Generating Viewsheds without Using Sightlines

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Abstract

A new simple algorithm for computing viewsheds using gridded digital elevation models (DEMs) is presented. By using reference planes rather than sightlines, considerable savings in computing time can be made. The time for computing a viewshed for every point of a DEM is constant, in contrast to with sightline-based algorithms in which the computing time varies with the location of a point in a DEM. The algorithm was tested by use of the DEMs of two areas. The viewshed of every point of both DEMs was calculated. The viewshed is, as might be expected, found to be strongly influenced by both relative and absolute position. Viewpoints at peaks and ridges have more visible area than the viewpoints at pits or bottom of valleys. However, the viewshed of the viewpoints at peaks or ridges with flat local ground surface, especially in plateau-like areas, could be less than the viewpoints in pits or bottom of valleys.

Introduction

The viewshed of a location may be defined as the distribution of the area of the surrounding region visible from that location. As an important terrain parameter, viewshed is widely used in civil engineering, environmental management, and the military. For example, viewshed is used for selecting the location of a fire monitoring tower in a forest area, or TV/radio transmission tower (Travis *et al.*, 1975; Fisher, 1991; Fisher, 1996). It is used for calculating the terrain irradiation from adjacent terrain (Proy, 1989; Wang, 1996; Wang *et al.*, 1999). It is also used for selecting the location with maximum visible area for military surveillance, or the path with least viewshed for military manoeuvre (Franklin *et al.*, 1994).

Viewshed analysis has become a standard function of geographical information systems (GIS). In a GIS, the viewshed calculation is based on gridded DEMs or triangulated irregular networks (TIN). In this paper, the discussion is focused on the algorithms based on gridded DEMs. Many algorithms have been developed for computing viewsheds using gridded DEMs (Goodchild and Lee, 1989; Floriani *et al.*, 1989; Travis *et al.*, 1975; Sorensen and David, 1993; Fisher, 1994; Franklin and Ray, 1994; Franklin *et al.*, 1994). These algorithms employ sightlines exclusively, where the sightline is defined as the line from the viewpoint to a target. Clearly, if the sightline is blocked by any part of the terrain surface lying between the viewpoint and the target, then the target is invisible to the viewpoint. Algorithms based solely on this criterion tend to be computationally inefficient, and, consequentially, the calculation of the viewshed of every point of a large DEM is time consuming. In the algorithm developed by Franklin and Ray (1994) and Franklin *et al.* (1994), much computing time can be reduced by use of an auxiliary grid in generating viewsheds. However, sightlines are still used and the intersecting point of the sightline between two DEM points must be interpolated. The authors presented an alternative approach (Wang *et al.*, 1996; Wang, 1996) in which the spatial relationship between the viewpoint and target was exploited to speed up the calculation of the viewshed and also to improve the quality of the results. However, sightlines were still used in the final step to determine the visibility of a target, which could not be found using the spatial relationship with the viewpoint. Based on the algorithms developed by Wang *et al.* (1996), Wang (1996), Franklin and Ray (1994), Franklin *et al.* and (1994), a new algorithm is presented. This new algorithm removes the need for sightlines entirely, and is faster than existing algorithms.

The New Algorithm

The new algorithm uses the concept of "reference planes" in deriving the viewshed for a given viewpoint. A reference plane is defined as the plane passing through the viewpoint and a pair of adjacent points lying on either the same row or column of an auxiliary grid. The auxiliary grid has the same number of points as the DEM and is denoted $R = \{r_{m,n}\}$ ($m = 1, 2, ..., M$; $n = 1, 2, ..., N$), where M and N are the number of rows and columns, respectively, of the DEM.

The algorithm is very simple. It is based on the principle that, for a destination point $d_{m,n}$ to be visible from the source viewpoint $s_{i,j}$, it must lie on or above the reference plane $p_{m,n}$ formed by the viewpoint and the two points on the auxiliary grid just "behind" it (Figure 1). If this is so, then the corresponding point in the auxiliary grid $r_{m,n}$ records the elevation of $d_{m,n}$ (Figure 1a); otherwise, it records the minimum elevation that would make $d_{m,n}$ just visible from $s_{i,j}$ (Figure 1b). By working outwards from the viewpoint, the reference planes defined by the reference grid and the viewpoint essentially define a local "horizon," which is used to determine the visibility of the next ring of points in the DEM, and so on, until the edge of the DEM is encountered. The viewshed area is determined by counting the grid points that are visible from the viewpoint as the algorithm proceeds.

For the purposes of efficiency, we have implemented the algorithm in a way slightly different from the above conceptual outline.

Once the viewpoint $s_{i,j}$ is chosen, we move the coordinate origin to $s_{i,j}$ and divide the DEM into sectors using lines drawn from $s_{i,j}$ through its immediate neighboring points. If $s_{i,j}$ is not at the edge of the DEM, these lines divide the DEM into eight sectors (Figure 2).

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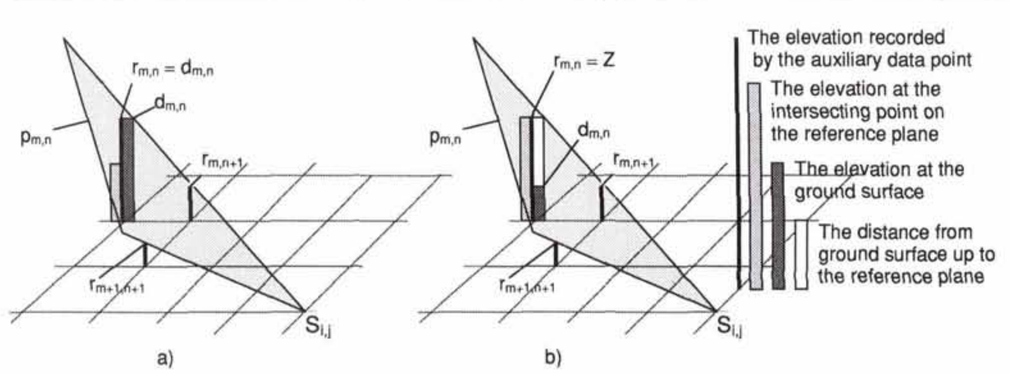

Figure 1. The plane, $p_{m,n}$, formed by $r_{m,n+1}$, $r_{m+1,n+1}$, and $s_{i,j}$ is used to check whether $d_{m,n}$ is visible from $s_{i,j}$. (a) $d_{m,n}$ is visible to the viewpoint $s_{i,j}$ because it is over the reference plane $p_{m,n}$. $r_{m,n}$ is given the value of $d_{m,n}$ and used for forming a reference plane to check if the point $d_{m,n-1}$ is visible to $s_{i,j}$. (b) $d_{m,n}$ is invisible to the viewpoint $s_{i,j}$ because it is below the reference plane $p_{m,n}$. $r_{m,n}$ is given the value of Z and used for forming a reference plane to check if the point $d_{m,n-1}$ is visible to $s_{i,j}$.

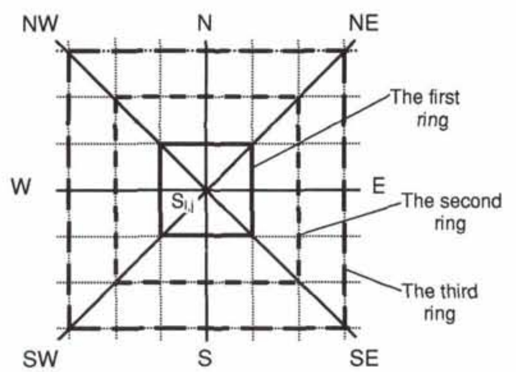

Figure 2. A DEM is divided into sectors by the lines from the point $s_{i,j}$ and its immediate neighboring points. The lines pass through the viewpoint, and its eight neighboring points lay in eight special directions: N, NE, E, SE, S, SW, W, and NW.

The algorithm uses the points immediately surrounding $s_{i,j}$ to initialize the reference grid, i.e., their heights in the DEM grid are assigned to the corresponding points in the reference grid (Figure 1). At this stage, these points are assumed to be visible from $s_{i,j}$. However, it should be noted that this is only true if the surface is locally planar or concave.

Because of their simple geometry, the points lying in the vertical, horizontal, and diagonal directions are processed first, moving outwards from the viewpoint in each direction. For example, in the case of the points lying in the northwest (NW) diagonal direction, the condition under which they are visible from $s_{i,j}$ is

$$d_{m,n} > Z$$

where Z is the maximum elevation at the point (m, n) that makes $d_{m,n}$ just invisible from $s_{i,j}$, and is determined geometrically using

$$Z = r_{m+1,n+1}\,(i - m)\,\Delta X/(i - m - 1)\,\Delta X$$

or

$$Z = r_{m+1,n+1}\,(i - m)/(i - m - 1)$$

where ΔX is the sampling interval of the DEM along the X direction. The corresponding point in the auxiliary matrix, $r_{m,n}$, is assigned a value according to whether or not $d_{m,n}$ is visible from $s_{i,j}$. If so, then $r_{m,n} = d_{m,n}$; otherwise, $r_{m,n} = Z$.

The algorithm then processes the remaining points on a sector-by-sector basis. For points lying within a particular sector, the order of processing depends on their orientation with respect to the local axes. In the case of the (W-NW) west-northwest sector, for example, processing is carried out column by column, starting with column $(j - 2)$. For each column n, the processing begins with $d_{i-1,n}$ and progresses row-wards. In these more general cases, the reference plane, $p_{m,n}$, is defined by three points: $r_{m,n+1}$, $r_{m+1,n+1}$, and $s_{i,j}$ (Figure 1), such that

$$z = -((r_{m,n+1} - r_{m+1,n+1})/\Delta X)\,x + ((m - i)(r_{m,n+1} - r_{m+1,n+1}) + r_{m,n+1})/(n + 1 - j)\,\Delta Y)Y$$

where ΔY is the sampling interval of the DEM along the Y directions.

The elevation of the point on the plane at the position $x = (m - i)\,\Delta X$ and $y = (n - j)\,\Delta Y$ is, therefore,

$$Z = -(m - i)(r_{m,n+1} - r_{m+1,n+1}) + (n - j)((m - i)(r_{m,n+1} - r_{m+1,n+1}) + r_{m,n+1})/(n + 1 - j).$$

As before, the condition under which $d_{m,n}$ is visible from $s_{i,j}$ is $d_{m,n} > Z$. If so, we let $r_{m,n} = d_{m,n}$ (Figure 1a); otherwise, $r_{m,n} = Z$ (Figure 1b). Points in the other sectors are processed in a similar fashion.

Case Studies

To test the efficiency of this algorithm, we coded it in C, along with two other viewshed algorithms (a simplistic one based on sightline analysis, and the algorithm developed by Franklin and Ray (1994) and Franklin *et al.* (1994)). These three algorithms ran on a Sun SPARCStation 10/30 Unix workstation using two gridded DEMs of two areas. The first is a 400 by 400 DEM of a mountainous area in the Snowdonia region of Wales,

Figure 3. The gray-scale illustration of Snowdonia area used in the experiment. The dark area is lower than the bright area. The minimum elevation in this area is 3 m. The maximum elevation in this area is 737 m.

Figure 4. The gray-scale illustration of the FIFE area used in the experiment. The dark area is lower than the bright area. The minimum elevation in this area is 309 m. The maximum elevation in this area is 463 m.

and is dominated by a Y-shaped valley (Figure 3). The second is a 512 by 512 DEM of the FIFE (First ISLSCP (International Satellite Surface Climatology Project) Field Experiment) test site in the Swede Creek, Kansas. This is a relatively flat area modulated by a shallow drainage network (Figure 4). The CPU times used for calculating the viewshed of a point by the first two algorithms are constant for every point of the DEMs, whereas the CPU time used by simplistic sightline-based algorithm varies with the position of the viewpoint in a DEM. In general, the time used for calculating the viewshed for a point in the central area of DEMs is less than that for other points (Wang *et al.*, 1996). Excluding the time for input/output, the CPU times used by the three algorithms to compute viewsheds are shown in Table 1.

The viewshed area for every point of both DEMs was calculated using the new algorithm. The number of the visible grid points over the DEM was defined as the visibility index of a viewpoint. The grey-scale illustrations of the visibility index of every point of both DEMs were created and shown in Figures 5 and 6, respectively. Because of the finite extent of the DEMs, the viewshed area of points near the edges tends to be underestimated. However, as might be expected, the results still show that for mountainous areas the viewshed area for positions on peaks and ridges is higher than the positions in valleys and local depressions (pits). But in certain areas the situation is

TABLE 1. CPU TIME (IN SECONDS) USED BY THREE ALGORITHMS FOR COMPUTING VIEWSHEDS FOR A SINGLE POINT ON A SUNSPARC WORKSTATION 10/30

	New Algorithm	Algorithm (Franklin and Ray, 1994; Franklin *et al.*, 1994)	Simplistic Sightline-Based Algorithm
400 by 400 DEM	0.4	0.6	26.4*
512 by 512 DEM	0.7	1.1	48.1*

*Viewshed computed for the central point.

Figure 5. The gray-scale illustration of the visibility index of the Snowdonia DEM area. The dark area has a lower visibility than does the bright area. The minimum visibility is only six grids. The maximum is 40,979 grids. The visibility is linearly scaled to the grey range from 0 to 255 in this figure.

Figure 6. The gray-scale illustration of the visibility index of FIFE area. The dark area has a lower visibility than the bright area. The minimum visibility is only five grids. The maximum is 78,774 grids. The visibility is linearly scaled to the grey range from 0 to 255 in this figure.

sometimes reversed, as may be seen by inspecting some of the ridge regions in Figure 6. This is because these areas are locally flat and hence a significant proportion of the DEM lies below the tangent plane at these points and is invisible to them.

Conclusions

A new algorithm is presented for calculating a viewshed by use of gridded DEMs. It uses reference planes rather than sightlines in computing viewsheds. Compared with traditional sightline-based algorithms, it uses much less computing time in calculating a viewshed. The new algorithm also has the useful property that the time required to compute a viewshed is independent of viewpoint position and is a constant. In contrast, the time taken by algorithms based on sightlines varies with position, being lowest for points in the central area of DEMs.

Both position and shape of the local surface of the viewpoint determine the area visible from it. Although points on ridges or peaks usually have a larger viewshed than the points in valleys or pits, there are circumstances where the converse is true. These situations occur where the local surface of a viewpoint is relatively flat; hence, a significant proportion of the DEM lies below the tangent plane at these points.

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