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The visual exposure in forest and rural landscapes: An algorithm and a GIS tool

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ABSTRACT

There have been many different approaches to the delineation and measurement of viewsheds using GIS. However, the quantification of visibility for each element within the viewshed is estimated by imprecise procedures. This paper proposes a GIS tool which analyzes the visual exposure of a terrain from single or multiple observation points, starting from a digital elevation model (DEM). The proposed procedure yields higher precision values than the existing methods, because it directly obtains the solid angle of each visible cell within the DEM. The procedure is based on building a triangle network from a DEM in a regular square grid (RSG), thereby eliminating the need to calculate the slope and aspect, which are necessary steps of other procedures. The visual exposure values for each cell can be added in order to estimate the visual impact of landscape elements represented by a set of cells in the RSG. The development of the tool was oriented towards mitigating the landscape impact caused by forestry activities, in order to comply with certification schemes for Sustainable Forest Management. The tool proved to be useful in assessing alternatives for distributing clear-cutting areas so as to minimize visual impact, and can be applied to any other landscape impact assessment, such as road construction, quarrying, farming or any other land use change.

1. Introduction

The systematic and objective evaluation of the physical characteristics of a landscape is an important topic in contemporary landscape research (Smardon et al., 1986). Looking at the main set of attributes used in aesthetic evaluation, visibility is always a main factor for decision making in visual impact assessment, as well as in other applications in archaeology, fire towers, radar sites, telephone transmitters, etc. In forest management, aesthetics is a major issue in many areas where forestlands provide recreational use; thus, fragmentation and transformation of the landscape by harvest scheduling must be carefully planned (Borgesa and Hoganson, 2000). A good evaluation of the visibility of harvesting patches and species distribution can be a complementary feature for existing models of multiobjective forest management (e.g., Seely et al., 2004; Shao et al., 2005).

Visibility is computed in 2D GIS environments by definition of viewsheds, on the basis of mutual visibility between two points when there are no obstacles within the line-of-sight. Beyond the geometric calculations, there are multiple factors constraining visibility that have a strong influence on what the observer actually "sees"; human perception is a combination of optical physics, atmospheric effects, and other more psychological and cultural factors (Ervin and Steinitz, 2003). Gross (1991) notes the following as main factors influencing the visual impact of objects on the landscape: covered surface area on the retina, visual acuity of the human eye, the eye's resolving capacity, atmospheric extinction, and color difference to the background. He defines specific visibility $S''(r, \mathrm{Ca})$ (unit: $\mathrm{sr/m^2}$) as a measure for the optical impression made by an object at a given observer point which must be calculated as an integral above the solid angle area of the retina Ω taken up by the object, evaluated with the visual acuity V; the color difference to the background and the atmospheric extinction ΔE, related to the observer's area $dA = 1\ \mathrm{m}^2$.

$$S''(r,\phi) = \frac{1}{dA}\int_{\Omega} V(a)\cdot \Delta E(r,\phi)\cdot d\Omega \qquad (1)$$

where, r, φ are the polar coordinates (distance and angle) relating the object and the observer; a is the angle of visual incidence on the retina.

Focusing on the geometric question, in reference to the surface area covered on the retina, Llobera (2003) defines "visual exposure" as 'a measure of the visible portion of whatever is the focus of the investigation'. If we talk of raster cells it would be the measure of how much each cell occupies the field of view of an individual at any location.

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Looking at previous works, one of the pioneer GIS developments, VIEWIT (Travis et al., 1975), implemented commands for visibility analysis that included visual exposure estimation using relative aspect and distance as weighting options. Within the viewshed, the program obtained the visual angle for each cell relative to the observer, taking into account the aspect and slope of the seen cell, elevation of that cell, and elevation of the observer. Each cell was assigned a maximum of 10 points, and this was scaled according to the relative aspect. The distance weighting option allowed the visibility of a cell to be weighted by its distance from the observer. For that purpose the user must define a distance–weight function, which expresses the desired relationship between distance and visibility. Weights are numbers between 0 and 1.0 inclusive.

Llobera (2003) estimated visual exposure for triangulated irregular network (TIN) models by (a) sampling the model at a fixed rate (20 m), (b) selection of a viewpoint location, (c) obtaining the orthonormal vector of the plane at each sampling point, (d) calculation of the line-of-sight (LoS) normal vector, (e) obtaining the visual exposure by projecting the surface orthonormal vector onto the LoS and multiplying by an additional factor derived from the distance between the viewpoint and the target point.

The cited methods provide relative values of visual exposure that may be adequate for comparing visibility of different objects in the scene. However none of these methods provides values of solid angle that can be integrated in Eq. (1).

In this paper we propose an algorithm for quantification of the visual exposure of any terrain within the viewshed, evaluated as solid angle or covered surface area on the retina of the observer. The algorithm is implemented in a software tool on ArcGIS.

The solid angle values obtained by the algorithm can be used in Eq. (1) or any other equation for visibility analysis, crisp or fuzzy, that include other influencing factors. Furthermore, the solid angle measure allows the addition of the visual exposure of a set of raster cells containing a given landscape feature; this makes it possible to evaluate the relative importance of the feature in the view.

As a GIS development, the algorithm is vulnerable to several of the sources of error which can occur in viewshed calculation: (a) simplification and aggregation in raster elevation data (Ervin and Steinitz, 2003); (b) factors that may modify the viewshed, such as vegetation screens near the observer, height of the observer, presence of unmapped human artifacts, etc., which cannot be modeled in advance by a traditional DEM model (Anile et al., 2003); (c) a data structure that produces a 2.5D model [only one possible z value for any particular (x,y) location] and is hence unable to deal with structures such as trees or building with any precision (Bishop et al., 2000).

This latter constraint can be overcome through the use of 3D visualization technologies, which have become useful and popular tools for design purposes, evaluating public preferences, and for making decisions regarding forest management (e.g., Wang et al., 2006) or the visual impact from man-made objects (e.g., Gross, 1991). 3D models can provide an agent at a specific location with the visual magnitude of the visible part of any object. However, GIS analysis will provide maps of all locations from which an object can be seen (Bishop, 2003), as well as cumulative viewsheds of times-seen or total visual exposure of each cell from a large set of locations.

2. Materials and methods

2.1. Preliminaries: viewsheds and DEM for visual exposure analysis

Visibility is computed in GIS environments by definition of viewsheds: given a viewpoint V on a terrain, the viewshed of V is the set of points on the surface that are visible from V. The data from those points are provided by a model of the terrain built up from a finite set of data in Euclidean space (x,y,z), which is called a digital elevation model (DEM); the points can be either distributed in a regular (x,y) grid or scattered. A DEM built on the elevations z of those points represents a surface that approximates to the real topographic surface.

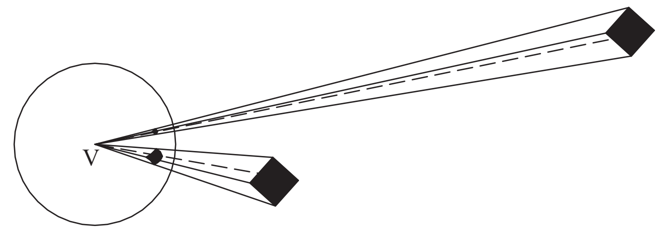

Fig. 1. Different visual exposures (solid angles) of two equal size cells projected on the unit sphere as function of distance. In most cases, the observer will see the cell somewhat obliquely rather than head-on. Consequently the apparent area of the seen cell will also be reduced.

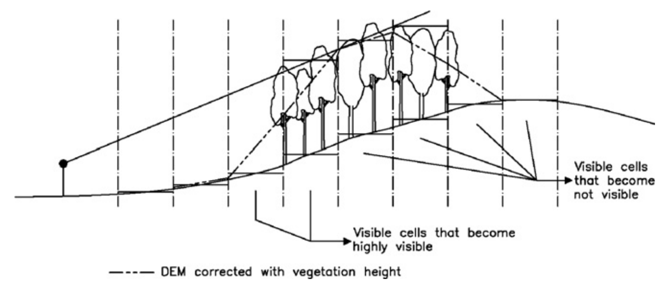

Fig. 2. Changes in visibility owed to vegetation screening and changes in the viewshed defined by the GIS. The line-of-sight showed belongs to the maximum vertical angle as it is read by the GIS from the corrected digital elevation model (DEMc).

GISs consider two main classes of DEMs: triangulated irregular networks (TINs) and regular square grids (RSGs); the review by De Floriani and Magillo (2003) describes both models as well as the different algorithms that obtain viewsheds from them. In this study we chose RSG as comparison between cells, in terms of visual exposure, is made easier where cells are of the same size (Fig. 1) as opposed to irregular triangles with variable surface areas.

The surface area covered by an object on the retina is called solid angle; thus an object's solid angle is equal to the area of the segment of unit sphere. The units of solid angle can be called steradian (sr). The sphere has 4Π sr and an infinite plane measures 2Π sr. In order to evaluate the visual exposure of each RSG cell we need to measure the value of solid angles of each cell from the viewpoint.

Vegetation and other obstacles on the terrain are not considered in the DEM although they have significant effects on visibility (see Figs. 2 and 3). Thus, in order to obtain a visibility analysis as close as possible to reality, the vegetation canopy can be considered

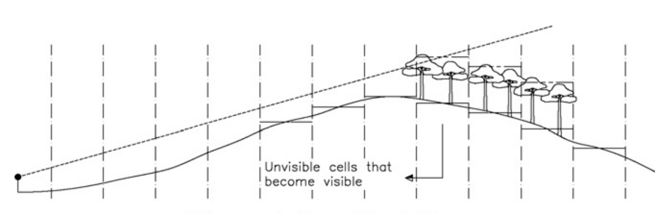

Fig. 3. Changes in visibility owed to vegetation screening and changes in the viewshed defined by the GIS. The line-of-sight showed belongs to the maximum vertical angle as it is read by the GIS from the corrected digital elevation model (DEMc). In this case the visible area increases owing to the height added to the terrain level by the vegetation canopy.