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Archaeological Application of an Advanced Visualisation Technique Based on Diffuse Illumination

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Abstract. The focus of interest in remote sensing for archaeology has shifted from aerial photography, which has been in use since the beginning of the previous century, towards multispectral and hyperspectral satellite imagery, and active techniques such as laser scanning. With airborne laser scanning we can observe details with high elevation accuracy and with a spatial resolution of less than one meter. However, an effective interpretation of the digital elevation models (DEMs) created from these data requires appropriate visualization. Hill-shading is the most frequently used relief visualization technique and is well suited for printed maps. Several authors have tried to overcome its limitations by using multiple angle shading and filtering. The sky-view factor is a new method that computes the portion of visible sky limited by the relief for every point on the ground. By applying it to lidar data we have been able to accurately map unknown archaeological sites and update the existing maps. Sky-view factor additionally proved to be a superior visualization technique as it reveals small relief features while preserving the perception of general topography. Rather than just presenting or visualizing the same information in a new way it extracts new information that can be further processed. In addition to the studies of the past cultural and natural landscapes it can be effectively used in other scientific fields in which digital elevation model visualizations and automatic feature extraction techniques are indispensable, e.g. geography, geomorphology, cartography, hydrology, glaciology, forestry and disaster management.

Keywords. Sky-view factor, relief visualization, historic landscape, airborne laser scanning.

Introduction

The spatial aspect is extremely important in the studies of the human past – both recent and ancient. In order to understand particular societies and their development, it is fundamental to recognize the spatial distribution of the preserved material traces of their life, their interaction with nature, as well as their range of activities. The elements of recent and past cultural landscapes are usually recorded through field surveys that continue to be inevitable for obtaining detailed data. However, remote sensing techniques enable much faster and more systematic acquisition of information. In addition they frequently enable the recognition of features that cannot be detected with traditional field reconnaissance techniques due to their configuration or environmental peculiarities. The focus of interest has shifted from aerial photography, which has been in use since the beginning of the previous century, towards multispectral and hyperspectral satellite imagery, and active techniques such as laser scanning.

Airborne laser scanning (also known as lidar imaging) has caused a revolution in remote sensing of the Earth's surface. Details with high elevation accuracy (centimetre level) and with a spatial resolution of less than one meter can be observed on laser scanning digital elevation models (DEMs).

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However, an effective interpretation of the DEM details requires appropriate data visualization. Analytical relief shading is used in most cases, but even though several authors described the advantages of sophisticated visualization [1-2], it remained limited to simple multiple angle shading and elevation data subtraction. Devereux et al. [2] stress that "… any image product which removes the directional problems of hill-shading would be of great value for archaeological survey."

1. Overview of terrain visualizations applied in archaeological investigations

Standard analytical hill-shade is widely used for archaeological interpretation because it reveals more than just the elevation of the relief – it is a plastic representation of the topography as it clearly offers information on relief morphology. It is easy to compute and easy to interpret. The surface is illuminated by a direct light – an imaginary light source at an infinite distance, which yields to the constant azimuth and zenith angle of the light beam for the entire studied area, is used to compute the incidence angle of the light on the relief surface. Areas perpendicular to the light beam are illuminated the most while areas with an incidence angle equal or greater than 90° are in a shade. A greyscale colour table is usually used for its visualization, because the colour change from white through grey to black enhances the perception of the relief. However, this limits the visualization - especially in the dark shades and the brightly lit areas, where no or very little detail can be perceived. A single direction of the light beam also fails to unveil linear structures lying parallel to it (Figure 1A and 3B).

Illuminating a surface from multiple directions, e.g. equally spaced between 0 and 360°, enhances the contrast but is inefficient at best for larger surveys and may lead to inconsistencies in the interpretation. Frequently, hill-shaded images are used to guide ground surveys as comparing multiple images in the field is extremely inconvenient. Combining multiple shading layers by considering only the mean or the maximum of an individual pixel represents a step towards an improved understanding of the results (Figure 1B). Even though this method is less appropriate for automatic edge extraction than i.e. the Sobel filter (Figure 1E), it is favourable in archaeological interpretations for it reveals not only the most perceptible edges but also the more subtle ones. Because images created by the illumination from several angles are highly correlated (the same scene is viewed) it is possible to mathematically transform them with the Principal Component Analysis (PCA) that "summarized" the information [2]. The first three components usually contain a high percentage (typically over 99%) of the information or variability in the original dataset. They can thus be expected to provide a basis for the visualization of all the shade direction data with minimal loss of archaeological features. The PCA components analysis - especially the combination of the first and second principal components, or the RGB composite of the first three - simplifies the interpretation of the multiple shading data (Figure 1C). However it does not provide consistent results with different datasets and is less appropriate that the sky-view factor image on several datasets where e.g. circular (especially concave, i.e. quarries) features are in question.

Height coding with the modulo distribution [3] dissects the area into equally high elevation bands and colours them according to the height within each band. The colour coding interval scheme is repeated in every band interval. This technique reveals the small differences within a flat landscape, while the bands can be interpreted as contours on a steep and diverse terrain. It is very illustrative for the discrimination of, for example, palaeochannels, especially when preceded by trend removal and combined with analytical hill-shading (Figure 1 D). Other methods such as logical and arithmetical operations, classification, visibility analysis, overlaying procedures, and moving window operations can be used for enhancing the edges of morphological features. For interpretation purposes the visualization usually combines the results with analytically shaded relief.

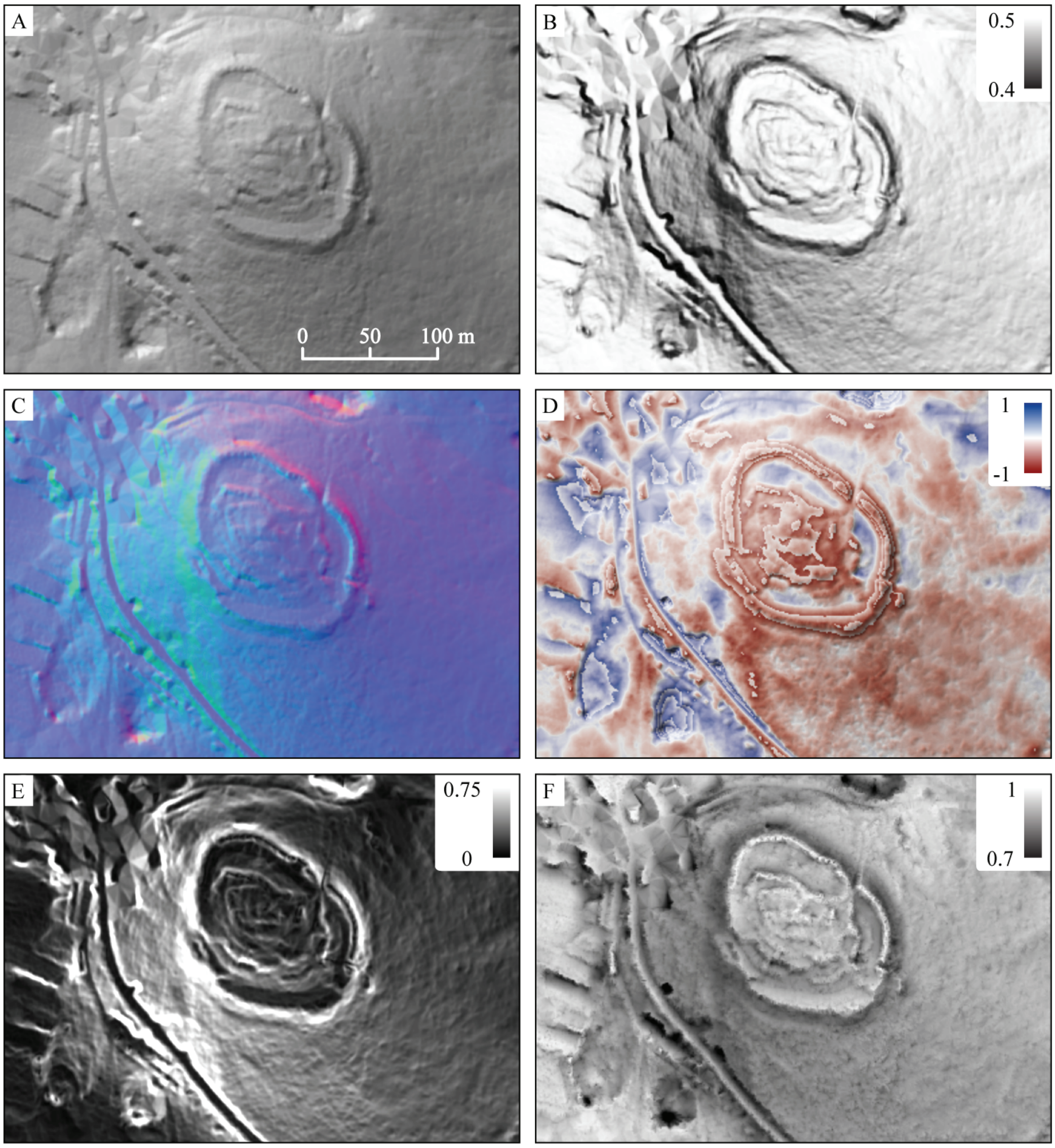

Figure 1. A comparison of visualization techniques used in archaeological interpretation: (A) standard analytical hill-shading (45° sun angle 315° azimuth), (B) the mean of analytical hill-shading from 8 directions, (C) a RGB composite of the first three components of the principal component analysis of analytical hill-shading from 8 directions, (D) Sobel edge detection, (E) sky-view factor (10 m search radius in 16 directions). Zagrajec hill fort, near Komen, Slovenia, is a known yet un-excavated site.

2. The sky-view factor

In order to overcome the directional problems of hill-shading we have used the sky-view factor (SVF) as an alternative method of relief mapping (Figure 1F & 3C). The SVF originates in geophysics and measures the portion of the sky visible from a certain point – the portion of the sky visible above the surface is especially relevant in energy balance studies – in general the surface warms up or cools down faster when a high portion of the sky is visible; several studies that investigate the correlation between the SVF and a heat island within a city or the correlation between frost and roads were preformed (e.g. [4,5]). SVF is also important for diffuse solar radiation – areas with a large SVF receive more diffuse solar radiation coming from the sky than areas that see only a small portion of a sky [6,7]. SVF additionally proved to be a superior visualization technique as it reveals small (depending on the scale of the observed phenomenon and consequential algorithm settings) relief features while preserving the perception of general topography. Rather than just presenting or visualizing the same information in a new way it extracts new information that can be further processed. In addition to the studies of the past cultural and natural landscapes it can be effectively used in other scientific fields in which digital elevation model visualizations and automatic feature extraction techniques are indispensable, e.g., geography, geomorphology, cartography, hydrology, glaciology, forestry and disaster management.

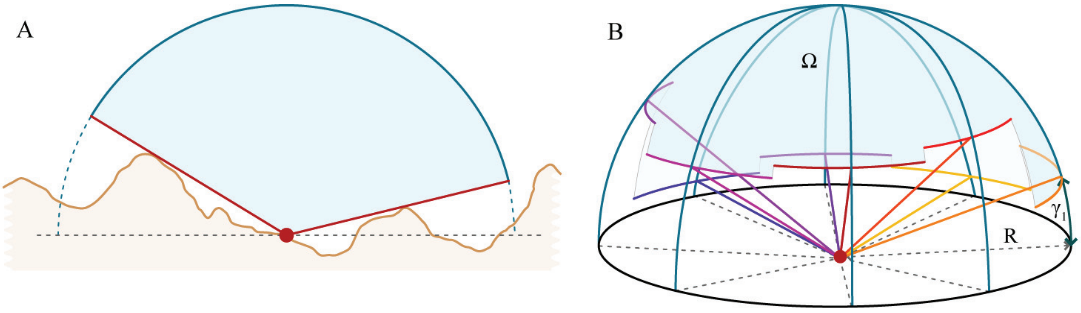

Figure 2. (A) The sky-view factor is defined as the proportion of visible sky (Ω) above a certain observation point as seen from a two-dimensional representation. (B) The algorithm computes the horizon angle γ in n directions (presented are eight) to the specified radius R.

Figure 3. Sv. Helena archaeological site, in the centre of the images, as visible on (A) a digital orthophoto (0.2 m resolution), (B) an analytically shaded lidar derived terrain (315° azimuth and 45° sun elevation; 0.5 m resolution), and (C) a sky-view factor image computed with a 10 m search radius in 16 directions..

The SVF computation is based on diffuse illumination. An imaginary light source illuminates the relief surface from the celestial hemisphere. The portion of the visible sky limited by the relief horizon (either terrain or surface, depending on the application) corresponds to the relief illumination; a ridge is more illuminated than the bottom of a steep valley because both are illuminated from the bright sky and more sky can be seen from the ridge than from the valley. The most convenient measure for expressing the portion of the visible sky is the solid angle, Ω, which is proportional to the surface area, S, of the projection of the object onto the sphere centred at the observation point, divided by the square of the sphere's radius, R ($\Omega = k \cdot S / R^2$) (Figure 2). The solid angle of the entire celestial hemisphere, which can be considered as the entire sky, equals 2π. In order to normalize the SVF between 0 and 1 the proportionality constant k is set to the value of $1 / 2\pi$ [8]. Values close to 1 indicate that almost the entire hemisphere is visible, which is the case in exposed features (planes and peaks), while values close to 0 are present in deep sinks and lower parts of deep valleys where almost no sky is visible.

The light that falls from the sky onto a certain part of the surface is reduced by the obstacles that form the horizon. These obstacles can be described in all directions by the vertical elevation angle above the horizontal plane. A good SVF approximation can therefore be performed with the estimate of the horizon vertical elevation angle in several directions. After the vertical elevation angle is determined in the chosen number of directions n, the SVF is determined as a sum of all portions of the sky within each direction: $\Sigma_i (1 - \sin \gamma_i) / n$, where γ_i is the vertical angle of the horizon in the direction i. The computation of the horizon in multiple directions is time consuming, thus simplified methods based on a relief slope analysis have been developed, but they are appropriate only for low resolution data and areas with a gentle geomorphology [9,10].

The SVF computation is additionally influenced by the search radius of the horizon. The larger the search radius the more generalized the results. When considering the effect of the relief on the diffuse solar radiation the search radius can be limited to 10 km. In contrast, a small search radius can be used to visualize and classify local morphological forms.

3. Results

We tested the potential of the SVF so that we could detect and map the remains of the past landscapes in several areas in Slovenia. As an example Sv. Helena, a known yet un-researched archaeological site, is presented here. It is located on a steep hill above the confluence of river Nadiža and its tributary Bela. Its setting is remote, but very suitable for a control point protecting the road towards the Italian territory. Broken pottery and tiles were found in the foundations dugout when Podbela villagers were building a wooden bell tower in the early 1990s, raising questions about a possible archaeological site [11]. An iron trilobate arrowhead has been coincidently found later. Arrowheads of this type were used in the late Roman period by the Roman army and Eurasian nomads [12] suggesting the site to be a Roman camp. Today the area is covered by a thick forest canopy, with only the immediate vicinity of the church unforested (Figure 3A).

Laser scanning of the Kobarid region (Slovenia), where the archaeological site is located, has been commissioned and performed (including data processing) with a clear focus on archaeological purposes. The survey was conducted in early March when the vegetation was not yet leafed, the ground was without snow cover and the fallen leaves from the autumn have already compacted – revealing the bare ground to the maximum degree. Lidar point cloud filtering with REIN algorithm (Repetitive Interpolation [13]) was less intense in order to remove the vegetation cover but leave remains of past human activities as intact as possible. The filter therefore preserved buildings, walls, dikes and trenches as well as retained some spruce trees, especially young, where the laser beam did not reach the ground.

No archaeological features can be recognised on aerial photography. While some remains can be noticed on a hill-shade image (Figure 3B), the sky-view factor renders a detailed plan of the site (Figure 3C). The shapes of buildings, earthworks and possible ramparts are all clearly revealed. An interpreted sky-view factor image gives an accurate and precise map of the site (Figure 4), gained with substantial timesaving than by traditional surveying.

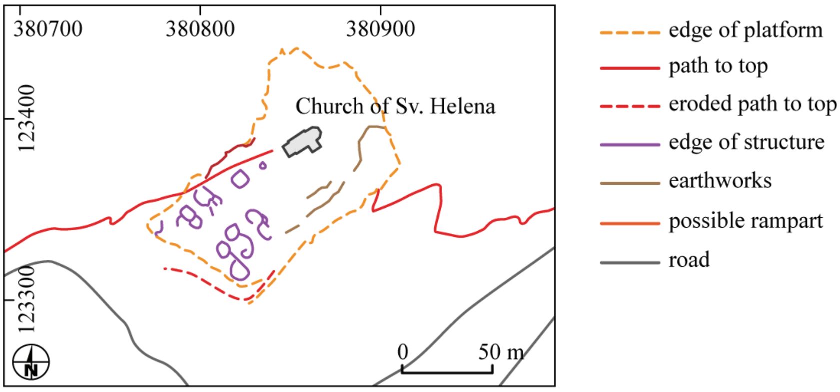

Figure 4. A ground plan (grey) of Sv. Helena archaeological site, Slovenia, as derived from a sky-view factor image.

4. Conclusions

A crucial advantage of lidar in the study of past landscapes is its ability to penetrate forest canopies. This enables detailed mapping and surveying of overgrown archaeological structures (houses, ramparts, trenches, ditches, etc.) [14,15], fossil fields and terraces [16], ancient land division (e.g. Roman centuriatio), abandoned quarries and mining areas, burial mounds, ancient roads (Roman, medieval), and other elements of cultural landscape in environments where other surveying techniques do not provide satisfactory results. Despite its obvious advantages, only some of its potential has been employed; the researchers usually use processed data provided by lidar operators, who in most cases fail to notice a substantial amount of information contained in the lidar point clouds. In the case of lidar DEM interpretation, in which subtle details can be detected, it is extremely important to use advanced visualization methods, not merely hill-shading as is most commonly the case.

Hill-shading is a method that considers merely the closest neighbours of a pixel (these pixels are used to estimate the relief slope and aspect that are required to compute the incidence angle of the light source). Hill-shading is therefore appropriate for representing sharp edges. Archaeological remains usually fail to have such characteristics as the destroyed walls are often mixed with other material that looks like gradual elevation anomalies. The optimal way to describe such remains is therefore not a method that describes every single pixel but a method that shows the context of the pixel within its surroundings. The sky-view factor, which is a proxy for diffuse illumination, is in our example the optimal visualization method because the sky-view factor reflects the amount of illumination received by an area regardless of its aspect. Therefore ridges, which receive more illumination, are always highlighted and depressions are dark because they receive less illumination.

We provide evidence that the sky-view factor based visualization of lidar elevation data can provide an effective means for the interpretation of past cultural landscape. It is suitable for visual interpretation and can be included in the first step of (semi)automated object recognition. We were able to map new and previously unmapped sites and enhance the existing maps of the known sites (e.g. Tonovcov grad where the excavations have been going on for decades).

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