GPS Survey: 3D data for easy digital terrain modelling

Robert Shaw
The Discovery Programme
34 Fitzwilliam Place, Dublin, Ireland

Abstract

Advances in GPS survey technology have made it relatively quick and easy for archaeological surveyors to gather high volumes of precise geo-referenced 3D data. At the same time the software to manipulate and display this data in the form of 3D models has become less technically demanding and more accessible. As a result its application in archaeology is becoming widespread. The aim of this paper is to look at some practical examples of these models and consider how they compare with the traditional methods of recording and depicting archae*ological sites.*

Introduction

The Discovery Programme, established in 1991, is a state-funded archaeological research company with the remit to enhance the understanding of Ireland's past. Projects undertaken have included research on the North Munster region, the Western Stone Forts, the Ballyhoura Hills and extensive study at Hill of Tara. Specialists from many disciplines are employed, archivists, environmentalists, excavation archaeologists, historians, GIS analysts and surveyors.

In 2001 The Discovery Programme began two new research projects, The Lake Settlement of Ireland, and The Archaeology of Medieval Rural Settlement in Ireland, both requiring extensive field survey programmes. No survey work had been undertaken for over a year as previous projects were in the report writing stage so a re-assessment of the survey department's equipment needs was undertaken. 3D modelling had been found to be a successful way of recording archaeological landscapes and sites, but that data acquisition using a total station was often too time consuming.

Global Positioning System (GPS) had been considered for the previous research projects but at that time it was decided that the technology was developing at such a rate that investment should be postponed until a later stage (Masterson 1999). An evaluation of the current technology in GPS indicated that development had 'stabilized' sufficiently and reached the level where we could invest in a system with a degree of security that it wouldn't be radically superseded in the lifetime of the projects (6 years).

GPS Systems

GPS is a term that most people have encountered today through its navigation uses in recreational activities such as mountaineering and sailing, or from news reports of its role in guiding missiles during military conflict. Most archaeologists have probably read articles outlining its impact in surveying but with conflicting claims of its precision and cost. We need to clarify what we mean by GPS and how it is applied in the context of archaeological survey (Wheatley and Gillings 2002).

Table 1 shows how GPS can be broadly grouped in three types based on how the measurement is made, and how the system is operated. It's beyond the scope of this paper to go into a full explanation of these processes, but it is important to appreciate the impact this has on the precision achievable and the cost of a system.

GPS Type	***Navigation***	***GIS***	***Survey grade***
Measurement	Code	Code	Carrier phase
Operation	Autonomous	Differential	Differential
Accuracy	10-20m	1-5m	<10mm
Cost	250 euro	5000 euro	40000 euro

Table 1 – Broad categories of GPS survey systems.

A navigation system costing €250 is a GPS, has many valid applications in archaeology, e.g. reconnaissance and prospective walking, but it is not a precise surveying instrument. Our surveying requirements; accurate control points, detailed site surveys, precise height data, mean that only the survey grade systems are appropriate.

1 System Specification

High quality GPS systems are available from all the major survey equipment manufacturers but with a cost in the region of €40,000 the selection criteria was important - balancing performance, durability, and system compatibility with cost. The environment in which it would be operating demanded that it be rugged and water resistant, and this was one of our major considerations. Other factors were ease of integration with our existing total stations and the quality of processing software. After evaluating a number of options the Trimble 5700 system was chosen. Table 2 summarizes the specifications of the system.

2 Real Time Kinematic (RTK) Surveying

GPS surveys are undertaken in the field in a RTK mode. To do this requires a pair of survey grade receivers operating in the same local area. One of them remains set up gathering data on a fixed point, known as the base station, while the other is moved around the site, the rover. Many of the errors that are inherent in the GPS system are the result of distortions as the signal passes through the ionosphere. These will be approximately the same in a local area, as the signals will have travelled through almost identical part of the ionosphere. As we know the precise position of the base station we can calculate the difference between the known and GPS calculated position at any instance – known as the differential correction. A real-time system broadcasts this correction to the rover via a radio link and the position is updated instantly. In this way the points we are surveying are measured to high accuracies relative to the base station. More than one rover GPS can be operated from one base station, allowing productivity to be effectively doubled by hiring and extra roving unit.

Trimble 5700 GPS Specification		
Measurement accuracy		
Static survey (control)	Plan:	5mm + 0.5ppm.
	Height:	5mm + 1ppm.
Kinematic survey (detail)	Plan:	10mm + 1ppm.
	Height:	20mm + 1ppm.
Physical specification		
Water resistance:	IPX7 for submersion to 1m.	
Shock resistance:	1m drop onto concrete.	
Climatic conditions:	-40 to +80°C, 100% humidity.	
Battery power:	7 - 10 hours continuous use.	
Weight:	Complete rover pole <4kg.	

Table 2 – Specification of the Trimble 5700 GPS.

3 Reference systems

RTK surveys result in precise positions relative to a base station but a requirement of our work is to position surveys in the national mapping reference system of Ireland, the Irish Grid. To achieve this the continuously operating reference system (CORS) provided by the Ordnance Survey Ireland is used. This system records GPS data continuously at a network of stations around Ireland which is then made available, currently free of charge, through a website (www.osi.ie). GPS data gathered from our base station receiver is processed with data downloaded from the CORS stations and a precise Irish Grid coordinate obtained. All our RTK survey data can then be transformed into precise Irish Grid coordinates.

4 Total Station Integration

GPS depends on receiving radio signals from satellites in space and therefore the receiver needs to have a clear view to the sky. However we often encounter sites that are all or partly obscured by trees, thick vegetation or tall buildings. In these cases we need to integrate total station surveys into our survey. The Trimble 5700 system operates with a TSCe controller unit that can be connected directly to a total station. Using control points set out using GPS total station data can be seamlessly integrated into the survey job. The controller has a graphic display that shows all the points surveyed so gaps can be easily identified and filled.

5 Software & Processing

Whether surveyed using GPS or Total Station each point is described using a feature code. The processing software, Trimble Geomatics Office (TGO) converts these codes into lines, symbols or areas depending on the symbology defined in our feature code library. This vector graphic forms the basic survey of the site from which GIS layers and maps can be extracted. Although often viewed as 2D plans all the points automatically retain their full 3D description (x,y,z) and this is what makes GPS such a powerful survey method when it comes to modelling surfaces.

3D Surface Models

GPS was the key to creating 3D models of archaeological sites and landscapes because it allows us to gather large quantities of high quality data efficiently. Even with experienced operators total stations record points at such a slow rate that extensive modelling becomes prohibitively time consuming. Photogrammetric methods seem very attractive but have the problem of acquiring suitable large-scale aerial photography to achieve high accuracy results. This can only be done with purpose-flown photography that is expensive,

and involve high performance high cost processing systems needing a high level of operator expertise.

Although we refer to our DTM’s as 3D models this is not strictly correct, as they contain no volume information. A more appropriate term 2.5D is often applied to these surface models (Wheatley and Gillings 2002).

1 Point Sampling Strategies

Figure 1 – Ringfort, Tulsk, Co. Roscommon.

Models are built from the network of surveyed points covering the landscape. The example around which this paper has been written is a medieval ring-fort site at Tulsk, Co. Roscommon, Ireland, see figure 1.

The fort and immediate environment cover an area of approx. 10,000 square m^2. The form of the site is an awkward combination of steep slopes (height difference 6.8 m) and the feint remains of features probably ploughed out over the centuries.

The sampling strategy employed is a combination of recognised spatial sampling strategies. The first stage is a modified systematic grid of points with approx. 1m spacing. It's considered modified because we increase the density of survey points where the surface is most complex. This is a subjective decision by the surveyor who has to assess whether the 1m grid is sufficient to reflect the subtleties of the surface.

A second stratified stage adds points along the obvious tops and bottoms of slope (break-lines) to ensure that they are included in the model.

This strategy has evolved from experiments with different approaches and seems appropriate to most of the sites encountered in the project so far. Importantly, it gives the surveyor flexibility to adjust the density of points to reflect changes in the terrain.

Figure 2 shows the result of the GPS survey of this site; two surveyors measured 8,750 points in two and a half days with two rover GPS units. This included a detailed reconnaissance of the site and the establishment of the base station.

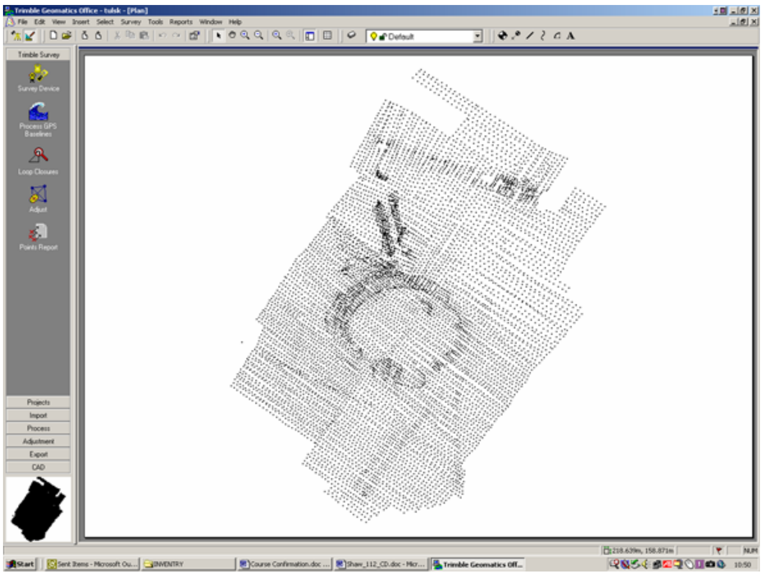

Figure 2 – GPS points surveyed for the Tulsk model.

2 Model Construction

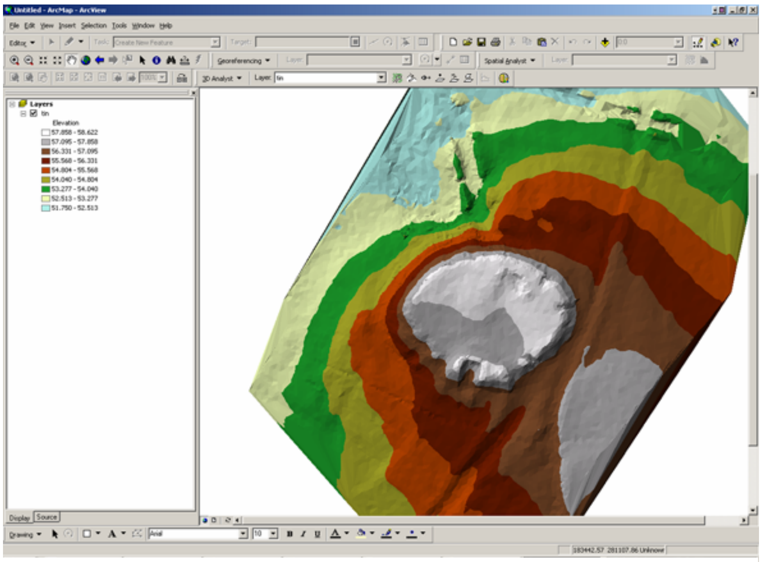

Figure 3 – TIN model created in ArcView

GIS analysis is a vital process in the archaeological research undertaken at the Discovery Programme, and ArcView 8.1 is the GIS software used. It includes a range of 3D modelling options and given our familiarity with ArcView as a whole we chose it as our model building software. TGO processing software has shape-file as an output option and this is added as a dataset to a new map in ArcView. The software extensions 3D Analyst and Spatial Analyst are core tools in the model construction processes. The first stage is to build a basic Triangulated Irregular Network (TIN). The functionality of ArcView is such that this is a simple process with little inputs to consider. The shapefile of points is our only input, the resultant TIN automatically output, see figure 3. Vector break-lines can be added and the TIN built to respect them to varying degrees, but experiments on the earthworks sites undertaken so far has found these to be unsuitable. Tops and bottoms of slopes on the ground are rarely hard lines and all the break-line options overly distort the modelled slope if included. Our best models were achieved by including the points making up the break-lines without treating them as hard vector boundaries.

3 Raster Models

Although the TIN gives an effective 3D model of the surface it has limitations. The faceted appearance limits its use as an illustration of a site, and its vector structure makes it less versatile for the further analysis vital to effective data interrogation. The solution is to interpolate the point data to create a raster map using the spatial analyst tools in ArcView. This process results in a raster map in which the interpolated heights for each cell are stored. Both the algorithm for the interpolation, in most cases we use a spline, and the cell size (which determines the coarseness of the image) are selected depending on the nature of the site. The result is the basic rasterized surface model shown in figure 4.

This rasterization process has to be approached with a high degree of caution. ArcView has a three of different algorithms for interpolating data, (nearest neighbour, kriging, and spline) and for each of these a range of parameters that can be adjusted. In the desire to produce more visually pleasing models it has to be recognised that the integrity of the data can easily be undermined. Interpolation in most cases does not totally respect the survey points that were surveyed using a carefully chosen sampling strategy. If the surface model then forms the basis for further analysis it's critical we are aware how the model was

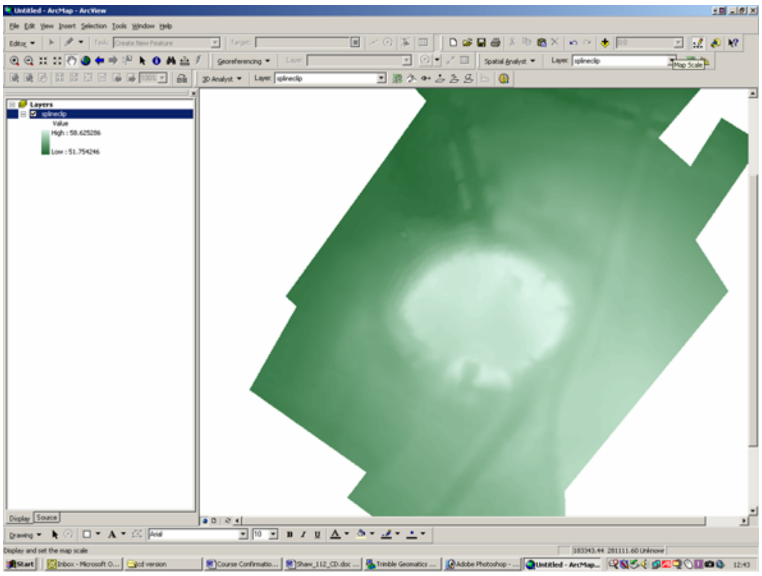

Figure 4 – The spline model created in ArcView

created. For each model created metadata should be included so the user can assess its validity. With the data now in a raster form a range of spatial analysis tools can be used to further refine our model of the surface.

4 Surface Analysis

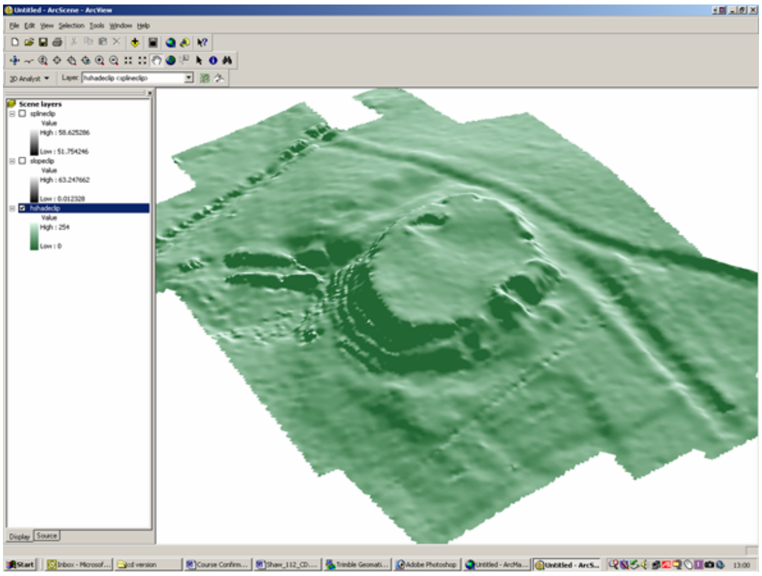

Figure 5 – Hill-shade analysis draped over spline model, viewed in ArcScene

The ArcScene image in figure 5 shows how some basic surface analysis tools can be used to improve the quality of our model. It shows a hillshade model draped over the spline model with the height exaggeration by a factor two.

The azimuth and elevation of the light source (the effective ‘sun’ position) have been chosen to emphasise features not obvious when walking on the ground. In this example of this are the faint cultivation remains at the rear of the site.

Theses hill-shade models are the standard end product of our survey and should result in a largely objective model of the true land surface.

However, we can go further with surface analysis to perform more sophisticated interrogation our data. Figure 6 shows the ‘synthetic’ landscape that can been created when the slope angle values are calculated and draped over the existing surface Added emphasis has been given to the feint line of the fosse to the rear of the fort.

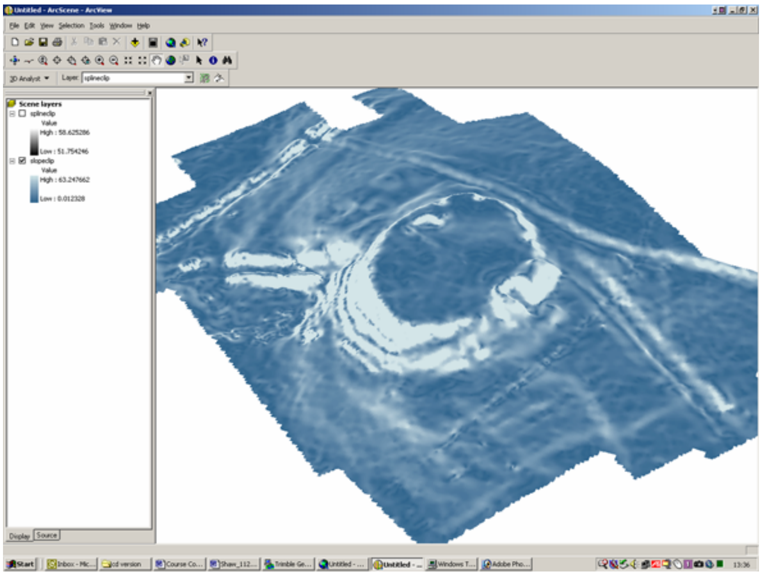

Figure 6 – Slope analysis draped over spline model, viewed in ArcScene

With such a system, and access to user-friendly manipulation software such as ArcView, it is entirely possible for non-specialist surveyors to consider surface modelling as a standard approach to recording archaeological sites.

But is this largely objective approach an appropriate way of recording and representing our surveys? To consider this we need the look more closely at the traditional approach to recording sites.

Traditional Approaches

The ring-fort at Tulsk was re-surveyed using the plane table survey method to allow an evaluation of the different techniques.

1 Hachure Plan

The process of drawing hachures immediately revealed the different level of interpretation and the subjectivity inherent in this type of survey [7]. How the different slopes interacted and related to each other had to be understood before they could be depicted. The process of defining tops and bottoms for the rows of hachures forced decisions to be made about phasing and relationships that could be largely ignored when surveying points for the 3D model.

In constructing the drawing compromises had to be made; which elements were selected for inclusion on the plan, how we depicted the long slight slopes and the short steep slopes. The process was translating our interpretation of the site to a graphical depiction on the paper. This was the key difference with 3D modelling – the emphasis on interpretation. The final drawing (figure 7) shows the result of our interpretation of the site and the way this was depicted.

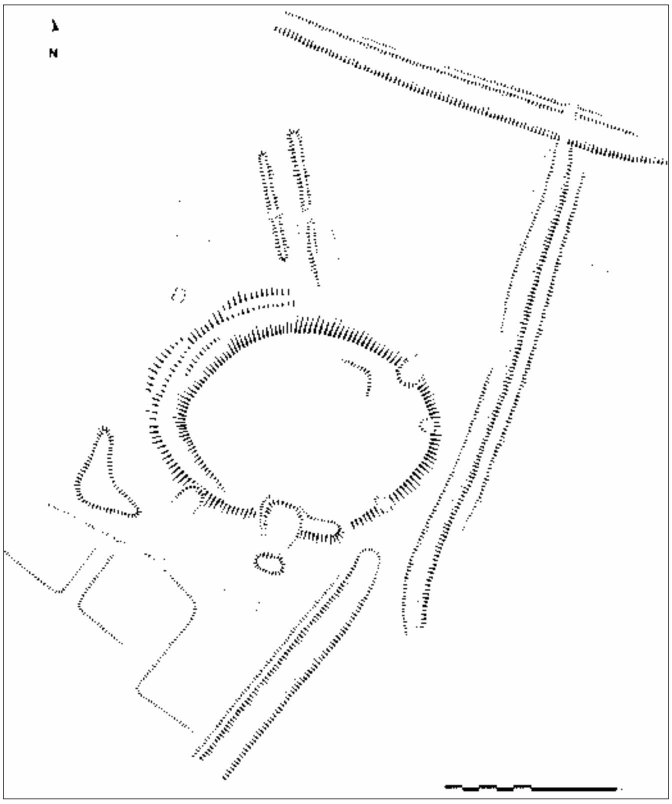

Figure 7 – Hachure plan of the Tulsk ringfort

It is important to acknowledge that this is a personal process and different surveyors with different levels of experience may produce very different plans.

As a method of portraying our understanding and interpretation of a site it has a great deal of merit, but an important part of any archaeological survey is to create a record of the site. Is a personal interpretation appropriate to be our record of what is there? Features omitted from the plan because we don't recognise their significance within the framework of our current knowledge base could turn out to be vitally important. We would have no idea they were there with our hachure plan but with a 3D surface the features are included even if we have failed to register their significance.

The more these two approaches were examined the less convinced we became that they were in fact comparable products. Our 3D surfaces appeared to be a good solution to the recording problem and an aid to analysing the site, but limited in presenting this understanding. How could this be resolved?

2 Automatic Hachure Programmes

One approach that has been subject of much research in the UK[1] has been the development of an automatic programme to generate hachures from the surveyed top and bottom of slope lines. This development is achieving good results with most hachures being resolved without the need for manual editing. As our surveys include the top and bottom lines, integral to creating our models, hachures could be output automatically. Taking the process a stage further the hachures could then be draped over the 3D model to present the interpretative element on the basic site record (Kennelly and Kimerling 2000).

However, to interpret hachures requires a level of understanding and experience that cannot be taken for granted, so alternative approaches were examined (Dykes, Moore and Wood 1999).

3 Virtual Tours

A straightforward export from ArcScene is a VRML file based on the TIN model. Free shareware makes this an easy way of allowing the model to be viewed. We are currently researching how we can program in VRML to take this a stage further and attach narratives to the model at the important way-points. This could take the form of 'pop-up' text boxes and images or possibly a recorded commentary (Fisher et al. 1997).

The tour would allow the interpretation to be presented in a logical sequence and ensure that the user is shown the important parts of the model. Different levels of narrative could be applied depending on the age or understanding of the user.

The obvious criticism of this is that it depends on access to the technology to view it. However as the illustrations throughout this paper show it is quite possible to represent excerpts and 'flat' images of the 3D world if needed.

Alternative data sources

Working with GPS on the ring-fort site the team felt restricted in how far we could extend the survey given our time constraints. It was highly unlikely that the hill-fort was isolated in the landscape and the potential of significant finds in the neighbouring fields was high. But needing to sample points at 1m intervals meant that ground survey was not a viable way to extend the survey.

1 Balloon aerial photography

One option has been to re-examine digital photogrammetric systems (Pollesfeys et al. 2002).

To eliminate the high costs associated with conventional acquisition of aerial photographs we have been investigating the possibilities of a balloon-based system. A metric digital camera suspended from a modern survey balloon has been proved to be a successful way of capturing images.

The latest software (e.g. Erdas Imagine) includes functions for automatically extracting surface models from stereo pairs using limited ground control and pixel matching. Such a system would not only extend our modelling capabilities but would also open up other archaeological possibilities e.g. modelling of excavations, or terrestrial photogrammetry.

2 3D Laser Scanning Systems

Terrestrial applications of this technology have proved a successful method of acquiring data for surface modelling. Our continuing research intends to test the cost effectiveness of such systems to see whether their productivity can offset the high equipment costs.

Conclusions

Advances in GPS survey technology combined with access to user-friendly modelling software opened up the potential benefits of 3D modelling to our research programme. It allowed us to challenge the conventional approaches to monument recording, and in evaluating these forced us to assess the merits of our 3D models.

The need to create both a definite record and an interpretative result from our surveys indicates the need to continue our research into VRML tours.

Ironically, as the latter part of this paper demonstrates GPS may not be the best solution for gathering the data for 3D models. Having introduced us to the techniques it may be that GPS will only play a minor role providing the control points for other methods.

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[1] Work undertaken by Edinburgh University funded by the Ordnance Survey (Nicolas Regnauld, William A. Mackaness & Glen Hart: Automated Relief Representation for Visualisation of Archaeological Monuments and other Anthropogenic Forms. Paper presented at GISRUK 2001, University of Glamorgan) and subsequent development jointly funded by English Heritage, RCAHMS and RCAHMW. Work undertaken by Edinburgh University jointly funded by English Heritage, OS, RCAHMS, RCHMW.