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An Empirical Assessment of the Arcpro Visual Magnitude Viewshed Plugin

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ABSTRACT

Numerous viewshed analyses have been developed over the past few decades, but the uptake of these within industry has largely remained stagnant. This project involves ground-truthing one of the more recent viewshed analysis variants (Chamberlain and Meitner 2012, 2015) to assess reliability and application. This viewshed analysis was developed as a plug-in for the ESRI ArcGIS Pro software, making it readily accessible by anyone with an ArcGIS license. The validation of this software was recently conducted using an empirical approach to measure the accuracy of the analysis in the GIS versus real-world. Results demonstrate extremely high validity in controlled conditions, this degree of validity decreased substantially in highly variable terrain. This variability likely stems from measurement controls that are difficult to produce in real-world contexts. In this paper, the analysis, procedures and lessons learned are provided, as well as a call for additional empirical testing of viewshed analyses more broadly.

INTRODUCTION

Viewshed analysis is a common function in GIS (Davidson et al. 1993) and is regularly used in landscape management (Smardon et al. 1986; O Sullivan and Turner 2001; Palmer 2004; Germino et al. 2001). Management includes a range of infrastructural elements such as conducting visual impacts from wind turbines (Bishop and Miller 2007), evaluating impacts on tourism (Olafsdottir and Runnström 2011) assessing visual impacts from forest operations (Chamberlain et al. 2015; Pâquet and Belanger 1997) and assessing the visual impacts of motorways (Jiang et al. 2015) and important cultural elements (Ogburn 2006).

From the early days of their development until even a couple decades ago, viewshed analyses were nearly exclusively a binary output (Fisher 1996). This output determined places on the landscape that were visible or not by providing a zero (not visible) and one (visible). At the time, these analyses were used to conduct many of the landscape management assessments listed above. However, in recent decades there has been a growing trend toward improving the means whereby visibility is measured, including early references to fuzzy viewsheds (e.g. Fisher 1991, 1992, 1993, 1996) which aims to represent visibility using probability or likelihood that an area is visible.. In the past couple of decades alone there has been a surge of new methods and applications, particularly those oriented toward human-centric aspects of visibility. Some examples include human perception of forest landscapes (Domingo Santos 2011), tourist experiences along highways (Chamberlain and Meitner 2013) and the perception of visual impacts to recreational places (Grêt-Regamey et al. 2007; Vigl et al. 2017).

While the variety of viewshed methods have grown, the reality is that they are not trivial to create (in code). Thus, practitioners rely on preexisting tools to help them facilitate viewshed analyses. Several viewshed analyses presented in the literature offer plugins for various GIS software (e.g. ArcGIS, GRASS or ERDAS). However, few of these are available as plugins for the most common adopted commercial

software that practitioners use: ESRI ArcGIS. With ESRI's migration toward their new ArcGIS Professional platform, preexisting plugins may no longer function. For this project, we use a ArcGIS plugin developed by Čech and Chamberlain (2018) as an adaptation from (Chamberlain and Meitner 2013). This software provides a far more nuanced analysis than the viewshed tool that comes standard in ArcGIS software. Whereas the viewshed analyses provide only a binary outcome (what you can and cannot see), the plug-in provides a degree of visual magnitude from one or more key observation points. Visual magnitude provides a metric for visual relevancy which, among numerous applications, can help professionals mitigate negative visual effects from development, prioritize the placement or arrangement of new infrastructure or optimize recreational routes for scenic vistas.

The focus of this paper was to conduct a ground-truthing of the software in real-world conditions. Previous work has examined the role data accuracy plays on the reliability of viewsheds primarily as a comparison to different kinds of algorithms and terrain models (Klouček et al. 2015; Maloy and Dean 2001; Riggs and Dean 2007). This project focused on assessing the accuracy of visual magnitude as calculated using a digital elevation model, relative to an assessment conducted on real-world terrain. The systematic empirical approach measures the difference of these two methods to compare the accuracy. The key research question of this research was: *to what extent does visual magnitude correlate with measures of visibility in the real-world?* To answer this question, a set of procedures and tools (UAV/drone, Adobe photoshop, ArcGIS Pro with the plug-in, georeferencing, and field-based measurement were conducted. Finally, a correlation analysis between the plan (plug-in-based) and perspective (field-based) views were conducted to determine the reliability of the method and model.

METHODS

The approach to this project involved numerous steps and technical procedures both in and outside of the Visualization, Instrumentation and Virtual Interactive Design Laboratory (http://laep.usu.edu/vivid). These procedures included the selection of sites and viewpoints, a structured sampling approach and methods to compare the Visual Magnitude analysis derived from digital models of the earth and that of a real photograph. All project boundaries were held consistent and updated aerial imagery was captured to ensure the most precise and updated spatial resolution. These procedures are highlighted in Figure 1.
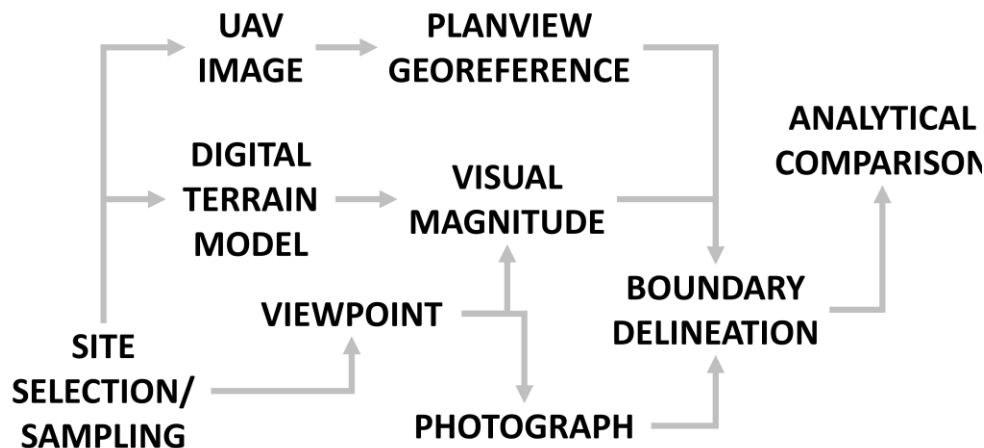

Figure 1: Methods Procedures, starting with site selection through a comparative analysis between visual magnitude plugin and real-world photograph.

Study Site

The project was conducted within Logan, UT at two distinctively different areas. The first location was at Maverick Stadium (41.7517204 N, 111.811642 W) at Utah State University and the second was at the southern entrance to the Logan Canyon Scenic Byway (41.741731 N, 111.786229 W) as depicted in Figure 2. Maverick stadium provided a near flat surface (football field) with varying options for collecting photos at different heights and locations. Additionally, the field provided existing markings that were highly regulated and controlled. Entrance to Logan Canyon is marked by the low point of two distinctive mountains (each over 1500m above the valley entrance) that have steep undulating terrain. These two sites were selected to provide extreme topographic conditions from which to evaluate the validity of the analysis.
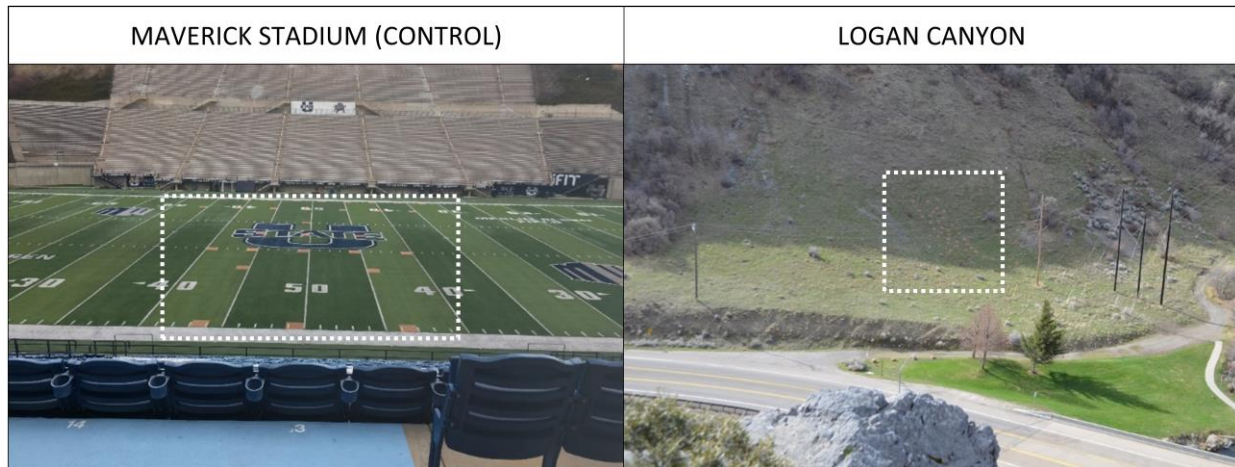

Figure 2: Two sites used in the study. Maverick (Football) Stadium with well defined measurements and clear hash marks (control). Logan Canyon with high topographic variability.

Approach

The methodology procedures represent a linear process whereby the digital assessment using the ArcGIS Pro plugin is compared to a real-world representation. This started by establishing a sampling method that distributed 30 sample locations within each site. These sample locations were indicated by 1m^2 plots of lightweight, orange tule fabric. Within each site, each fabric square was staked as flat as possible on top of the surface. These were not randomly distributed because the context limited this kind of distribution. Examples from each site are shown in Figure 2 within the dashed boxes. At Maverick stadium, we intentionally included sample squares on each of the four project edges, with relatively equal spatial distribution allowing use of existing hashmarks, providing a precise ground reference for aerial imagery (UAV Image in Fig. 1). At the Logan Canyon site, a pseudo-random distribution of sample locations was used. This was effected by topographic limitations (staying away from very steep locations for safety), creating minimal impact on vegetation and soil conditions, and finding large enough areas where vegetation did not significantly influence the plane of the fabric (ideally fabric would be a flat plane on the surface as in the first site location). Each sample location was placed while an assistant was confirming that each location would be captured from within a camera lens.

After the sample fabric squares were placed at each site, photographs were captured from a designated viewpoint. The photographs were collected using a 50mm lens to minimize distortion, particularly at the edges (Palmer 2008). Additionally, an UAV captured aerial photos of the same site, directly over the center of the boundary of the sample fabric grids. These photographs were later modified using geospatial and photo editing software. The UAV Images were georeferenced using ground references

within the GIS system. A Combination of known GPS locations and landscape features were used. At Maverick Stadium, the intersections or ends of white painted lines (e.g. hashmarks), or features identified within the U-State logo were used. This is a standard process outlined in georeferencing functions within ArcGIS. At the Logan Canyon site, landscape elements such as rocks, tree trunk bases, poles and other identifiable features were used to georeference the aerial image, as well as known GPS locations recorded by cell phones. For each of these sites at least a dozen georeferenced points were used. The Root Mean Squared Errors (RMS) are as follows: Maverick Stadium (15ft) and Logan Canyon (<3ft). Lower RMS indicates higher accuracy and better alignment of the low-resolution aerial imagery available within ArcPro with the higher resolution UAV imagery. At this point in the process, all imagery had been prepared for photo editing, and the next step was to generate the Visual Magnitude analyses.

Visual Magnitude requires two datasets, viewpoint(s) and a digital elevation model. The lat/long location of the viewpoints used for the photographs were also used in the production of the Visual Magnitude analyses. The City of Logan, UT provided a 1m digital elevation model interpolated from a 10-25cm resolution lidar dataset. The resolution of this dataset was matched with the resolution of the sample fabric grid size. These two datasets were then used to produce a Visual Magnitude analyses for each site using the ArcGIS Pro plugin.

The final two components of the methods focused on analytical comparison of the two different approaches (Visual Magnitude and real-world photograph). First, all imagery produced (Visual Magnitude) or captured (photograph and UAV imagery) were calibrated using a shared boundary. The shared boundary was developed by delineating the edges of the four corners of the fabric grid sample locations in both the photograph and georeferenced UAV imagery. This provided a means to compare the perspective view photograph and the Visual Magnitude analyses such that the area represented by the gridded fabric squared was relative to the entire area of consideration (boundary). If this was not done, the measures would not be consistent as the perspective view would have a different extent than the aerial imagery.

With the boundaries delineated, each of the two comparison methods were then measured. For the real-world context, Adobe Photoshop (polygon lasso tool) was used to edit the photograph such that only the boundary was included as raster values (white), each of the fabric grids were converted to black (increased visibility for human operator) and values outside the boundary were empty. Then each fabric grid was assigned a unique identifier and the total cells in black, for each sample location (were counted and divided by the total area within the boundary.

This same photoshop editing procedure was used for the georeferenced UAV Imagery with one difference. Once the photoshop editing was done, the image was brought back into ESRI ArcGIS Professional. Then, the image was used to extract the Visual Magnitude values using only those values within the boundary (white pixels in photoshop UAE Image). Then the black pixels from the photoshop image was converted to polygon. These polygons were assigned the same unique ID as with the photograph fabric grid locations. Zonal Statistics was then used to extract the sum of Visual Magnitude values for each of the unique IDs. This value was then divided by the sum of all Visual Magnitude values for the entire boundary. Figure 3 depicts the process including the modification of the photograph and overlay of the UAV image onto the Visual Magnitude output.
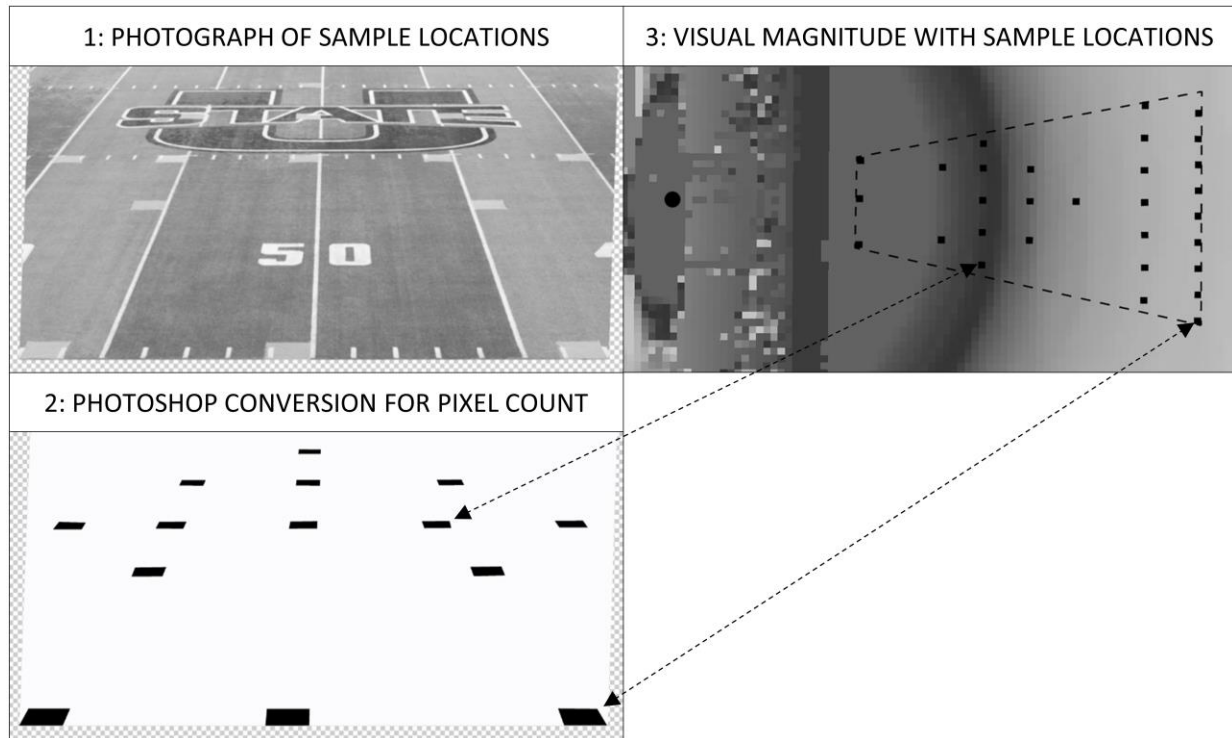
Figure 3: Images depicting the fabric square sample locations (1), conversion in Photoshop (2), and in the case of the aerial imagery, they overlay onto the visual magnitude analysis (3). Hashed lines indicate the scheme of perspective (2) and plan (3) views where each sample location was calculated relative to the extent of the tightest boundary of all sample locations.

These efforts were done very carefully, but inevitably there is error in this process. These errors cannot be mitigated by automated computer techniques alone. The human operator needs to address how to delineate each of the boundaries and fabric grids amidst topographic variation, perspective view warping and image quality. Considering these elements, our attempts as systematizing the process resulted in mixed results. Nevertheless, the procedures demonstrate a very direct means to empirically measure the difference between real-world perspective view and the digital representation using Visual Magnitude.

RESULTS

Correlation coefficients were generated for each of the sites (Maverick Stadium and Logan Canyon) by comparing the GIS-based plan assessment (visual magnitude plug-in) and perspective measurements (field-based). One of the benefits of the visual magnitude plug-in, as identified in Chamberlain and Meitner (2013), is that all values are absolute measures ranging from 0-1. The output from each site, relative to the perspective, is thus directly comparable to the perspective view photograph assessment.

Figure 4 depicts the first comparison at Maverick Stadium. On the graph, each dot represents one of the 30 fabric sample locations. The result provided and R^2 of 0.9981, suggesting that the theoretical calculations are extremely accurate and precise at the 1m resolution, relative to the photograph. The outcome is arguable a good control condition given the very high correlation. While the correlation was high, the match between the calculated values from both methods align quite well. The lower values (less than 0.15%) appear to have a near perfect 1:1 correlation, while the three sample locations with

values above 0.35% are not quite as precise. These three sample locations are the nearest of the three locations relative to the viewpoint.
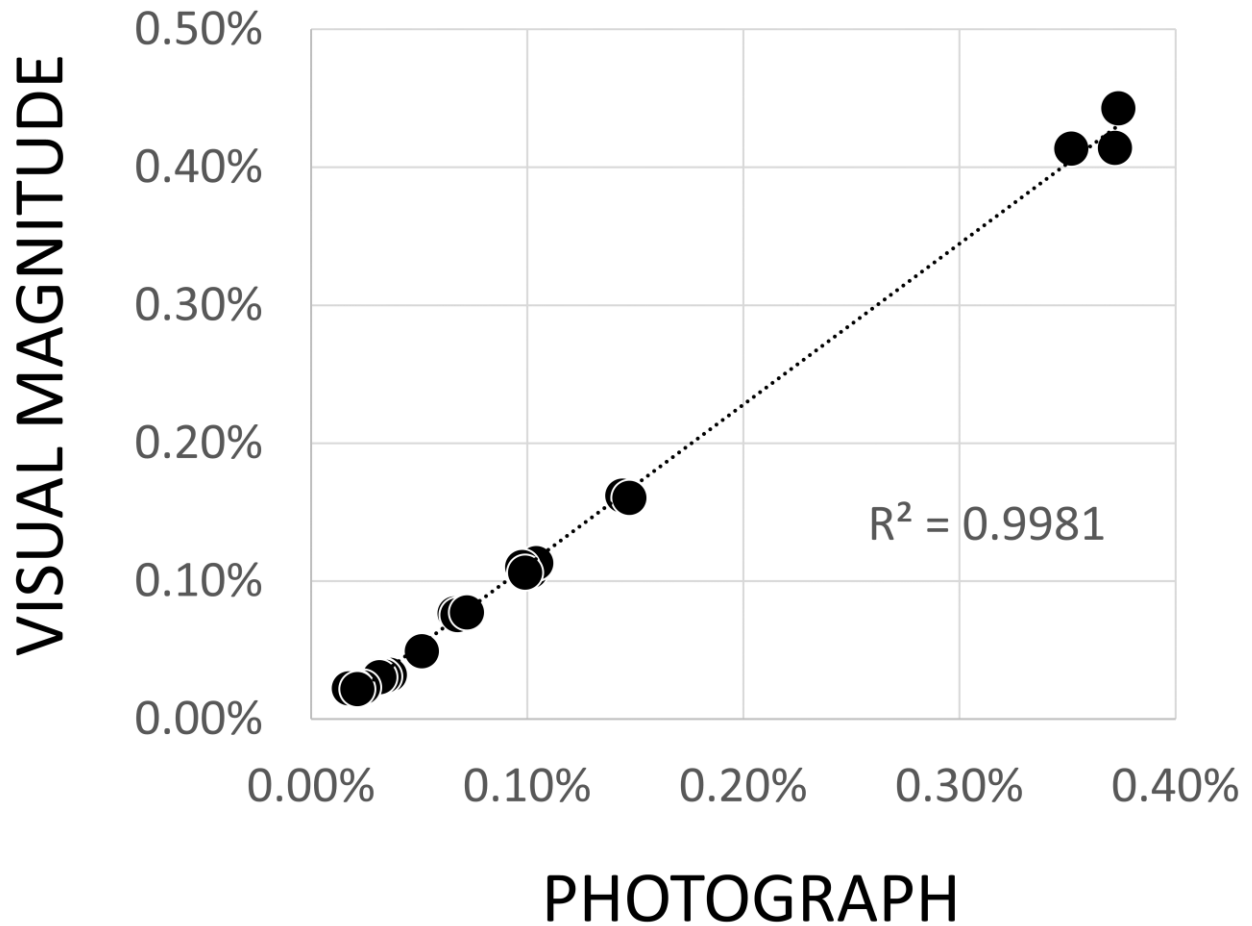

Figure 4: Results from Maverick Stadium comparing the visual magnitude analysis and the photograph in the real-world setting. Both values were calculated using the same viewpoint location and boundary.

The result from the second site (Fig. 5) Logan Canyon follows the same representation, with each dot depicting one of the 30 fabric sample locations. This result varied substantially from Maverick Stadium. The result provided and R^2 of 0.3904, suggesting that the Visual Magnitude calculation does align with the photograph, but there are other factors that may influence the accuracy of this output. Logan Canyon values in both the photograph and Visual Magnitude values range roughly 1% - 5% of the absolute values measured at Maverick Stadium. This variation is mostly due to the viewpoint at Logan Canyon being much further away from the sample locations than at Maverick Stadium. Like Maverick Stadium, the three highest values are representative of the three closes sample locations.
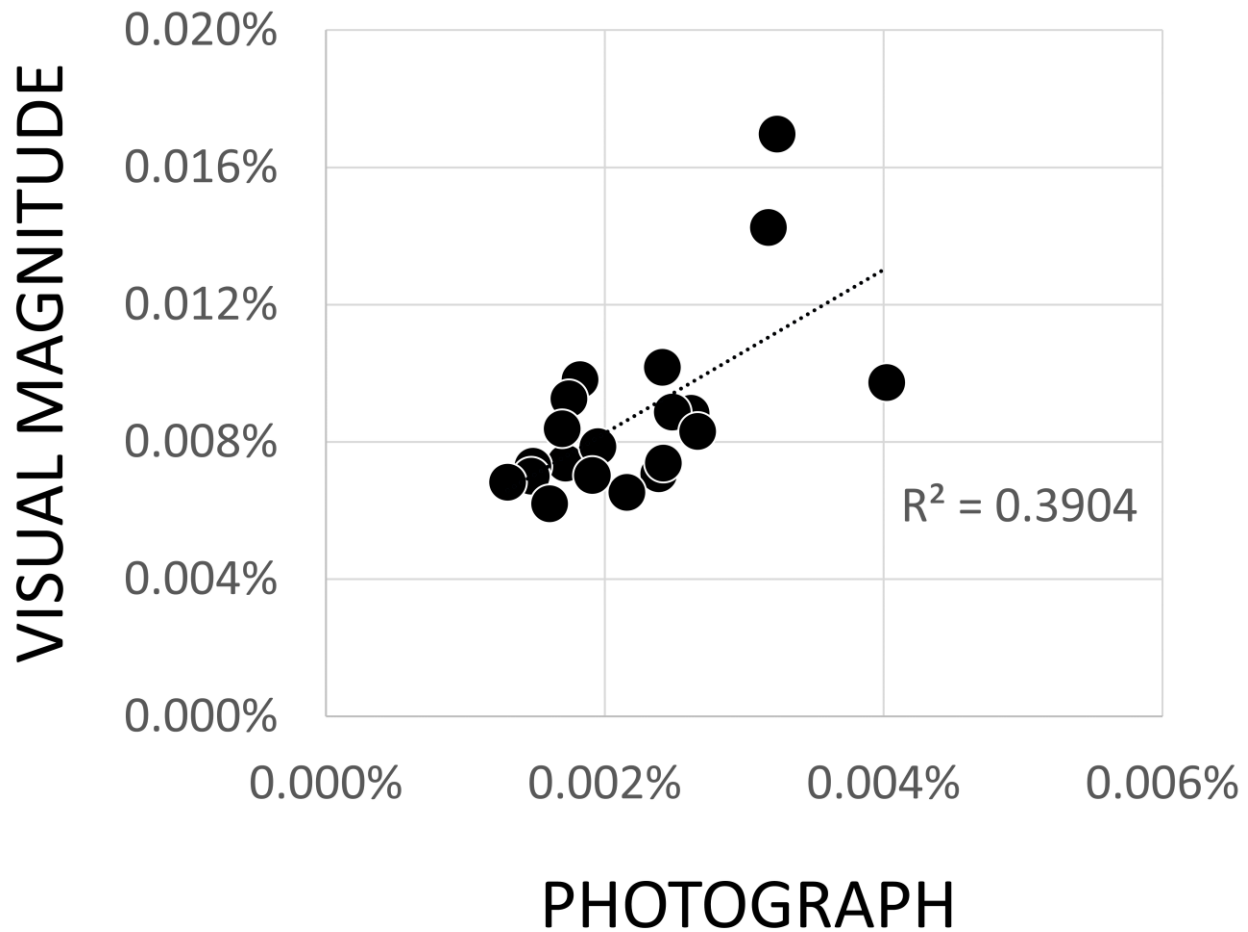
Figure 5: Results from Logan Canyon comparing the visual magnitude analysis and the photograph in the real-world setting. Both values were calculated using the same viewpoint location and boundary.

DISCUSSION

Klouček et al. (2015) argued that data accuracy could play a role in the accuracy of viewshed models, demonstrating that higher resolution digital surface models increased the accuracy compared to real world visibility. The empirical approach conducted for this paper used a high resolution ($1m^2$), similar to that in Klouček et al. (2015). However, while these authors used a standard viewshed (binary), this paper used the Visual Magnitude plugin, which adds additional variables and thus demands greater precision to the calculation of visibility. Results from this research demonstrate that in a controlled environment (Maverick Stadium), the plugin is extremely reliable, approaching nearly perfect correlation between the real-world measure and the result from the plugin. A high correlation was expected (Maloy and Dean 2001), but these numbers exceeded expectations, suggesting that the mathematical approach is justified as a foundation for this analysis.

Nevertheless, the results from the second site, Logan Canyon, deviated substantially from the control site. This deviation suggests that other variables were substantially influencing the comparative model. After multiple efforts to measure, calibrate and improve the precision of the data, these results hold firm. Through these efforts to investigate possible causes to the lower correlation, several variables seem suspect. Should one move forward to expand testing of the empirical data, the following are recommendations.

Increase the resolution of the photographs (both from the viewpoint and the UAV) and take multiple measures for each sample site location. While the digital surface model was held constant at a 1m^2 and the fabric samples were cut to the equivalent size, the variation in resolution of the photographs could play a key role in predicting model accuracy. Both photographs used to capture the amount of each fabric square were edited in photoshop. This required the user to manually delineate the edges of each of the fabric squares. In the Maverick Stadium example, each of the fabric grids constituted between 1,600 - 35,000 pixels (furthest to nearest sample locations), whereas in the Logan Canyon example the fabric grids constituted about 150 – 200 pixels in total. In the cases of the extremely small values in the Logan Canyon example, this represented selecting edges of a very small number of pixels in the photographs, likely leading to more error in the delineation process, not just due to the fewer number of pixels available for selection, but also because the resolution made it harder to identify the edges of the fabric in the image. Despite the challenge in determining the fabric edge, the mere conversion from raster to vector increases the likelihood for modelling error (Goodchild 1989). Increasing the resolution will increase accuracy that can be effected by topographic and distance variation (as indicated in Chamberlain and Meitner 2013).

Another likely culprit in the model error for Logan Canyon was the georeferencing process. In this process a UAE image was generated from multiple stitched images to provide a higher resolution image of the site. The process required the identification of control points in existing aerial imagery. Unfortunately, the existing imagery lacked good surface control points, requiring the use of less accurate features, such as the base of trees, power poles, large rocks and limited edges (trail, road, etc.). Instead of using these control points, we used 23 GPS control points collected from cell phone signal to georeference the image. The result was a RMS error of about 15ft., which varied substantially from the Maverick Stadium RMS of less than a few feet. The challenge of relying on poor control points, lower precision GPS devices and in an area with high topographic variation (average slope about 10° or 17%), likely contributed to the overall error. Errors from this process would only be exacerbated by resolution of the UAE image creating a combination of hard to delineate edges that may have been incorrectly located on the real-world surface.

Another likely candidate in contributing to the error with the Logan Canyon example is the representation of the surface using the fabric grids. In the Maverick Stadium example, the 1m^2 fabric squares lay perfectly flat on the surface, minimizing edge distortion. However, in Logan Canyon, the fabric squares were difficult to lay flat due to vegetation, rocks and topographic variation caused by erosion, even within one meter. This resulted in edges that were not linear between each edge vertex. This likely resulted in some degree of error when attempting to delineate the edges in both the photograph and aerial image. To improve on this condition, a rigid material (e.g. foam board or plywood) could be cut to 1m^2 and laid on the surface.

These potential contributors to error in the Logan Canyon example highlight the challenge of empirically testing the accuracy of viewshed analyses. While the Maverick Stadium demonstrated that, theoretically, the plugin does accurately correlate with the real-world condition, it is a very simplified condition. Given the results from Maverick Stadium, it is likely that the measures provided by the plugin can be relied upon, even if the results from Logan Canyon seem inconclusive. Given the likelihood that image resolution, georeferencing and the surface sample material explain a large degree of the error in Logan Canyon, improving these elements would likely improve the correlation of Visual Magnitude plugin with that of the real-world.

The results from this experiment suggest two recommendations for future development of viewsheds. First, that viewshed should be thoroughly tested to assess the reliability across multiple conditions and contexts in the real-world. The proposed method offers one means to evaluate the accuracy of the Visual Magnitude (or related visibility analyses), whereas Klouček, Lagner, and Šímová (2015) or Maloy and Dean (2001) offers means to evaluate binary viewsheds. Second, it is recommended to test a range of digital surface resolutions, topographic conditions and using various instantiations of photographic or aerial imagery resolution.

CONCLUSION
The Visual Magnitude plug-in used for this project was empirically evaluated for its accuracy in real-world conditions. In a highly controlled environment (football stadium), with no change in slope and existing verifiable measurements, the plugin showed very high accuracy and precision with R^2 greater than 99%. In a less controlled condition, correlation was found to be far inferior, however, this is likely due to a combination of high topographic variation, limited digital resolution and representation of sample site locations. While further research should be conducted to validate the plugin in more conditions, the theoretical measurements do demonstrate high fidelity. This plugin is freely available and can be used by a variety of industries involved in natural resource management. Continued use and evaluation can help to improve the validation processes, algorithm and help landscape management practitioners understand the limitations, benefits and best practices for these kinds of tools.

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