VIEWSHED ANALYSIS AND VISUALIZATION OF LANDSCAPE VOXEL MODELS

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Abstract

In this study, we carry out viewshed analysis to landscape voxel models derived from airborne laser scanner data. The objective is to make comparisons of viewshed analysis with different voxel models; the ground model representing the bare Earth, the surface model including also all above-ground features, and the combined model, which is formed from the ground model and the laser measurements in voxel domain. The combined model contains openings in vegetation below tree crowns. This paper explores the variation in the size of the visible area when the different voxel models are used. The generated voxel models and results from viewshed analysis are visualized using a number of cartographic means.

The methods include generation of voxel model, implementation of the Line of Sight (LoS) algorithm and visualization techniques. The airborne laser data is classified to ground and other points before creation of a voxel model.

Results of the study present the influence of using a real 3D model instead of 2.5D surface in the calculation of viewshed analysis. The produced visualizations are compared, and positive and negative aspects of the representations are analysed.

1 Introduction

1.1 Background

Airborne laser scanning is an efficient method for measurement of terrain. It enables the measurement of large areas and provides high-resolution 3D data. The typical density of laser data is several points per square meter. Therefore, airborne laser scanning provides detailed information not only about the ground surface, but also the objects on the top of the ground surface.

In this study, we carried out viewshed analysis to 3D models, which were derived from airborne laser scanner data. The study applied voxel models, where volume was divided to sub-volume particles, voxels, with a constant scalar or vector value inside. Unlike the 2.5D surfaces, the voxel models enabled efficient utilization of the full geometrical potential of the 3D laser scanner data.

The models derived in the study were utilized in calculation of visibility. Visibility here refers to unobscured Line of Sight (LoS) between two locations. In order to find all areas, which were visible from certain location, LoS examination was carried out for all voxels in the model using the same viewpoint. This analysis is referred to in the study as the viewshed analysis. In the literature, viewshed analysis is sometimes referred to as *isovist analysis* (Tandy, 1967). The distinction here to the meteorological visibility is that the weather conditions are ignored.

Applications for visibility and viewshed analysis are numerous. Originally, the idea was introduced in the field of geography by Tandy (1967) and in the field of architecture by Benedikt (1979). Since then, approaches to study viewsheds can be found in various fields, such as urbanism (Batty, 2001; Turner et al., 2001), architecture (Benedikt, 1976), geography (Fisher, 1995) or archaeology (Wheatley, 1995; Fisher et al., 1997; Lake et al., 1998). The studies within architecture and urbanism are concentrated to 3D city environments, whereas in geography the DEMs of urban and rural environments are used. Recently, isovists analysis indicators have been visualized using 3D voxel model (Morello, Ratti, 2009). In these studies, 2.5D surfaces or 3D vector elements have often been used.

1.2 The research objectives and hypothesis

The presented study applied a real 3D voxel model of forest environment. The research objectives were (1) to compare the results of viewshed analysis based on the ground model, the 2.5D surface model and the real 3D model and (2) to visualize the original models and viewshed analysis results in a comprehensible way. The hypothesis was that the result of the viewshed analysis will be larger, if a real 3D model is used instead of 2.5D surface.

2 Materials

The Finnish Geodetic Institute has the test environment for research purposes in the Lake Nuuksio uplands, southern Finland (Sarjakoski et al., 2007). The airborne laser scanner data acquisition was carried out in the Nuuksio test area during summer 2008. With the measurement frequency of 100 000 Hz and a flying altitude of 1000 m, a point density of 4/m2 was gained (Pyysalo and Sarjakoski, 2008). The study area of 200 m ×

200 m covered by mixed forest besides the lake was taken under closer attention. The infrastructure includes two buildings, dirt roads and a bridge to an island.

3 Methods

The methods included generation of voxel model, implementation of the Line of Sight (LoS) algorithm and visualization techniques. Before creation of the voxel model, the airborne laser data was classified to ground and other points using algorithm based on adaptive TINs (Axelsson, 2000). The algorithm is implemented in Terrascan software.

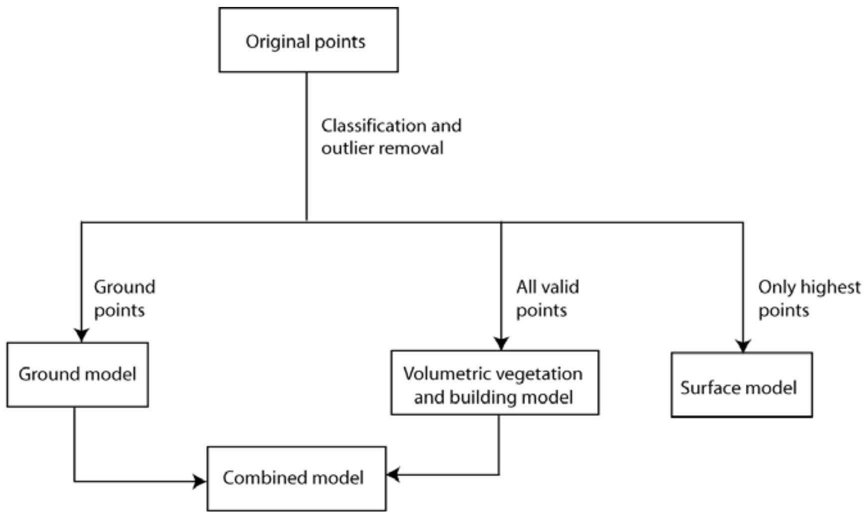

Figure 1. Processing flow of the voxel models.

3.1 Implementations of the voxel models

The laser measurements were expressed in a voxel domain, which was defined by the voxel size, the origin of the test area, and the aerial dimensions in x, y and z- directions. The edge length of cubic shape voxel is referred to as resolution in the following text. The models were formed using 1 m resolution, which exceeded the average area illuminated by a single laser pulse.

The voxel models created were (1) the ground model, (2) the surface model, (3) the volumetric vegetation and building model and (4) the combined model.

Initially, two continuous surfaces, namely digital elevation model (DEM) and digital surface model (DSM), were created. The preliminary DEM surface values were calculated as the averages of the z-co-ordinates from the ground points within each surface cell. The DEM surface was completed by interpolating values for the gaps (43% of the surface cells) from the closest neighbours. DSM surface values were gained from the highest z-co-ordinates from all points within each surface cell.

The ground (voxel) model and the surface (voxel) model were created by filling up the voxel space from the bottom layer up to the surface cover of the DEM and the DSM respectively (Figure 2).

The volumetric vegetation and building model was produced from the original laser measurements by addressing all voxels with one or more laser hits inside as 1, and the others, voxels without any hits, as 0 (Figure 3, left). An additional attribute calculated for all voxels in this model was the average of the intensities from the laser hits observed within each of the voxels. These values were scaled between 0-255.

Finally, the fourth voxel model, namely the combined model, was created as a union of the ground model and the volumetric vegetation and building model (Figure 3, right). If either one of the models had voxel addressed as one, the voxel in the resulting model was addressed as one.

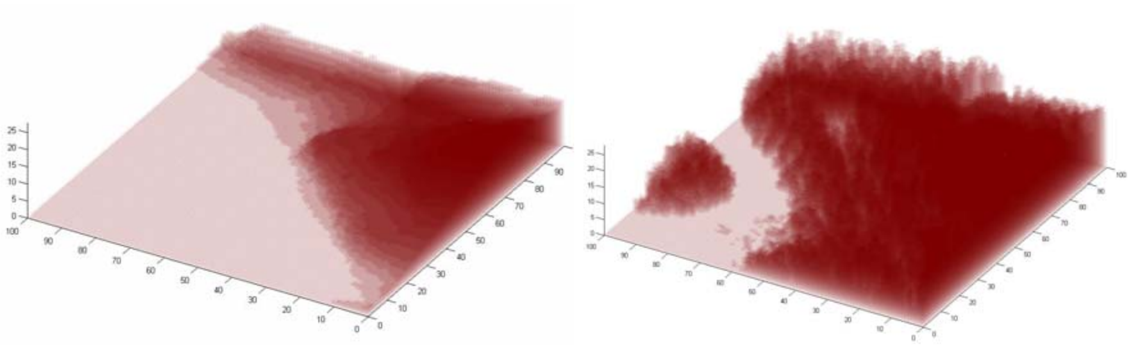

Figure 2. The ground model (left) and the surface model (right).

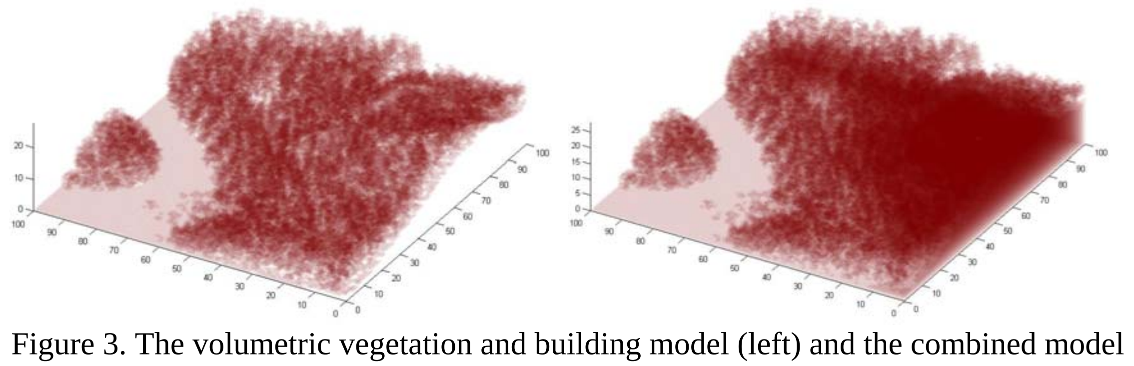

Figure 3. The volumetric vegetation and building model (left) and the combined model (right), which is a union of the ground model and the volumetric vegetation and building model.

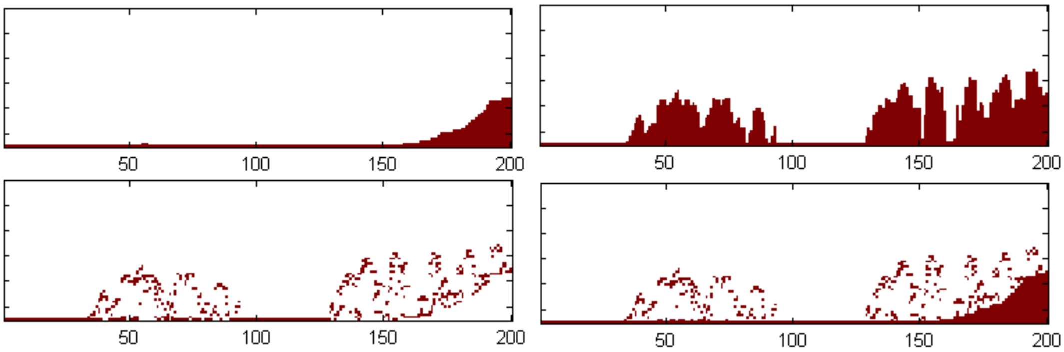

Figure 4. Side profiles of the four different models. Top left, the ground model; top right, the surface model; bottom left, the volumetric vegetation and building model; bottom right, the combined model.

3.2 LoS algorithm

The LoS was calculated with the transversal algorithm for voxel space (Amanatides and Woo, 1987). The purpose of the algorithm is to detect, in an efficient way, all voxels which are penetrated by pre-defined ray. In the study implementation, the equation of the single ray line was determined from the viewpoint and the target point co-ordinates. The visibility between two points in the model space was found if all voxels detected by the algorithm were empty.

A single LoS analysis was expanded to a viewshed analysis by moving the target point around the entire model area. Each voxel was classified to one of the five classes based on the target voxel value and LoS analysis:

Class No.	Class description
0	Voxel is the viewpoint
1	Voxel is full and visible
2	Voxel is full and not visible
3	Voxel is empty and visible
4	Voxel is empty and not visible

Table 1. Classification of the viewshed analysis

3.3 Visualization methods

Several visualization experiments were carried out. The general problem with the 3D visualization of the voxel model is the information overload, caused by the top layers obscuring the bottom layers. Two cartographic means were tested to make voxels behind the top layer visible; (1) voxels were presented as transparent and (2) voxels were visualized with symbols, smaller in size than the voxel resolution.

Another approach was to reduce the amount of data to be presented. The subvolumes were selected according to the voxel value (full/empty), the classification result (visible/not visible) or the voxel index (row, column and layer cross-sections).

The volumetric vegetation and building model, in which an additional voxel attribute was available, was visualized using adaptive transparency. The average of the intensities was applied as a transparency value in a way which high intensity values were considered opaque and low intensity values transparent.

All visualizations were carried out with MATLAB (*www.Mathworks.com*) and Volocity Visualization (*www.Improvision.com*) software.

4 Results and discussion

4.1 Volume and visibility

The test site volume (200 × 200 × 55 voxels) was as follows;

- Proportion of the voxels in the ground was 16,8 %. These voxels were full in the ground, surface and combined models.
- Proportion of the voxels in the air above the tree canopy surface was 62,0 %. These voxels were empty in the ground, surface and combined models.
- The remaining proportion of voxels in the intermediate space containing vegetation and buildings was 21,2 %. All of these voxels were full in the surface model, but in the combined model 16 % of the voxels were full and 84 % were empty.

The viewshed analysis was calculated from the same viewpoint using the classification expressed in Table 1 for the ground model, the surface model and the combined model. The viewpoint was 8 meters above the lake surface (Figure 5). The results are in Table 2.

Model/ Class	The ground model, %	The surface model, %	The combined model, %
Full and visible	1,19	0,26	0,29
Full and not visible	15,65	37,84	21,11
Empty and visible	82,52	30,30	30,79
Empty and not visible	0,64	31,61	47,81
Visible volume	**83,71**	**30,55**	**31,08**

Table 2. The result of the viewshed analysis from one viewpoint.

The difference between the visible volume of the ground model and the other two models was almost 53 %. As expected, the impact of vegetation was large, because the test site is in the forested area. However, even without the vegetation, the ground cover was not completely visible from the viewpoint, since the highest ground point in the area was 26 m above the viewpoint.

The difference between the visible volume of the combined model and the surface model was 0,53 %. Since the portion of empty voxels in the intermediate space was 84 % in the combined model, the difference was expected to be larger. The visibility was increased locally around the viewpoint (Figure 5). However, although the difference in percentage units was small, the absolute volume was approximately 10 000 m^3.

The viewshed analysis is sensitive to the viewpoint location. The presented results were calculated using the viewpoint, which was located below the tree crowns. At this height, the lower branches of the trees were obscuring the visibility. The study area is mixed forest dominated by pines, spruces and birch. Especially spruces have branches close to the ground surface. More tests should be carried out in order to determine how different viewpoint locations are affecting the visibility. This is carried out in the future studies.

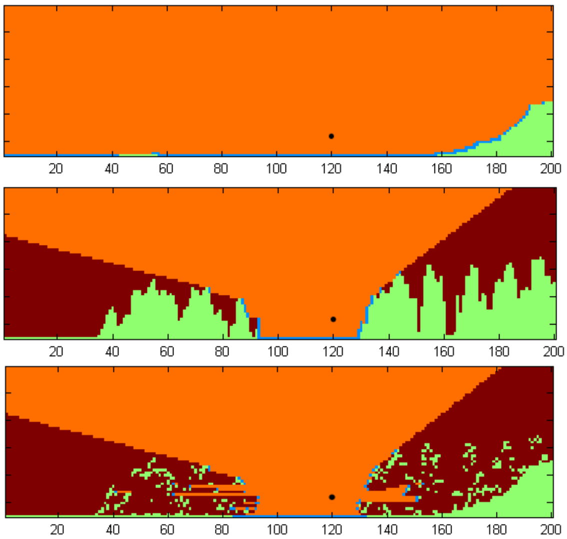

Figure 5. Profile representations of the viewshed analyses carried out to the ground model (top), to the surface model (middle), and to the combined model (bottom). Colors: light blue is full and visible, green is full and not visible, orange is empty and visible and dark red is empty and not visible. The view point is the black dot at the location 120.

4.2 Visualization results

The results of the visualization experiment are illustrated in Figures 2-7. The subvolume content and the applied cartographic technique were as follows:

- In Figures 2 and 3, only full voxels are visualized. The transparency value of 60% was used.
- In Figure 4, the single cross-section is visualized. Only full voxels are shown.
- In Figure 5, the single cross-section of the viewshed analysis result is visualized. The classification combines the visibility analysis result and the binary value (full/empty) of the voxel (Table 1).
- In Figure 6, only full voxels of the volumetric vegetation and building model are shown, and the viewshed analysis result is visualized. The blue dot represents full voxel and the red circle represents full and visible voxel.
- In Figure 7, the volumetric vegetation and building model is visualized with adaptive transparency. The transparency varied according to the average of the intensities from the laser hits observed within each of the voxels. Empty voxels have transparency of 100%.

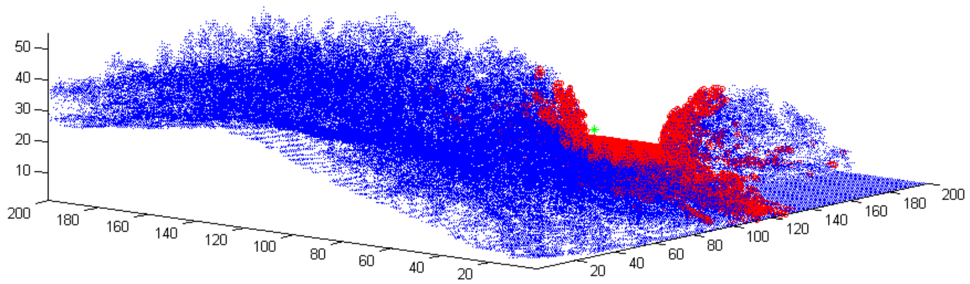

Figure 6. Example of the symbol representation of the volumetric vegetation and building model; the full voxels in the original model are represented as blue dots, which are surrounded with the red circle in cases where they are visible from the viewpoint (the green asterisk).

Figure 7. Captured image of the Volocity presentation of the volumetric vegetation and building model. The model has been made by Christopher Wood.

Based on the visualization experiments, it appears that the 3D visualization of voxel models is challenging. The voxels in the front layer are obscuring the voxels behind them. If transparency is used, the voxels behind the front layer are seen through the upper layers, and, therefore, their color is mixed. However, the 2D profiles provided an unobscured view to the model. Isosurfaces, which are normally used in volume representations, were not used due to the lack of voxel attributes.

The cartographic means, which are commonly used with all 3D models, applied also with 3D voxel models. The shape of the model could be perceived when the model was rotated dynamically. In order to see a stereoscopic view, two images could be captured from the model from different positions. The grid structure of the model was possible to use as the scalebar clarifying distances within the model.

5 Conclusions

This paper explored the differences of viewshed analysis results, when true 3D voxel model of the landscape was used instead of 2.5D surfaces. The airborne laser scanner data was used to produce landscape voxel models. Original models and visibility analysis results in voxel domain were visualized using a number of methods.

It was found that:

- The combined model, which is a union of the ground model and the volumetric vegetation and building model, both sustains the real 3D shape of environment, and maintains a continous ground surface. The difference between the full volume of the surface model and the combined model was remarkable.
- The visibility was dramatically decreased when above ground terrain features, such as vegetation and buildings, were included into the model. Using the real 3D voxel model instead of the 2.5D model increased the visibility.
- 3D visualization of voxel space was found to be challenging due to the information overload. The overload problem may be reduced by visualizing only subvolumes, and using representations which enable visibility through the top layers.

In the future experiments, the difference between the viewshed analysis based on the different voxel models will be thoroughly investigated by using a number of viewpoint locations instead of one fixed viewpoint. In addition, the effect of viewpoint elevation will be taken under closer attention. Finally, the possibility to include intensity values of the penetrated voxels to the LoS analysis will be examined.

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