Optimising terrestrial LiDAR field deployment

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Summary: Terrestrial laser scanners use near-infrared pulses to acquire detailed 3D measurements of their surroundings. Acquiring datasets in dynamic, rugged, non-urban environments is a complex task presenting significant project planning challenges. Here, we introduce a methodological approach that has been used to develop a set of survey project planning tools designed to optimise scanner field deployment. These tools use geospatial processing based on viewshed analysis to estimate the optimal scanner deployment configuration and calculate required scan parameters**.**

KEYWORDS: Terrestrial laser scanner, viewshed, project planning, optimisation, deployment

1. Introduction

Terrestrial laser scanners (TLS) are tripod-mounted instruments that use near-infrared laser pulses to acquire 3D measurements of their surroundings. Data can be acquired at ranges of up to several kilometres providing significant capacity to obtain high spatial density topographic datasets of hazardous and difficult terrain (Sturzenegger and Stead, 2009; Welkner et al., 2010; Du and Teng, 2007). Here, we focus on TLS use in non-urban environments, where data are collected for a wide range of applications including landslide and slope stability assessment (Dunning et al., 2009; Viero et al., 2010; Teza et al., 2008), glaciology (Schwalbe et al., 2008; Avian et al., 2009), and volcanology (James et al., 2009; Pesci et al., 2008).

However, the availability of tools to efficiently plan and manage scanning projects lags behind the current developmental state of scanner hardware. TLS measurements require line-of-sight visibility between the scanner and the target and, as such, acquiring datasets in dynamic, rugged terrain typical of many field sites can be a complex task presenting significant project planning challenges. In most cases, scan data need to be acquired from multiple locations in order to capture the full geometry of the target. Identifying site locations that maximise target coverage whilst minimising the number of times the scanner needs to be relocated is critical in order to increase efficiency in the field and enable rapid measurement of regions of interest. Limited TLS portability and accessibility restrictions to potential deployment locations also add to the complexities involved in scanner project management.

This paper introduces a methodological approach that has been used to develop a set of survey project planning tools to optimise TLS data capture in the field. These tools use pre-existing but low-resolution digital elevation models to estimate the optimal scanner deployment configuration and to calculate scanning parameters required.

2. Planning tool methodology

The TLS project planning tools have been developed in the open source GIS software package Quantum GIS. Using geospatial processing based on viewshed analysis, it is possible to derive predictive maps that enable the identification of potential deployment sites that would maximise scanner coverage of the target.

A viewshed represents the region visible to an observer from a given location. Viewshed derivation is undertaken by calculating the line-of-sight visibility between cells on a raster Digital Elevation Model

(DEM) and relies on the same fundamental principle of intervisibility between an observer and target that is also critical in TLS data capture. Consequently, viewshed analysis provides a technique that allows the prediction of the visible extent of surfaces from given scanner locations. Viewshed analysis is computationally intensive, thus the project planning methodology developed aims to minimise the processing overheads to enable flexible and rapid re-calculation of parameters in the field.

The calculation of optimised deployment parameters is defined by three fundamental steps:

1. *Site characterisation*: The scanner target is defined and intervisibility across the field site is calculated. A distribution of good TLS locations (subject to practical and access constraints) is determined.
2. *Optimisation of scan locations*: The minimum set of TLS locations that allow maximum/full coverage of the target is estimated.
3. *Calculation of scan parameters*: The geometric parameters required to automate scanner control at each location are derived.

2.1 Site characterisation

In order to start the analysis, the target area is defined as a vector polygon representing the region required to be scanned. The initial step then uses a cumulative viewshed approach to characterise the surrounding area in terms of its visibility from the target. For each raster cell in the defined target, a viewshed is calculated (using the pre-existing low resolution DEM) representing the estimated visibility across the field site from that cell (Fig. 1). All the calculated viewsheds are then summed to produce a cumulative map illustrating the number of times each cell in the DEM can be seen from across the target.

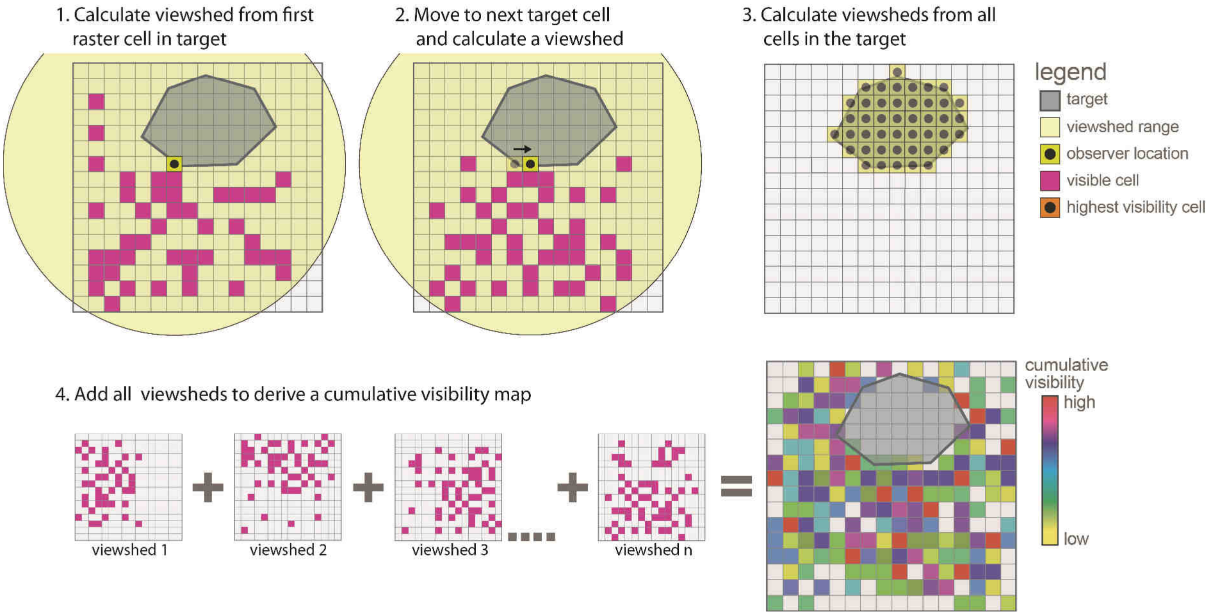

Figure 1. Cumulative viewshed analysis.

Site characterisation is further extended by creating a set of vector features defining real-world, site-specific constraints that influence scanner deployment. Using freely available online aerial imagery, features such as forests, lakes and difficult to access locations are identified, digitised, and can be excluded from the analysis (exclusion zones). Roads and footpaths are also digitised and can be used as constraints limiting the analysis to linear features that may represent the most accessible locations. Other areas of easy access (inclusion zones) can also be defined. The site is then divided into an 'observation' grid at a user-defined grid interval. For each observation grid cell, by combining the deployment constraints and cumulative visibility map, the accessible location with the maximum target visibility can be determined (Fig. 2).

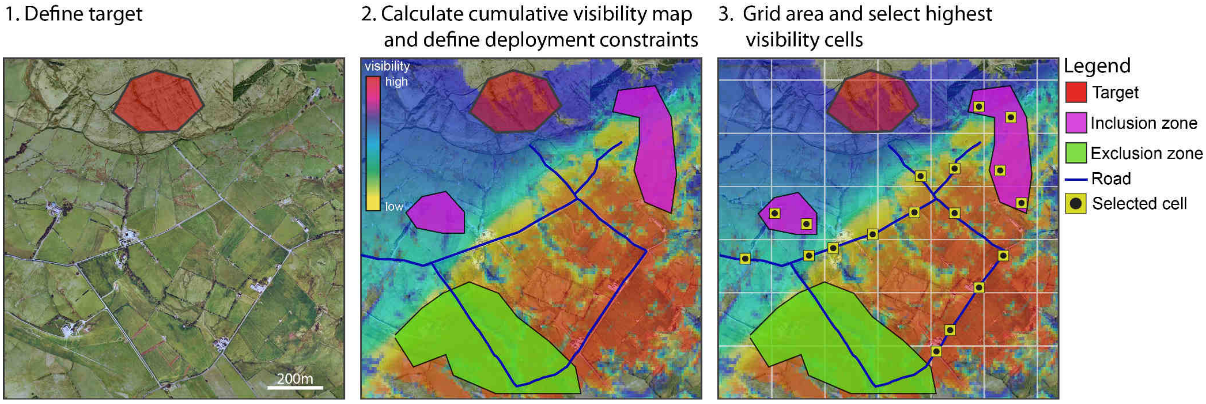

Figure 2. Field site characterisation. Spatially distributed high-visibility points are identified by selecting the cell in each grid box with the highest cumulative visibility that also meets the requirements of the defined deployment constraints.

2.2 Optimisation of scan locations

The scan locations identified in the site characterisation give practical areas of good target visibility, but the minimum set of sites required for full (or maximum) target coverage is not yet defined. Consequently, the next optimisation is to identify the best of these locations to maximise spatial coverage of the target whilst minimising the number of scanner deployment sites. The initial cumulative visibility map records the number of target cells that can be seen from selected locations across the field site, but does not record which cells in the target these are. By calculating a second set of viewsheds that use the high-visibility points selected in the characterisation stage as the observer locations, the actual spatial extent of target visibility from each point is derived (Fig. 3). By testing combinations of these viewsheds, it is possible to determine the optimal locations from which data should be collected (Fig. 4).

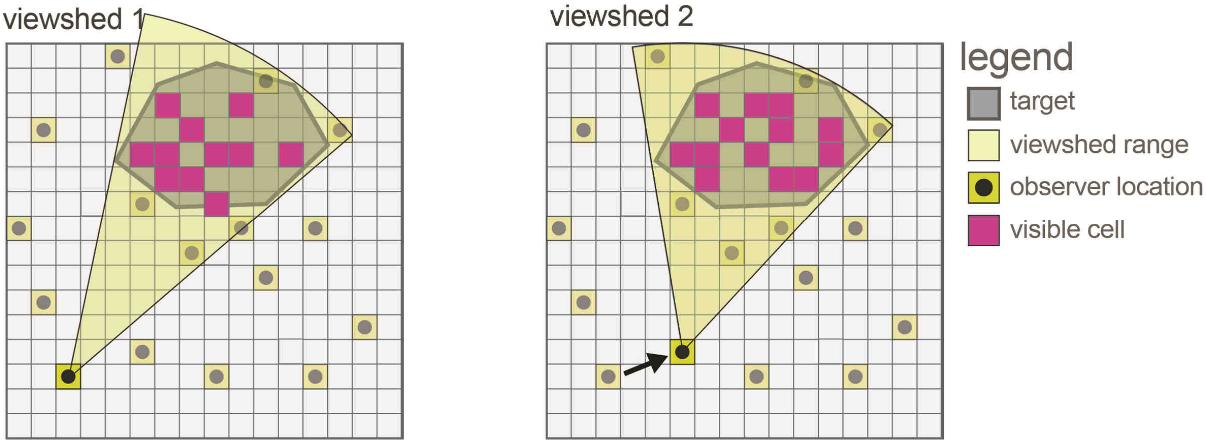

Figure 3. Secondary viewshed calculation. Cells in the target are coded as visible or not visible from each observer location in turn providing spatial coverage maps of the target from all the selected high visibility points

2.3 Calculation of scan parameters

With the optimum TLS locations determined, the final stage is to calculate the scan parameters for each site that control data collection from the instrument. The horizontal and vertical rotation of the scanner is controlled by selecting start and stop angles that define a rectangular scan window.

Calculation of these angles can be automated by using the geometric relationship between the selected scan locations and the defined target. In the vertical plane, the angle between the observer location and the height of each DEM cell bounded by the target region is calculated and the minimum and maximum angles are used to define the scanner start and stop angles. The target vertices are used in the horizontal plane to derive the observer to target angular relationship with the minimum and maximum angles calculated also being used to define the start and stop angles**.** These values are used to directly control the TLS in the field and constrain scanner coverage to just the surface of interest. This enables minimisation of the time required to capture the target by optimising the angular extent of data collection at each location.

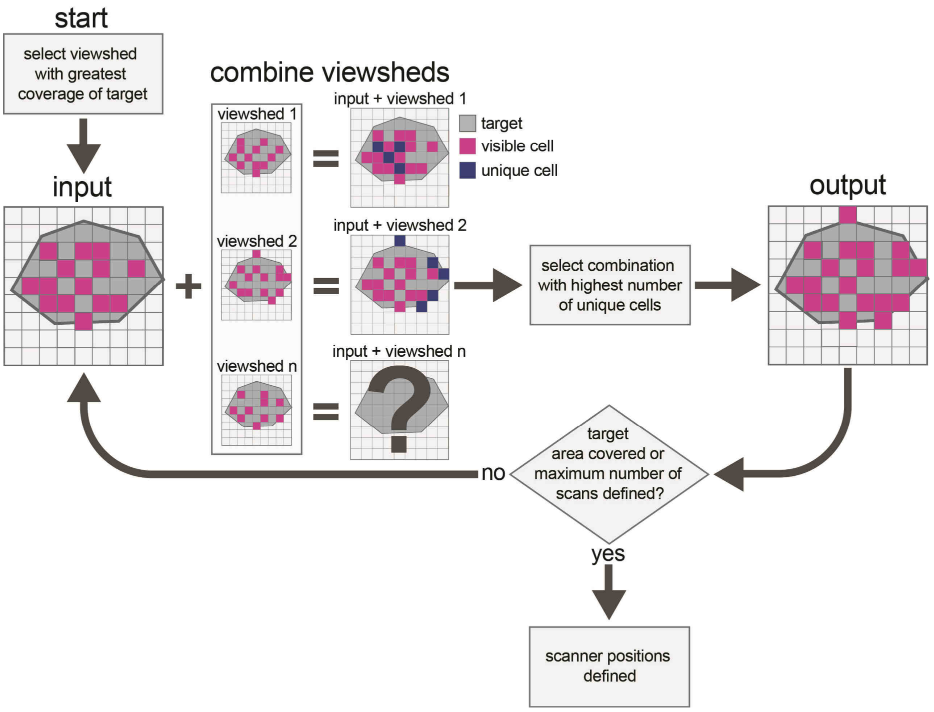

Figure 4. Optimisation of scan locations. The viewshed with the greatest coverage of the target is selected as the initial input to the optimisation routine. All other viewsheds are then sequentially added to the input and a uniqueness index is maintained that counts the number of new cells visible in the output that were not visible in the input. The combination with the highest uniqueness value is then fed back to the input of the optimisation routine and the process is repeated until the target is fully covered or a user-defined maximum number of scan locations have been determined.

3. Discussion and future work

The methodology outlined uses viewsheds calculated on low resolution DEMs to optimise TLS deployment locations. Analysis of the influence of DEM resolution on the functionality of the optimised scanner configuration is critical in order to determine the practical limitations of the technique. Calculation of scanner control parameters is also derived from the DEM and as such, DEM vertical error will be strongly reflected in the calculated angles. Uncertainty in these angles could directly impact the completeness of data captured in the field and as such, a practical strategy that minimises the influence of vertical errors needs to be developed. Future research will concentrate on addressing these issues by conducting comprehensive field tests aimed at determining practical operational constraints and quantifying the time savings available in TLS deployments.

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6. Biography

Neil Slatcher is a second year PhD student at Lancaster University. Research interests cover the application of monitoring technologies in the measurement of dynamic physical systems. Current work includes high-resolution terrain mapping and the development of low-cost acoustic sensors for deployment on volcanoes.

Mike James is an RCUK Academic Fellow in Environmental Informatics whose research involves understanding physical aspects of Earth surface change, with emphasis on volcanic processes. Areas of particular interest are lava flows and volcanic domes, coastal erosion and sediment dynamics, and the development of appropriate and adaptive field methodologies.

Graham Hunter is a founding member of 3D Laser Mapping Ltd, and has over 10 years experience in the LiDAR industry, leading the development, sales and marketing of airborne and terrestrial laser mapping systems.