

Short Report

A Comparison of Visualization Techniques for Models Created from Airborne Laser Scanned Data

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ABSTRACT The uptake of airborne laser scanned (ALS) data (commonly known as airborne lidar) for heritage landscape assessment has grown rapidly in the past decade as data have become increasingly available. Likewise there has been a recent upsurge in published techniques for modelling the ground surface from ALS data to highlight archaeological features. However, many end-users of the data are not trained in remote sensing and visualization techniques and the lack of comparative assessment of techniques has increased the complexity of interpretation of the ALS-derived models. This study quantitatively compares five visualization techniques ranging from the commonly used shaded relief model to newer local relief and sky view factor modelling for a study area in the UK. Outputs are compared with the baseline data of the English Heritage National Mapping Programme aerial photographic archive transcription and assessed with respect to percentage visibility of feature length. Ancillary aspects of the outputs are discussed, such as geospatial shift of features, suitability for profile mapping, ease of interpretation and ability to combine with other data sources. It is concluded that although the overall performance of the models in terms of feature recognition is relatively even, consideration of all factors enables more transparent modelling choices to be made and facilitates critical interpretation of the features recorded. Copyright © 2012 John Wiley & Sons, Ltd.

Key words: Airborne laser scanned; archaeology; lidar; remote sensing; terrain model; visualization

Introduction

Topographical models derived from airborne laser scanning (ALS) are becoming a common tool for landscape-scale prospection. Their potential for the improvement of land management and historic environment records is increasingly recognized (Challis *et al.*, 2008) and the accessibility of archive data is improving worldwide.

Until very recently, almost all analysis of ALS data was undertaken using one type of visualization technique – shaded relief modelling. This type of model is highly directional, i.e. the azimuth and angle of illumination have a severe impact on the visibility of features

(Devereux *et al.*, 2008), requiring multiple models to be created and assessed. Several alternative approaches have been put forward to improve the visualization of archaeological features in terrain models. This paper quantitatively compares five published techniques to the baseline aerial photographic transcription of English Heritage's National Mapping Programme (NMP) (Crutchley, 2000). The comparison used an area of 4 km² of archive ALS data acquired in 2005 and analysed as part of a wider study of the value of remote sensing for the archaeological study of the Salisbury Plain landscape in the UK (Bennett *et al.*, 2011).

Methods

The ALS data were collected on 3 November 2005 using the Optech ALTM 2033 sensor and were supplied

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gridded to a 1-m resolution Digital Elevation Model (DEM) using the last return from each laser pulse. The data were not filtered to remove vegetation as the study site comprised open fields with little scrub. The five techniques selected for the analysis were slope (calculated in degrees), aspect, principal components analysis of shaded relief models (PCA), local relief modelling (LRM) and sky-view factor (SVF) (see Table 1). The technical details of each technique are published elsewhere (Devereux *et al.*, 2008; Hesse, 2010; Kokalj *et al.*, 2011). Each model was created from the same DEM and all calculations were undertaken in GRASS GIS (GRASS Development Team, 2010) with the exception of the SVF which was created using the Interactive Data Language (IDL) executable provided by Kokalj *et al.* (2011).

Individual archaeological features were mapped to the standards of the NMP, which aims to identify and transcribe all possible and probable features showing as crop marks, soil marks and earthworks in aerial photography (Crutchley, 2000). For this study, lynchet features comprising field systems were considered as single entities. Features were also profiled as an aid to interpretation and to take advantage of the full 2.5-dimensional nature of the rasterized ALS data. Point-cloud and fly-through visualization were not included as it is not possible to map archaeological features to NMP standard using these techniques. Walkover survey, comprising coverage of the study area on foot in 20-m transects, was undertaken before and after the analysis to verify features. The visibility of features in the models was compared both in terms of binary visibility and average percentage feature length (APFL). The impact of land use on the visibility of features within the models was measured using Chi-squared analysis of the APFL data. The models were also assessed against the original DEM with regards to both positional and geometric accuracy of

features using a series of profiles, providing cross-sections of known features.

Both the LRM and SVF models allow the user to adapt the basic model to a spatial resolution that is suitable for the scale of archaeological features expected to be encountered (this scaling factor is referred to as 'kernel size' (Hesse, 2010, p. 68) and 'search radius' (Kokalj *et al.*, 2011, p. 268)). Prior to comparison, different sizes were iteratively analysed at 5-m intervals for both models, covering a range of feature sizes from <5 m to 30 m. The 10-m step size was selected reflecting the average dimensions of archaeological features in the study area.

To create the PCA, 16 shaded relief images were created at azimuth intervals of 22.5° (as per Devereux *et al.*, 2008). The angle of illumination above the horizon was assessed in 2° intervals in the range from 4° to 25° reflecting the angles of raking light identified as ideal for microtopographic feature detection by Wilson (2000, 46). The final shaded relief images were illuminated from an angle of 8° above the horizon, which proved to be the optimum angle for highlighting archaeological features in the study area based on the assessment above. Archaeological features were digitized from the first three principle component (PC) images; no features could be seen in PC images 4–16. The features from PC 1–3 were then combined into a single total for the PCA analysis.

Results

Binary visibility

Combining the results of all the visualization methods, a total of 122 topographical features were mapped from the ALS models, in comparison with 89 features

Table 1. Details of ALS visualization models used in the analysis.

Technique	Brief description	Source
Slope	Slope mapping produces a raster that gives slope values for each pixel, stated in degrees of inclination from the horizontal	(Jones, 1998)
Aspect	Aspect mapping produces a raster that indicates the direction that slopes are facing, represented by the number of degrees north of east	(Skidmore, 1989)
Principal component analysis (PCA) of shaded relief models	A multivariate statistical technique used to reduce redundancy in multiple images. The product is a series of images representing statistical variance in the light levels of the original shaded relief images	(Devereux <i>et al.</i> , 2008)
Local relief modelling (LRM)	Developed for mountainous regions and produces a model where the affect of the macro-topography is reduced while retaining the integrity of the micro-topography	(Hesse, 2010)
Sky-view factor (SVF)	A visualization technique based on diffuse light. The product is a representation of the total amount of light that each pixel is exposed to as the sun angle crosses the hemisphere above it	(Kokalj <i>et al.</i> , 2011)

that were known from the NMP data. This increased the number of known features by 37%. In total 76% of the features mapped in the NMP were also recorded in the ALS data. An illustration of the output of the various models is given in Figure 1.

The PCA, LRM and SVF models outperformed the slope and aspect models in terms of number of features

recorded (Figure 2), with PCA, LRM and SVF performed equally well in terms of feature identification overall although the PCA model returned fewer of the features already known from the NMP.

The complementarity of different modelling techniques is shown by the fact that no single technique recorded more than 77% of the total number of features

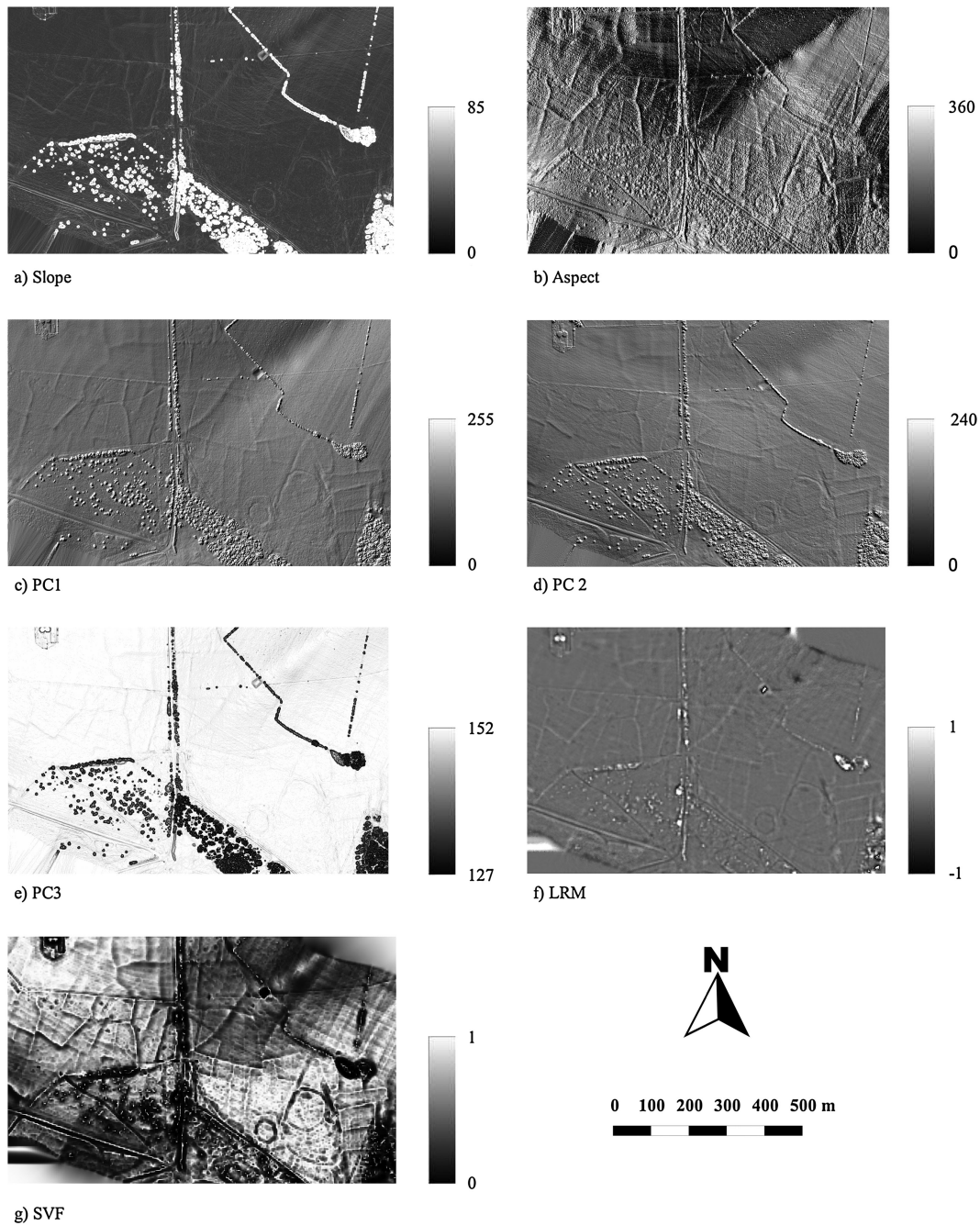


Figure 1. Comparison of visualization techniques used: (a) slope, (b) aspect, (c) PC1 of shaded relief images, (d) PC2 of shaded relief images, (e) PC3 of shaded relief images, (f) local relief modelling and (g) sky-view factor.

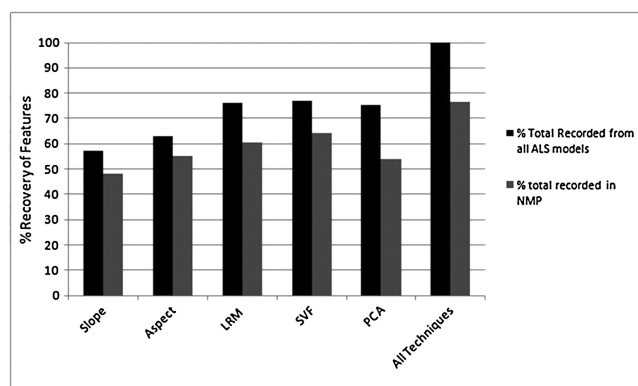


Figure 2. Percentage of total number of features digitized from all airborne laser scanned (ALS) data models and percentage of features previously known from National Mapping Programme (NMP) transcription.

seen in the study. Table 2 illustrates the percentage increase in the number of features recorded when combining two sources compared with the recovery from the single sources. All combinations of two techniques recorded over 80% of the total number of features, but combining LRM and SVF or PCA and SVF recorded 93% of all features. The best performing combination of three models (SVF, PCA and aspect) recorded 97% of the total digitized features

Percentage feature length recovery

It can be seen that the APFL across the models is almost identical, with each showing that on average for the features that were digitized, over 80% of their known length was recorded (Figure 3). This was shown to be of a comparable level to the NMP transcription. The SVF model performed slightly better than the others and was the only visualization to outperform the NMP, although there was just 7% difference between the best and worst performing models.

Land use

The study area comprised three land-use categories: cultivation to a depth >0.25 m, disturbed grassland

Table 2. Percentage increase in the number of features recorded when combining two sources.

	Aspect	PCA	LRM	SVF
Slope	14	12	12	10
Aspect		17	12	10
PCA			8	19
LRM				17

PCA, principal components analysis; LRM, local relief modelling; SVF, sky-view factor.

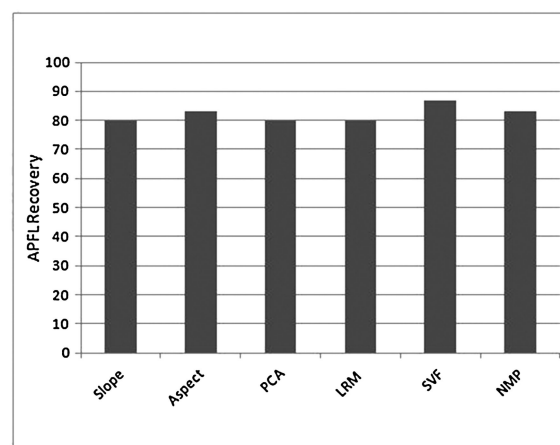


Figure 3. Average percentage feature length (APFL) recovery across all models and compared with the National Mapping Programme (NMP) transcription.

and minimal cultivation. The results of the Chi-squared analysis of the APFL data showed that there was no significant association between land use and feature visibility in the Salisbury Plain study area (Table 3). As expected, features in the ploughed areas are more degraded than their counterparts in other land-use zones; for example, the same lynchet upstanding to ca. 0.15 m in the scheduled area has a height of ca. 0.05 m in the adjacent ploughed field (Bennett *et al.*, in press). Therefore this result indicates that all the visualization techniques used were sensitive enough to detect microtopographic features of the order 0.05–0.15 m rather than that there was no difference in feature preservation.

Positional accuracy and scale

The results of profile analysis of features within the models are illustrated in Figure 4. As can be seen the representation of elevation features in profile varies dramatically between models. There are changes in both the scale and position of features represented. In

Table 3. Results of the Chi-squared analysis of the APFL data. The low Cramer's V measures indicate that the Chi-squared statistic was unlikely to have occurred by chance.

	χ^2	$P < 0.001$	Cramer's V	Significant association between land use and visualization technique?
Aspect	0.68	Yes	0.6	No
Slope	1.24	Yes	0.9	No
PCA	5.1	Yes	0.18	No
LRM	4.17	Yes	0.16	No
SVF	1.44	Yes	0.93	No

PCA, principal components analysis; LRM, local relief modelling; SVF, sky-view factor.

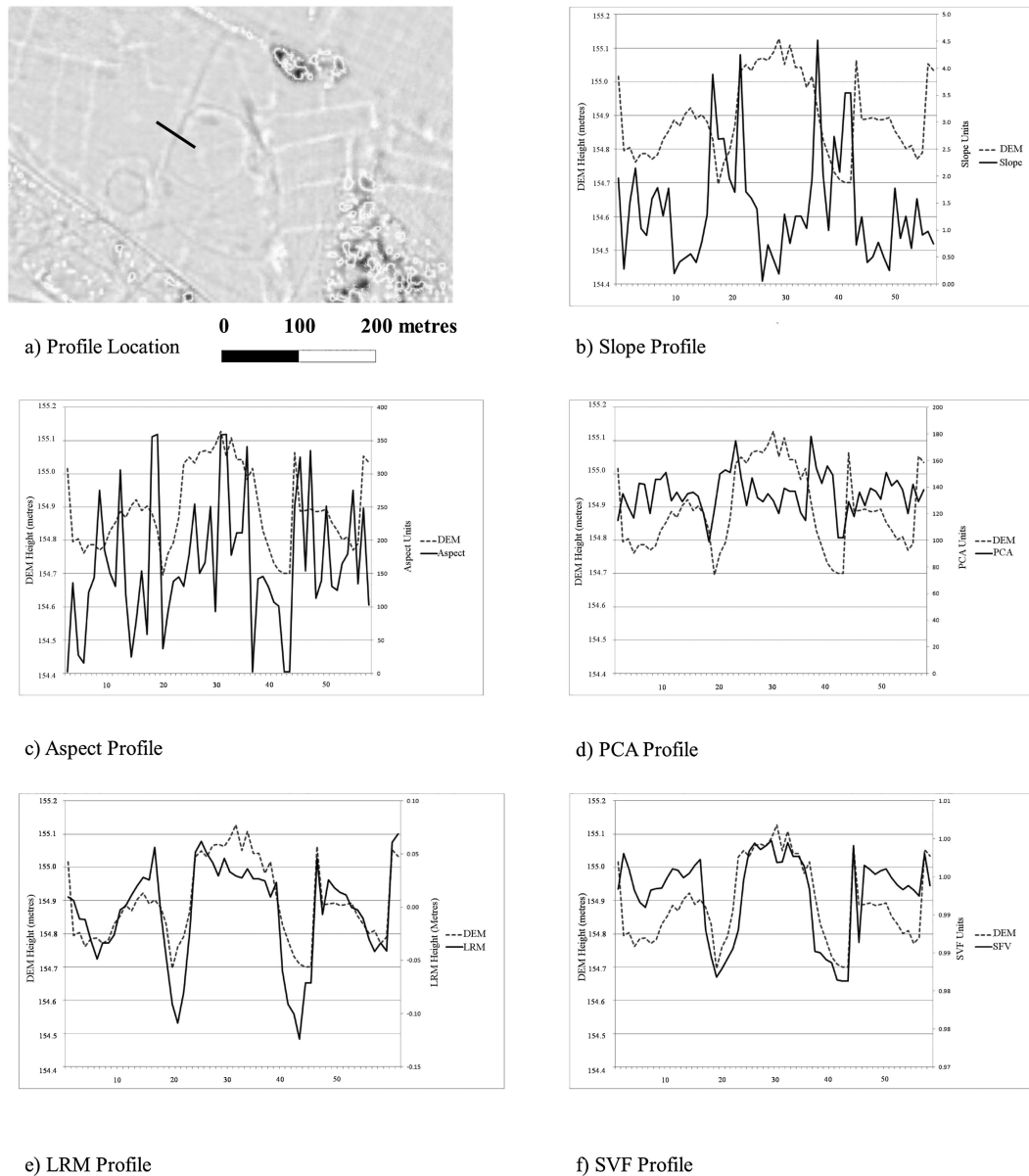


Figure 4. Profile analysis of the models: (a) profile location overlay on the PC1 image, (b) slope profile, (c) aspect profile, (d) PC1 profile, (e) local relief modelling profile and (f) sky-view factor profile. DEM, digital elevation model.

particular, inconsistent horizontal shifts of up to 5 m in the position of positive and negative features were noted in each of the PC images when compared with the original DEM, making accurate mapping of location difficult (Figure 4d). This shift is caused by directional bias introduced to the representation of the features via shade or brightness when using a moving light source.

The scale of the models poses a problem for digitization, as in all cases except the LRM the scale is not in the original units of elevation. Other models record the amount of light, aspect, steepness of slope

and horizon exposure: all factors related to but not directly representing elevation. These are useful indicators of local topography but they can be complicated to interpret archaeologically, especially if only one model is used. For interpretation purposes, the LRM provides a summary of positive and negative features along with relative heights/depths in the correct order of magnitude (Figure 4e). However, the spatial resolution of the ALS data used in this study and lack of contemporary ground observations make it difficult to assess the absolute accuracy of the LRM for the features observed.

False positives

During the course of the digitization it was noted that the derivation of some models led to enhanced representation of interpolation artefacts. Although this is to be expected to an extent given the nature of archive ALS acquisition and processing (see Crutchley, 2010, p. 26), this can be problematic where artefacts resemble archaeological feature types. In this study a series of linear features resembling ridge and furrow earthworks were not seen in the DEM or PCA models but were noted to be visible in profile of the LRM and prominent in the SVF (Figure 5). Viewing the features

in context and with the benefit of a number of visualizations, it is clear that they are artefacts. However, such artefacts could easily be misinterpreted as archaeological features if a single visualization technique is used without comparison or supporting ground/aerial observation. Models that enhance such features should be interpreted with caution.

Discussion

The results of this investigation allow an assessment of the relative value of the different visualization

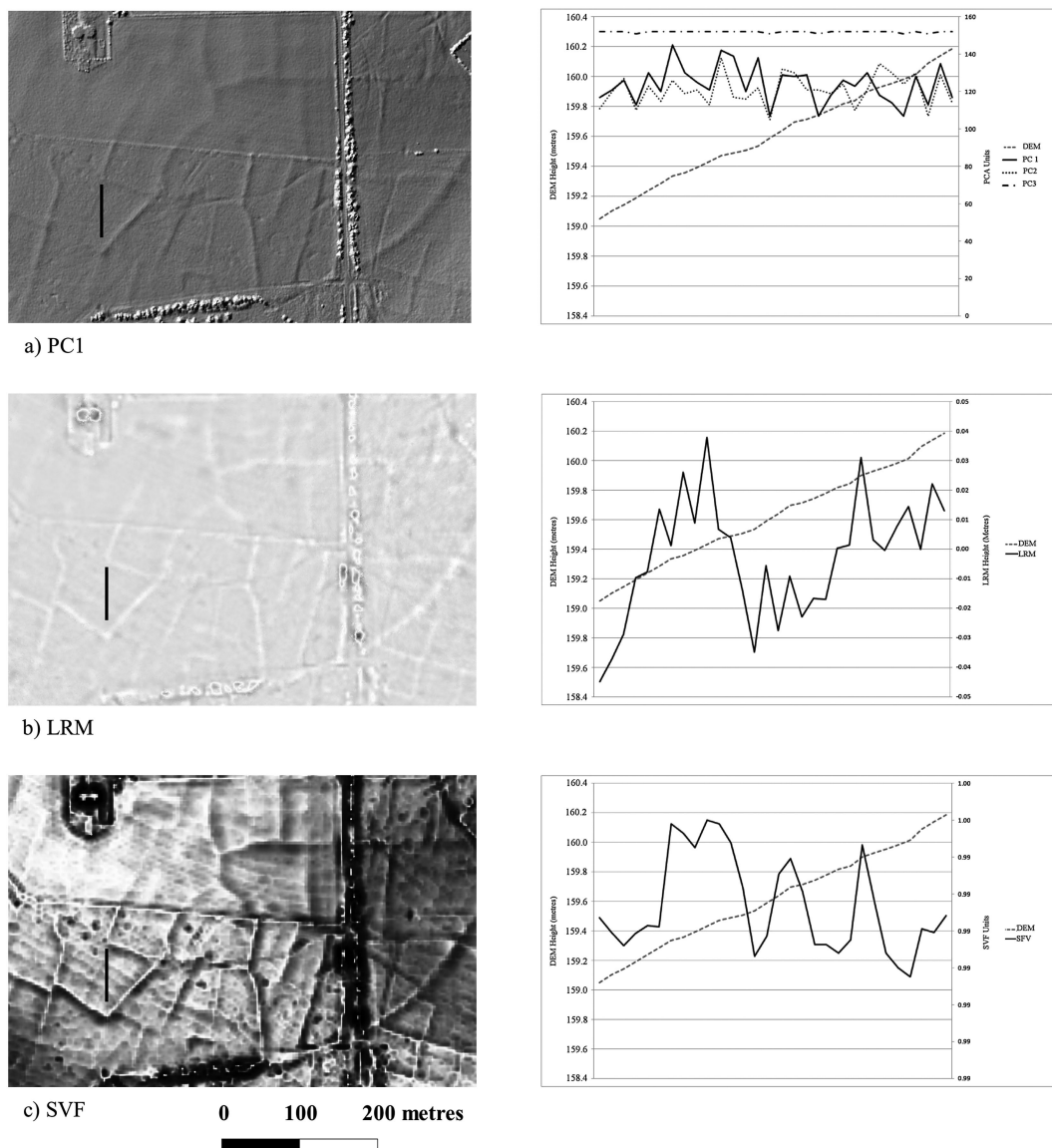


Figure 5. Profiles comparing the interpolation artefacts to the original digital elevation model (DEM) for (a) principal components analysis, (b) local relief modelling and (c) sky-view factor models.

techniques for the study area and give an insight into the comparative strengths and weaknesses of each. All models were shown to increase the number of features in the study area and to provide verification of features known from the NMP. That this increase is lower than the results of the comparative exercise undertaken by Challis *et al.* (2008), is principally attributed to the extensive nature of the previous aerial mapping in the Salisbury Plain study area by the NMP programme. Feature visibility (as represented by APFL) was also shown to be unaffected by the changes in land use for all models.

In general terms the aspect and slope models are the simplest to generate and provide good locational accuracy, although with a lower return of known and new features when compared with other models. As such they provide complementary information rather than a holistic primary source for feature digitization.

The multiple shaded relief images and PCA of shaded relief images are the most commonly used techniques to visualize ALS data for historic environment purposes. Their usefulness is shown in the high proportion of features identified. Although relatively easy to compute, the user is still left with a number of images to process, which significantly increases the time needed for digitization. In addition this study has shown that the horizontal position of features can 'migrate' in varying PC images making accurate digitization difficult.

Although LRM and SVF models are more complex to compute, both have resources online to aid processing. These models were shown to be of identical value to the PCA in terms of feature numbers recovered and the SVF performed slightly better in terms of APFL. Although a greater incidence of interpolation artefacts were observed, particularly in the SVF model, both LRM and SVF are advantageous in that they result in a single image that is not biased by the direction and angle of illumination. There is also an element of trial and error required to define the most appropriate parameters for each model, which can be done by visual comparison and is therefore much quicker than multiple digitizations. Furthermore, it has been shown that both models are suitable for profiling to aid feature interpretation, especially the LRM where the scale remains in the original units of elevation. In this respect the LRM model is unique in this study in that it represents real changes in elevation rather than calculations based on steepness and direction of slope or exposure to light, that act as a proxy for elevation change. To this end there is potential for incorporation of the LRM as an elevation

model for combination with other data sources such as aerial photography or digital spectral imaging.

It was shown that the level of complementarity of ALS visualization techniques was high. This emphasizes the sometimes overlooked fact that the modelling technique chosen to represent ALS data has a distinct impact on the visibility of archaeological features. The addition of a second technique was shown to improve the number of features mapped in every case, sometimes by as much as 20%. The strongest combination of techniques was shown to be LRM/SVF and PCA/SVF. By using these combinations it was possible to recover almost all the features digitized and 72% of the NMP features.

This study relied on archive ALS data and it could be argued that certain models may produce better results given higher spatial resolution data and subject to improved filtering techniques to reduce artefacts. However, the ALS data used are representative of the type of data most frequently available to heritage professionals and as all models were created from the same DEM the comparison between them is fair. It is also noted that contemporary ground observations would enable stronger assessment of the elevation accuracy of the models, in particular the LRM, but as with most archive ALS coverage, these data are not available.

Conclusions

The study has assessed the value of a range of ALS visualization models for digitizing archaeological features and shown that different techniques give real differences not just in feature visibility but in the accuracy with which features can be recorded. Where possible, digitization from more than one technique is preferential for recovery of known and unrecorded features. Techniques that allow intelligible profiles to be mapped are the most useful for aiding feature interpretation and the authors strongly encourage the use of profiles to take advantage of the 2.5-dimensional nature of rasterized ALS data.

With improvements in technology and access to archive data, an awareness of the biases that modelling can bring will be increasingly important in allowing heritage professionals to assess, interpret and commission ALS data. This understanding can be achieved only via quantitative comparison of techniques with archaeological objectives in mind. This study is not exhaustive but it provides an insight into the use of five common visualization techniques and highlights both their potential and pitfalls for archaeological users.

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