Line-of-Sight Derived Indices: Viewing Angle Difference to a Local Horizon and the Difference of Viewing Angle and the Slope of Line of Sight

Jan Caha and Alexandra Rášová

Abstract The determination of visibility within GIS is often treated as a Boolean phenomenon. The surface is classified into two classes—visible and invisible parts of surface. This classification is result of the algorithm that compares whether a point of interest rises above all points on a line of sight that can be constructed between a viewing point and a point of interest. This comparison reduces all the information originally contained within the line of sight into simple true or false statement. However, the issue visibility is in fact more complicated than simple true/false statement. One of the other elements affecting visibility that has been already identified is the distance from the viewpoint or the relation of a point of interest and a local horizon. The distance affects the suitability of visibility: closer areas have obviously better visibility than distant places. Besides distance there are also other factors that can significantly affect visibility or more precisely the suitability of visibility. In this paper we would like to introduce two indices that can be calculated from the line of sight and that have potential to help user with better interpretation and also reasoning about visibility. The first index is based on the difference of the vertical viewing angle of a local horizon and a point of interest. The second index is the difference of a viewing angle and slope of line-of-sight (LoS) at the point of interest. Both these factors influence how well a point of interest is visible from a viewing point. The paper presents the methods and algorithms for calculation of these indices as well as case study to present these indices in a practical example.

Keywords Visibility analyses · Viewshed operation · Line of sight · Viewing angle

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1 Introduction

Visibility analyses (often referred to as viewshed operation (Fisher 1993, 1996) in GIS usually provide Boolean result classifying the surface into visible and invisible parts of the surface. The operation is known to be rather sensitive on quality of the input data—mainly accuracy of the surface. There has been a significant amount of research dedicated to this topic e.g. Fisher (1992, 1994) and (Nackaerts et al. 1999). While precision and accuracy of the surface is very important for the calculation of visibility it is only one of the aspects affecting the calculation. Another issue is that the nature of visibility in the real world is not Boolean. Indeed, the area can be classified into categories "visible" and "invisible" with respect to the observer. However, when describing the situation, the observer will probably describe what was visible well, what was barely visible and what he/she could not see at all. This is what Ogburn (2006) describes as "levels of visibility".

In this article the line-of-sight (LoS) refers to a line consisting of points with known x, y and z coordinates. LoS can be visualized as a profile of the surface between the viewpoint and the point of interest (Fig. 2). The process of calculating visibility can be divided into two main steps. First, the points of LoS on the grid are determined and their elevations are calculated. There are several variants of this part of the algorithm that are described by Fisher (1993). This step leads to the creation of the actual LoS, which is later used in the second part of the algorithm that is relatively simpler and consists of calculations on the LoS. While classic viewshed operation determines only if the LoS intersects the surface between the viewpoint and the point of interest, there are also other types of visibility that can be calculated. For example Fisher (1996) mentions the horizons viewsheds. The horizon viewsheds provide information about the position of a point of interest and local/global horizons, which enriches the information of classic Boolean viewshed. As mentioned by Fisher (1996) it is substantial for GIS users to understand the operations correctly and use them to answer queries that the operations are designed for, otherwise serious misunderstandings may occur.

In this paper we would like to present two indices that significantly enrich the information provided by the viewshed analyses. These indices are calculated from the LoS and provides user with better information about the visibility of points on the LoS.

2 Line of Sight Determination and Visibility Calculation

2.1 *Inferring LoS from Grid*

The visibility analyses are most often calculated on raster data model even though the variants of the algorithm for TIN do exist as well (Llobera 2003) (Fig. 1). Fisher (1993) identifies four possible approaches to the inferring of elevations on LoS:

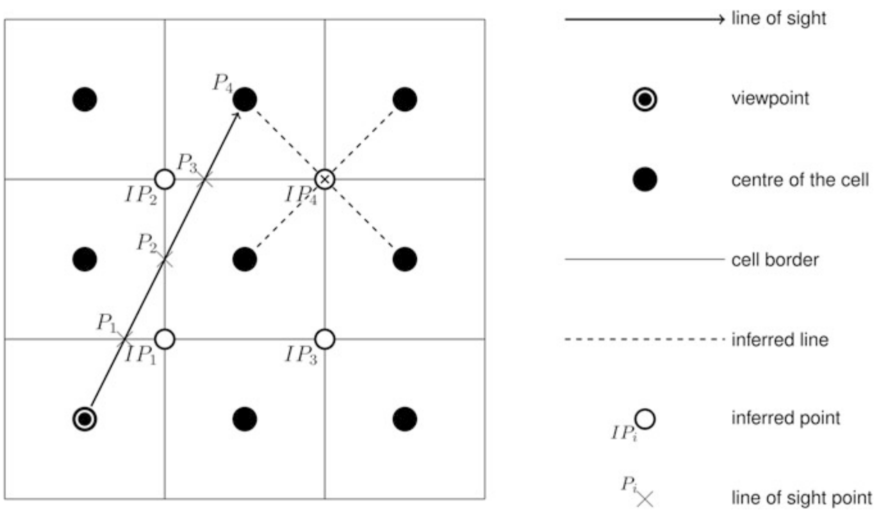

Fig. 1 The stepped model for inferring elevations from the grid

linear interpolation between grid neighbours, triangulation of the grid, grid constraint of the mesh and the stepped model. The choice of the inferring method does affect the result of the viewshed operation, because it determines how much and what types of elevations (besides the centres of cells of the grid) are added to the LoS. However, it does not affect the calculation of the indices from the LoS because the algorithms are not dependant on the specific structure of LoS. In this research the stepped model for the inferring of points and their elevation on the LoS is used. Figure 1 shows how the points on the LoS are obtained from the surface. The inferred points are calculated as mean value of four neighbouring cell values (as show on IP4) and the points on LoS are calculated as weighted mean of two inferred points on the cell border that the point lies on (e.g. P3 is calculated as weighted mean of IP2 and IP4).

2.2 Calculation on LoS

The LoS consists of viewpoint denoted V and a set of points P_i (Fig. 2). The viewpoint has the elevation Ve that consists of elevation of the surface at the location of the viewpoint plus an offset that describes height of the observer above the surface. Each point P_i has the distance from the viewpoint denoted as P_id and the elevation P_ie. Points are sorted according to their distance from the viewpoint from the closest to the farthest. The point with the highest distance is the point of interest. However, that does not apply in all cases; the calculation of the global offset viewshed (Fisher 1996) requires LoS to extend farther behind the point of interest. The points between

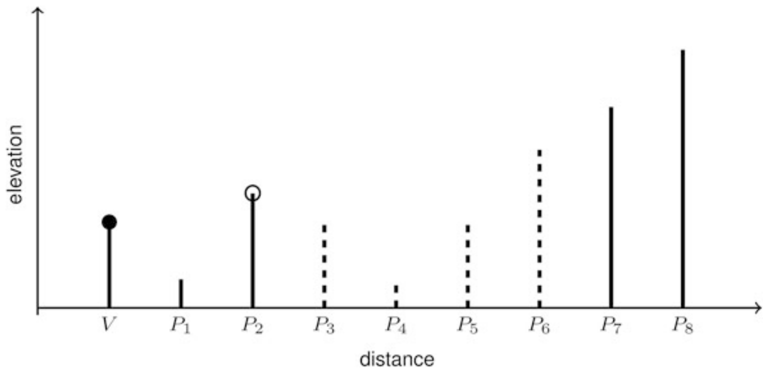

Fig. 2 The LoS with visible points shown as *full lines*, invisible points shown as *dashed lines*. The point P_2 is a local horizon

the viewpoint and the point of interest are used to determine whether the point of interest is visible. For each point P_i a viewing angle can calculated as:

$$P_i\alpha = \frac{180}{\pi}\arctan\left(\frac{P_ie - Ve}{P_id}\right) \tag{1}$$

A point P_n is visible if $P_m\alpha < P_n\alpha$ for all $m < n$. The determination of classic Boolean visibility is relatively simple calculation. Besides visibility, there are other indices that can be calculated from LoS, e.g. difference of the vertical angle of the point of interest from horizontal plane at height of the observer (Neteler and Mitasova 2004) or vertical difference of a point of interest from local or global horizons (Fisher 1996). For the purpose of this research, the local horizons on LoS are of interest as they will be further used in calculations. A local horizon is a visible point on LoS that is immediately followed by at least one point that is not visible. LoS may have several local horizons. A global horizon is a horizon where the terrain meets the sky; there are no further visible points behind it (Fisher 1996).

3 Proposed Indices

As mentioned previously, the LoS contains a lot of information about visibility, which, as Fisher (1996) showed, can be used for various applications, e.g. landscape planning or fire detection. In this section we would like to present two indices that should help users to reason about visibility and provide them with information not only about what is visible but also how well it could be visible.

Both proposed indices are based on viewing angle of the point of interest and its relation to other characteristics of LoS. Through the rest of the text the highest local horizon between the viewpoint and the point of interest will be denoted LH. In the same way as other points on LoS LH have the elevation LHe, the distance LHd and the vertical viewing angle LHα from the viewpoint.

3.1 Viewing Angle Difference to a Local Horizon

Fisher (1996) provided an index named local offset viewshed that is calculated as the difference of LHe and P_ie. Such index could be used to identify whether an object (e.g. building) of height x will be visible from the viewpoint. Indeed, this is a useful characteristic for the landscape planning or any other application where the difference of heights matters. With slight modification, this index can help the user to identify areas that are visible, but the difference of their elevation to the local horizon is so small that these points barely rise over the horizon. To identify such areas the actual difference of elevations is not important because it is not possible to compare elevations at different distances from the observer. To allow comparison, these elevation differences must be converted to differences in angles (according to Eq. (1)). For every point of interest the difference angle to a local horizon (Fig. 3) can be calculated as:

$$LH\Delta\alpha = LH\alpha - P_i\alpha \tag{2}$$

Two special cases may occur: if the P_i is not visible, then the value of $LH\Delta\alpha = -1$ denotes invisibility, and if there is no local horizon between the viewpoint and P_i then the value of $LH\alpha = -90$ is used for calculation to emphasize that the user is not limited by a local horizon thus the difference is calculated from the downward direction.

The utilization of viewing angle difference instead of elevations, as proposed by Fisher (1996), allows comparison of the differences at various distances. Elevations,

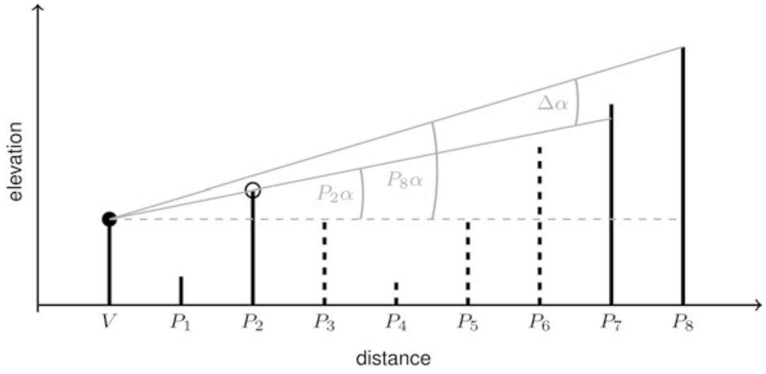

Fig. 3 Visualization of the angle difference to a local horizon (P_2)

on the other hand, can only be compared if they occur at approximately similar distance from the observer. This index provides information about how significantly the point of interest rises above the horizon; obviously points with small values will be barely visible. Also small value LHΔα can be used to identify points that can be easily affected by uncertainty of the surface. If the angle difference is small, then a small rise of the elevation of local horizon will render the point invisible, so this index can be used to point out areas that may be influenced by uncertainty.

3.2 Difference of Viewing Angle and the Slope of LoS

The slope of a surface is quite an important factor that indicates how well are specific parts of the surface visible. Imagine an observer standing in a relatively flat area with some hills farther away. This observer can see relatively well in the area close around him, but as the distance grows, the flat land is no longer well visible, because the slope of the surface aligns with the viewing angle. The hills on the other hand are likely to be well visible to him, because the slope there is higher. This is caused by the slope of surface intersecting with LoS with higher angle. An example is show in Fig. 4 where the viewing angle is denoted as $P_8\alpha$ and the slope of LoS is denoted as $P_8S\alpha$. The slope is defined by the point of interest (P_8) and the point that is just before the point of interest (P_7). If the point P_7 has higher elevation the angle difference would be smaller making the visibility of the point P_8 worse. On the other hand, if the elevation of P_7 is smaller than the angle difference would be higher and the visibility would be better. The reason why there is a need to calculate the angle difference and not only the slope of LoS is the situation when observer at elevated terrain looks on lower flat terrain. Such terrain is well visible to him, because the angle difference is higher.

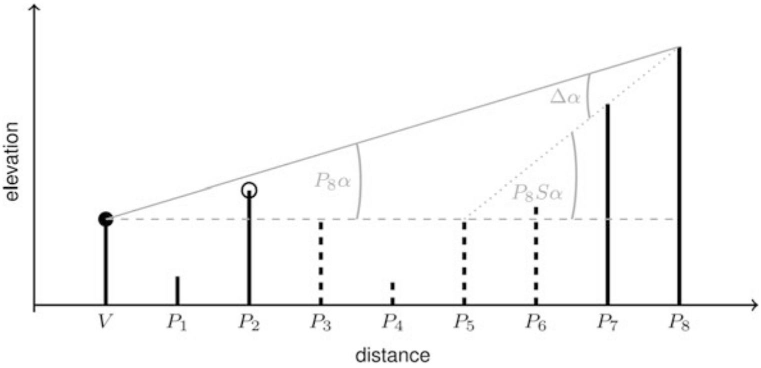

Fig. 4 Visualization of the angle difference to a local horizon

Formally the slope of LoS at point P_i is defined based on height of this and the previous point $P_{(i-1)}$ of LoS:

$$P_i S\alpha = \frac{180}{\pi} \arctan\left(\frac{P_i e - P_{i-1} e}{P_i d - P_{i-1} d}\right) \tag{3}$$

If the point of interest is P_1 then elevation of the viewpoint V is used as $P_{(i-1)}e$ (obviously the surface value is used—that means Ve without the offset of the observer) and $P_{(i-1)}$ d = 0.

The angle difference of the slope is than calculated as:

$$S\Delta\alpha = P_i S\alpha - P_i \alpha \tag{4}$$

The result is always a positive number. For the invisible points on LoS the value $S\Delta\alpha = -1$ is assigned.

4 Case Study

Visibility analysis is often used in archaeological studies to inquire about spatial relationships of monuments and their placement in the landscape, such as the analysis of Bronze Age cairns of Mull (Fisher et al. 1997), stone circles in Ireland (Flanagan 2006), Nasca geogplyphs in Peru (Lambers and Sauerbier 2008).

Proposed indices were used in the analysis of roundels located in the Western Slovakia, Piešťany district. Roundels are circular ditched structures from the Middle Neolithic era (first half of the 5th millennium BCE) that can be found in Central Europe (Germany, Austria, Czech Republic, Slovakia). Although they occur in various configurations and differ in sizes and forms, they share some common features: round form, four gates, one or more ditches, and a palisade. The function of roundels is still unknown, there are assumptions about their social, cultural, and ritual usage, astronomic calendar, solar temple, or more pragmatic function as a fortification, marketplace, or a shelter for people and animals (Melichar and Neubauer 2010).

Considering the nature of these monuments, it is relevant to analyse their placement in the landscape in relation to other roundels, significant landscape features, or astronomic phenomena. In this study we calculated the viewing angle difference and the difference of viewing angle and the slope of LoS for 3 roundels: Prašník, Šterusy, and Borovce. This dataset was provided by the Institute of Archaeology of the Slovak Academy of Sciences in Nitra. The location of these objects is visible from aerial photographs and was confirmed by geophysical measurement to verify their origin. The digital elevation model used in the analysis was the digital terrain model "DMR-3.5" with 10 m resolution provided by the Geodetic and Cartographic Institute Bratislava (GKU) (Fig. 5).

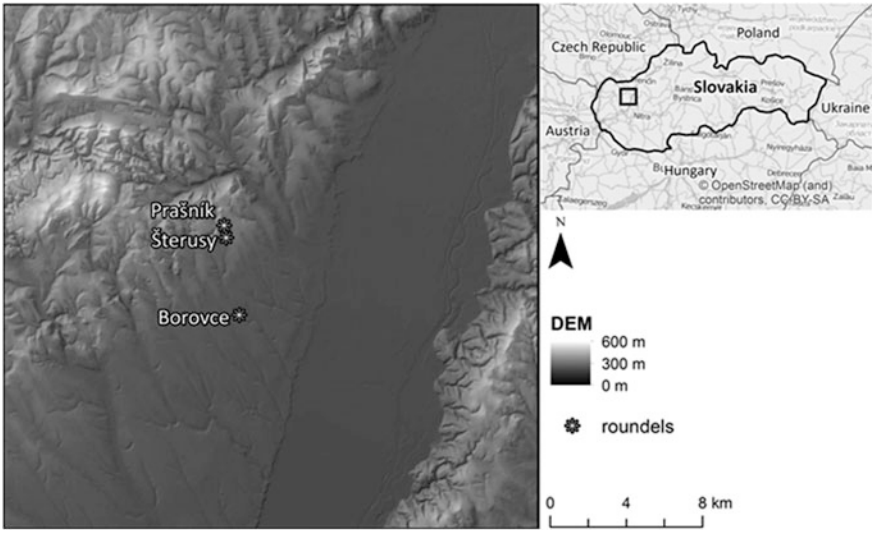

Fig. 5 The digital elevation model DMR 3.5 with observer points (roundels)

Computed indices—viewing angle difference to a local horizon and the difference of the viewing angle and the slope of the LoS—are valuable mostly in the analysis of the areas visible from the roundel in the landscape, but they can be used also in the analysis of mutual visibility of the roundels. In Fig. 6 there is the line of sight between two roundels, Borovce and Prašník, along with the illustration of the viewing angle difference and the difference of the viewing angle and the slope of the LoS. These indices confirm the mutual visibility of these points: viewing angle difference of 1.6° is higher than the human eye acuity (about 1 arc minute), and the difference of viewing angle and the LoS slope of 37°. This is also the case of the

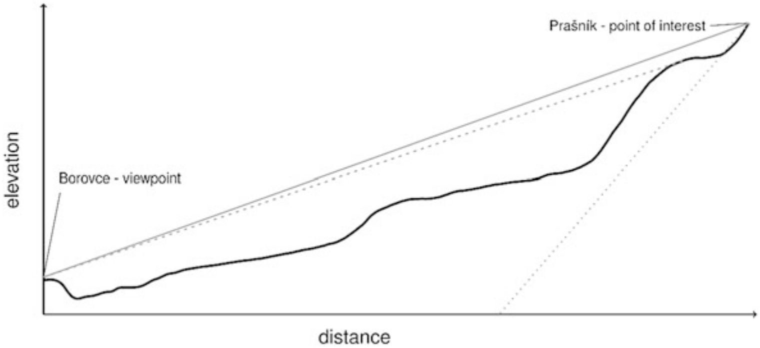

Fig. 6 LoS between two roundels. *Full gray line* shows viewing angle, *dashed gray line* shows viewing angle to a local horizon and the *dotted gray line* shows slope of LoS at the point of interest

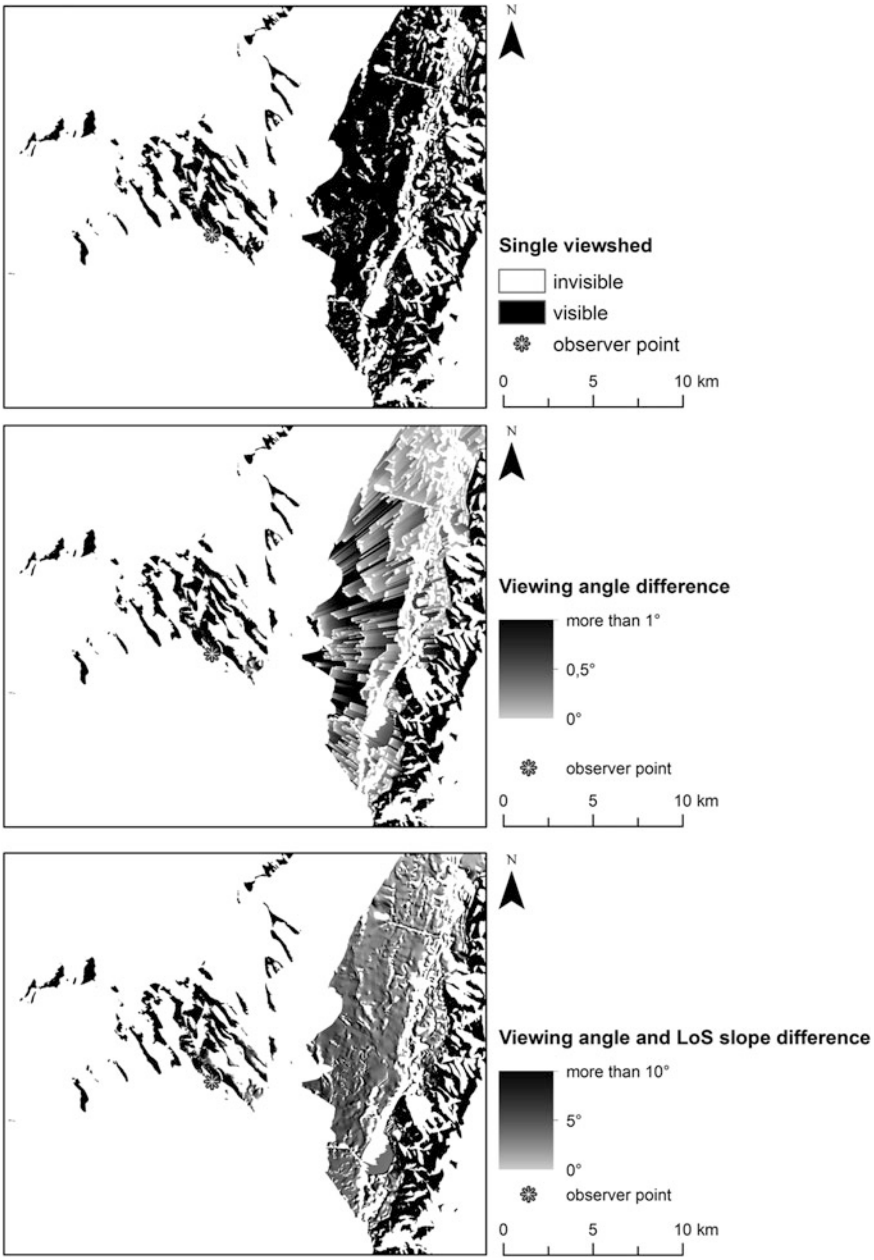

Fig. 7 Single viewshed (*top*), viewing angle difference (*middle*) to a local horizon, and the difference of the viewing angle and the slope of the LoS (*bottom*) computed for the roundel "Borovce"

other pair of visible roundels, Borovce and Šterusy (Roundels Prašník and Šterusy are not mutually visible despite the fact that they are very close to each other), which has the difference of viewing angle about 7° and the difference of viewing angle and the LoS slope about 35°.These values—and also the values of reciprocal indices computed for a situation with exchanged target and observer point—speaks for relatively good visibility between these points, especially considering the roundel construction, which could have been few meters high (offset above the ground), that would increase the value of the difference of the viewing angle.

More interesting is to examine the areas visible from the roundels (not specific points) to examine what portion of the landscape could have been observed and how well could this visibility been. An example is in Fig. 7, where the single viewshed, the viewing angle difference to a local horizon and the difference of the viewing angle and the slope of LoS is displayed for the roundel Borovce. While the single viewsheds provides only the information about visibility or invisibility of cells in the computing area, the two indices provide a piece of information with higher interpretation value about the suitability of visibility: the hills and hillsides have much higher values of both indices than the flatter areas in the valley. In the viewing angle difference we can observe that the areas with higher value of the index closer to the observer act radially as barriers for areas right behind them.

Using these indices it is possible to analyze the visibility more qualitatively and the results represents the reality better than the binary viewshed operation. They can be used to compare the visibility patterns of structures such as roundels in archaeological research to find whether the location of one of them could have been more preferable than the other, in future research maybe also with consideration of significant landscape features.

5 Conclusions and Future Work

As mentioned previously, visibility is more complex phenomenon than its representation in classic Boolean viewshed suggests. Fisher (1996) suggested several indexes that were designated for the usage in landscape planning. In this paper we propose two indices with more general utilization. The main purpose is to provide the user with more information that can be obtained from the line of sight. As mentioned by Fisher (1996), there are many possible queries regarding the visibility that the user may ask. The binary viewshed does not sufficiently cover all these queries, so new indices calculated from LoS are both necessary and useful. It is interesting that new variants of visibility algorithm (the boolean variant) are being proposed (e.g. Tabik et al. 2013), yet information that could be obtained from LoS is studied very rarely.

The proposed indices—viewing angle difference to a local horizon and the viewing angle difference to the slope of LoS should provide user with more information about the fitness of visibility and allow to reason about the visibility in a qualitative way. The binary information provided by classic Boolean viewshed is significantly enriched, as described on the case study. For both indices a limit values, denoting what is distinguishable in real world, could be identified. That would allow specific parts of visible areas, e.g. viewing angle difference to a local horizon smaller than 1 arc minute, to be proclaimed as invisible or problematically visible. However, specific values of these limits are a question to be answered. This is an issue for a further research. Another interesting topic for further research is the utilization of the proposed indices on visibility calculated from a line (Růžičková et al. 2012). In such cases the indices can provide information about how well are specific areas visible from a line, such line can represent for example a hiking trail or a road.

Both these indices could be also used in their reversed variants. The reverse variant of the viewshed algorithm according to Fisher (1996) is the calculation of pixels from which a specific point can be seen. Due to a problem with intervisibility, this is query differs from the one about the area visible from this point (Fisher et al. 1997). In the same way both proposed indices have a reversed variant. The reversed variant is describing the angle difference of a viewing angle to a specific point from a local horizon for each pixel of the surface. The second index then describes the difference of a viewing angle to a specific point from the slope of the LoS for each pixel of the surface. Both these variants would provide interesting information about how well a specific point could be seen from the area of interest. This issue will be studied in further research as it is of importance for archaeological studies.

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