was developed to cater for the coniferous forest in North America. However, with realistic tree location coordinates, it provides excellent relative positioning and density visualisation albeit not spatially linked to a coordinate system that enables integration with other GIS or remotely sensed data. Figure 1 illustrates one of the field plot sites at Injune. Each tree was visualised in SVS and this is shown in Figure 2.

It is obvious that the visualisation of the irregular nature of eucalypt canopies is not well represented in SVS. Adaptation of the tree models may rectify the problem, but it would be time-consuming. The outputs from SVS would also need to be changed such that they can be exported to other programs. The value of this approach was therefore limited.

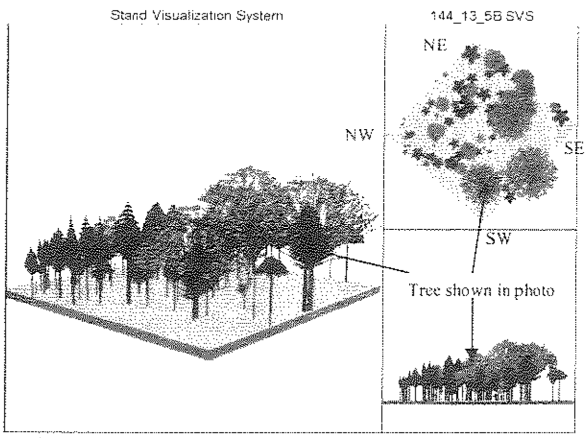

Figure 2: 3-dimensional stand reconstruction of field plot data using SVS. The perspective view in the main window is from the south-west to the north-east (as per photo view).

Another option was to use ArcView 3D Analyst combined with lidar data. Lidar data were visualised using colour, which allowed us to differentiate first and last returns. Figure 3 illustrates the result of this visualisation, and compares the lidar return cloud with the actual tree as seen in the field (Hunter study site).

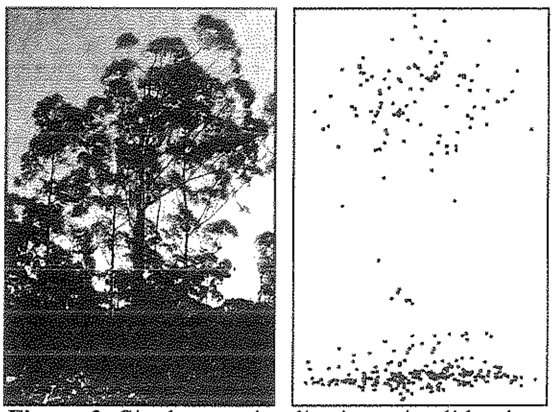

Figure 3: Single tree visualisation using lidar data and digital photo of same tree in the field.

Lidar returns had been provided as pre-processed vegetation and ground returns. Further inspection of the returns, while out in the field, allowed differentiation of various canopy structural components. Pulses coded as vegetation first return corresponded to the outer canopy and some internal branches. Ground first returns corresponded to trunk, understorey vegetation, and some base ground points respectively. Vegetation last return pulses identified trunk and major internal branches, whereas ground last returns were generally all base ground points. Overall SVS proved better for quick initial assessments of tree density, species location, and general form based on height, due to the stylised nature of the tree output. However, ArcView allowed greater understanding of the actual tree form using lidar data, as well as its position with respect to other trees in the stand and the surrounding terrain. Problems arose using this method in heavily stocked stands where many interlocking branches prevented individual tree recognition.

4.2 Stand Level Scale

While improving field data can provide significant enhancement to models, it is costly and time-consuming. Using stand based data we can extrapolate over much larger areas, and so realise more of the spatial variability that is not evident at the tree level scale. Using a sampling strategy combining lidar with other remotely sensed data such as interpreted aerial photography or high resolution hyperspectral data, we can enhance stand measurements of height, canopy cover, species composition, growth stage, disturbance and so on.

An example of stand-based improvements through lidar, as well as visualisation of the results is illustrated in Figure 4, which demonstrates the combined ground with canopy model, with a 1:4000 aerial photo draped over it.

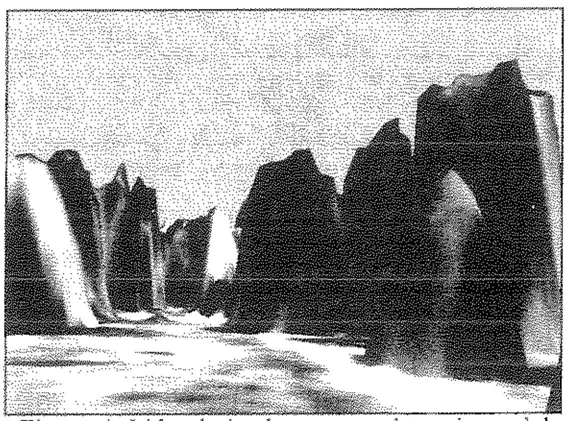

Figure 4: Lidar derived canopy and terrain model (1m resolution) with draped 1:4000 aerial photo.

Realistic location and spatial extent of tree canopies are achieved, but not accurate representation of canopy form or volume. As with most GIS based visualisation packages, photo-realistic effects are limited by the resolution of draped data, especially the terrain when viewed closely. Using lidar data, improvements were made in representing the range of tree and stand forms found in forests and woodlands. However, a number of significant issues still exist in the application of terrain surface models for lidar data analysis at the stand level scale. With the 1-2m proximal tolerance used, we observed that approximately a third of all lidar returns were utilised in TIN or DEM generation. This was due to a large number of returns and redundancies in the significance of returns for representation of a surface. Note that many of these returns were from internal canopy hits and were not required for outer canopy edge volume rendering. A more serious issue was the loss of returns from under a canopy that resulted in a tree model resembling a blanket draped over a tree as seen in Figure 4. Figure 5 illustrates an extreme example of this process for a single tree in the Hunter study region (see Figure 3). The lighter areas of the grid represented high points in the canopy, and gaps in the canopy were clearly identified. Lidar returns, from which the grid was derived, are shown as black points. The contours derived from the grid were at 2m intervals for clarity. In planimetric view the contours adequately described the shape and extent of the canopy, and showed two distinct portions to the canopy.

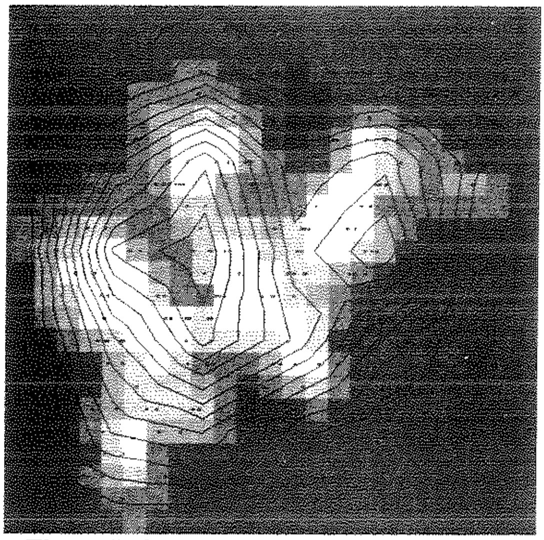

Figure 5: Canopy contours derived from 0.5m interpolated grid (background).

When the contours are displayed in 3-D (as illustrated in Figure 6, left), it became clear that they did not represent the correct shape of the canopy when compared to the lidar cloud. The contours representing the extent of the canopy were not at their correct heights. As the DEM is being generated, ground returns have more influence on the final cell height that is calculated for the edge of the canopy. As a result of this height averaging, the cells at the outer edge of the canopy are assigned the relative height of between 1-5m, depending on the shape. Trees and stands are therefore "grown" from the ground up such that a generalised conical shape is created. When these virtual trees are displayed in 3-D, the canopy does not assume the spherical or irregular ellipsoidal shape of the eucalypt trees. Canopy models developed in this way tend to be dominated by spikes, where the high (but sometimes not the highest) parts of the canopy exert the greatest influence. It was observed that this effect occurred in both TIN and raster derived elevation models. We then conducted an analysis that used raw point data at 2m height intervals and created a stacked set of surfaces within the canopy. Contours were generated from these surfaces, and were stacked in 3-D to give a better representation of canopy shape (see Figure 6, right). These stacked contours are only viewed in 3-D as established cartographic rules would be violated due to multiple contours crossing in a planimetric view.

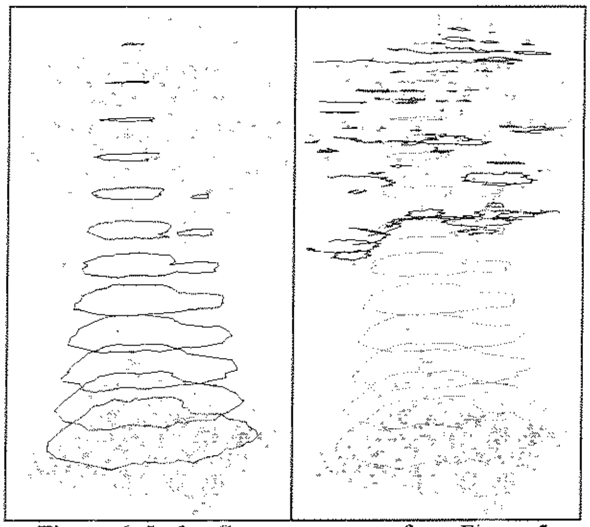

Figure 6: Left - Canopy contours from Figure 5 shown in 3-D, with the lidar return cloud. **Right** - Potential canopy contours (in black) derived from surfaces generated at 2m intervals.

A visual assessment of the tree indicated that a ellipsoid shape best described the canopy. Canopy volume was then calculated using actual crown dimensions in the x, y and z planes. This was then compared to the volume derived from the TIN surface for the same tree. It was found that the TIN volume was 40% of the ellipsoid volume, indicating that current canopy DEM's may not be adequate for volume calculations, and therefore biomass estimates. Existing biomass calculations are often constrained when using tree height due to trees expanding in canopy width rather than height after a certain age. Canopy volume would then allow improved biomass estimates at the stand level scale as both tree height and canopy width would be used. We will be using Research Systems IDL to further refine the results of volume visualisations, thereby improving our canopy volume calculations and ultimately, biomass estimates.

4.3 Compartment Level Scale

Accurate tree and stand-based parameters improve the quality of empirical models and subsequently harvested volume estimates. Existing 2-D map or satellite images draped over simple terrain DEMs may prove inadequate to convince the public and/or experts that all spatial requirements for non-timber values are being met. At compartment level broad vegetation types are investigated using a tool such as ERDAS Imagine Virtual GIS. Imagine is noted for providing virtual tree models that have been created from digital photos of real trees. These tree models can be manually placed, or used with point or attribute polygon layers to populate a scene for more realistic density visualisations. These models are general in nature and do not convey the variety of forms observed in the study areas. Individual models can be scaled with respect to height, width and depth, but accurate portrayal of non-standard canopy dimensions cannot be done. Therefore, current landscapes that use points or polygons for automatically populating forests with trees will have tree species of the same dimensions. This does not reflect typical woodlands and forests in Australia. Figure 4 illustrates an example of virtual trees in a lidar derived DEM, and shows the few Australian virtual trees that are currently available.

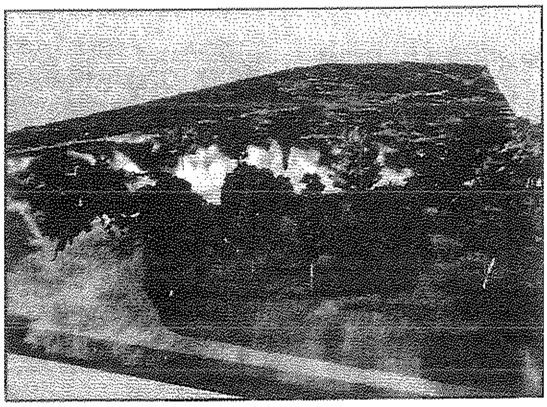

Figure 7: Lidar derived ground terrain model with virtual trees arbitrarily placed.

These species are not indicative of the species found at the study sites. Height and shape of virtual trees are less than what's observed in reality.

5. CONCLUSION

This current work has demonstrated the potential of visualising stand structure (for optimisation results of spatial harvesting), information that is invaluable in determining viable animal habitat and visual impact. There are, however, hurdles still to be overcome, given that visualisation tools are not yet seamlessly linked with mainstream GIS software. Also computer programs such as BRYCE, by Corel Corporation will assist in designing tree forms that represent each species and environment, rather than the pre-generated tree forms in visualisation programs.

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