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Personalising the viewshed: Visibility analysis from the human perspective

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Viewshed analysis remains one of the most popular GIS tools for assessing visibility, despite the recognition of several limitations when quantifying visibility from a human perspective. The visual significance of terrain is heavily influenced by the vertical dimension (i.e. slope, aspect and elevation) and distance from the observer, neither of which are adjusted for in standard viewshed analyses. Based on these limitations, this study aimed to develop a methodology which extends the standard viewshed to represent visible landscape as more realistically perceived by a human, called the 'Vertical Visibility Index' (VVI). This method was intended to overcome the primary limitations of the standard viewshed by calculating the vertical degrees of visibility between the eye-level of a human and the top and bottom point of each visible cell in a viewshed. Next, the validity of the VVI was assessed using two comparison methods: 1) the known proportion of vegetation visible as assessed through imagery for 10 locations; and 2) standard viewshed analysis for 50 viewpoints in an urban setting. While positive, significant correlations were observed between the VVI values and both comparators, the correlation was strongest between the VVI values and the image verified, known values ($r = 0.863$, $p = 0.001$). The validation results indicate that the VVI is a valid method which can be used as an improvement on standard viewshed analyses for the accurate representation of landscape visibility from a human perspective.

Introduction

How many residents will be visually affected by the development of a particular wind farm? Does an increased view of the ocean improve wellbeing? What landmarks were visible from this location a thousand years ago? These are just some of the questions that are often answered using viewshed analysis. As a method for deriving areas of visibility from any given vantage point or area, viewshed analysis is an important tool used to describe the visible spatial structure of an environment. In the field of GIS, viewshed analysis has proven to be the most popular methodology for quantifying visibility (Turner, Doxa, O'Sullivan, & Penn, 2001), and its application is now common practice in a range of fields including archaeology (Wheatley & Gillings, 2000), urban planning (Danese, Nolè, & Murgante, 2009), forestry (Domingo-Santos, de Villarán, Rapp-Arrarás, & de Provens, 2011), impact assessment (Howes & Gatrell, 1993) and in the military (Van Horn & Mosurinjohn, 2010).

The term 'viewshed' was first coined by Tandy (1967) who introduced it as an analogy to the watershed, and by 1968 it was implemented in the first computer program designed to automatically quantify visibility across terrain (Amidon & Elsner, 1968). Viewshed analysis quantifies visibility by generating Lines of Sight (LoS) between an observer point and all cells of a gridded elevation surface or Digital Elevation Model (DEM). Every cell is initially treated as visible, unless the LoS detects intervening topography or other obstructions. In its most basic form, this is the basis of the 'binary viewshed' which produces a raster surface indicating visibility by '1' and non-visibility by '0' for all cells (Wheatley & Gillings, 2000). However the viewshed is a poor measure of visibility from a human perspective for two primary reasons. The 'visual significance' of perceived terrain is a term that can be used to describe how influential visible terrain is to one's perception of the environment and this is heavily influenced by two factors; the distance between a perceived object and the observer, and the vertical dimension (i.e. slope and aspect) of terrain. Closer visible

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objects are perceived as having more significance than distant objects. This is a result of many factors such as relative size of objects and object-background clarity, all which are a function of the distance between the perceived object and the observer. For example, Bishop and Miller (2007) found while lighting and atmospheric conditions affected the visibility of offshore wind farms, distance and background contrast has the most influence. Distance decay functions offer a method for weighting visible cells of the viewshed as a function of their relative distance to the observer's location where nearby cells hold more significance than distant cells. The 'fuzzy viewshed', an adaption of the binary viewshed, harnesses distance decay functions to illustrate the degree to which a cell is visible (Fisher, 1994). Typically, a exponential distance decay function is used which states the visual significance of an object decreases exponentially with increasing distance from the observer (Kumsap, Borne, & Moss, 2005). A host of differing distance decay functions can be selected to represent atmospheric conditions such as fog, haze and rain (Fisher, 1994). An alternative method developed by Higuchi and Terry (1983) called the 'Higuchi Viewshed', well demonstrated by Wheatley and Gillings (2000), accounts for distance by developing a standardized index. Three distance bands are defined which reflect three identified 'visibility zones'. The foreground corresponds to a proximal area centred on the viewer where clarity can be considered perfect. In the middle ground, clarity begins to decay and objects become nearly indistinguishable towards the further edge of the zone. The background zone essentially begins where objects cannot be individually identified, and only broad landscape features are distinguished. These three visibility zones are not fixed distances and can be chosen to reflect the climatic conditions and nature of the visible landscape. For example, the distance between the edge of clarity will decrease with increased atmospheric interference. By identifying these three areas as distinct zones, characteristics of a subjects view can be defined by calculating descriptive statistics e.g. is the view dominated by visible ground within the foreground, or is there a distant mountain range which has a larger influence in the visual scene?

While the above adaptations to the viewshed offer partial solutions mitigating the influence distance has on visibility, and are a step closer to portraying visibility from the human perspective, they fail to account for the vertical dimension of visibility. The vast majority of visibility analysis is conducted in either the 2nd dimension such as isovists (for urban and architectural studies) or in 2.5 dimensions with viewshed analysis (Bartie, Reitsma, Kingham, & Mills, 2011). While the viewshed can be an extremely useful tool, especially in large scale terrain analysis for which it was designed, it takes a bird's eye view approach and fails to portray the vertical dimension of terrain, a characteristic of visibility which is particularly important from the human perspective. Slope, aspect, distance and elevation of visible areas all influence the visual significance of observed features, none of which are accounted for in standard viewshed analysis. Fig. 1 below shows two DEMs representing two hills. The second DEM is a replicate of the first after applying significant vertical exaggeration. While the vertically exaggerated DEM holds much more visual significance from the human perspective, there is no difference in the resulting viewshed. A realization of this sparked a new generation of visibility analysis called 'viewscapes' which move away from 2.5 dimensional viewsheds and express visibility within a 3D sphere (Bartie et al., 2011).

Travis, Iverson, Gary, and Johnson (1975) developed the computer model VIEWIT which was the first tool to extend the viewshed and quantify visibility across environments after factoring in the vertical nature of terrain. Each cell considered visible in the viewshed was assigned a maximum of 10 points based on the relative elevations of the observer and visible cell, the visible cell slope and the visible cell aspect, while a distance decay function was conducted independently to weight closer cells as more significant. More recently, Domingo-Santos et al. (2011) made further improvements by developing a visibility tool that calculated the solid angle of each visible cell within a DEM. Solid angles are described as the "surface area covered by a given object on the retina of the observer" (Domingo-Santos et al., 2011 p. 57) and take into account every visible cells relative aspect, relative elevation, slope and distance from observer, all of which influence the visual structure of an environment. The work by Domingo-Santos et al. (2011) represents the beginning of a shift in focus from environment visibility to visibility of the environment from a human perspective.

This study aimed to extend the standard viewshed to represent visible landscape as perceived by a human, by creating a measure termed the 'Vertical Visibility Index' (VVI). The VVI undertakes a similar approach to Domingo-Santos et al. (2011) calculation of the solid angle. Here however, the focus lies in the vertical nature of visible terrain and the method favours highly undulating settings where standard viewshed methods are unable to provide an accurate representation of the view from the human perspective.

Methods

The VVI methodology extended the viewshed by recalculating values for each cell deemed visible by LoS analysis in a meaningful way from a human perspective. Firstly, a standard viewshed output from a single observer location was created using the ESRI ArcGIS viewshed tool (Redlands, CA). A two-step process was then used to capture the 'visual significance' of terrain. The calculation of the 'vertical angle' initially improved visibility measures by taking into account i) surface slope, ii) distance between the observer and visible terrain, and iii) elevation difference between the observer and visible terrain. Secondly, the visual significance was adjusted for the aspect of visible terrain (i.e. which direction the surface slopes relative to the observer) giving the 'adjusted visual significance'. This two-step process was developed as an automated python script which iterated through each cell deemed visible from

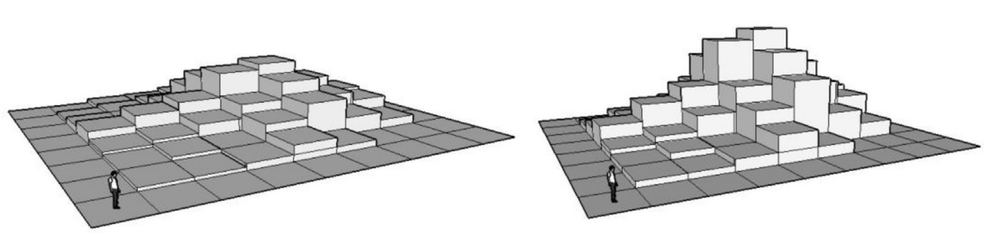

Fig. 1. A DEM representation of a hill (on left) and a vertically exaggerated copy (on right). While the second holds much greater visual significance than the first, both return the same viewshed values.