3D Laser Scanning
New techniques of observation

Paul Bryan *Metric Survey Team Leader and Head of the Photogrammetric Unit, York*

New developments in laser scanning now provide a high-speed, high-density observation of 3D data.

Electronic Distance Measurement equipment (EDM) and its reflectorless version (REDM) allow the user to select a range of points for measurement ('point and shoot' devices). Laser scanners offer an alternative to EDM and REDM by providing an automated, reflectorless process that collects three-dimensional (3D) data in a 'mass capture' manner. Often referred to as a 'data or point cloud', this collection of 3D observations holds no 'intelligence' on the object that has been surveyed, unlike observation using EDM or REDM with its selected measurement points. Depending on the choice of scanner, this 'data cloud' can contain an immense amount of 3D data, ranging from thousands to millions of points recorded every second. Such large volumes of data, however, require time and computing power to convert them into useable products. For projects that provide only a short time for survey, though, laser scanning is of great benefit.

Types and applications

Though this article is focused on terrestrial applications, laser scanning can be applied to any scale of survey, from a sub-millimetre analysis of an archaeological artefact to the visualisation of an entire historic landscape. Such variations require different equipment, and for larger-scale applications, aerial platforms such as fixed wing aircraft or helicopters are regularly used to transport the scanning equipment across the landscape at the desired speed and flying height for appropriate observation.

Aerial LiDAR survey

This application – commonly referred to as aerial LiDAR (Light Detection And Ranging) – produces 3D 'data clouds' which can be processed to provide a Digital Terrain Model (DTM) of the landscape. This can be used either as an output in its own right or as the basis for further 3D modelling using artificial rendering or image-draping techniques.

There are currently two types of terrestrial systems in use, based on LiDAR technology or on 'structured light' principles. The LiDAR system, similar in operation to the speed cameras used by many UK police forces, works by emitting a series of infra-red measurement beams in an array, using automated sweeps. The intensity, speed and array type all vary, depending on the device used, but they still produce a 3D 'point cloud' that is capable of supplying both surface and reflectance information from the scanned scene. The point accuracy is typically 5–25 mm and the range 5–50 m, making the LiDAR system more useful for medium- to large-scale projects.

Close-range scanners are based on 'structured light' principles and consist of a laser and charge coupled device (CCD). The CCD records the displacement of a stripe of laser light projected onto an object. The fixed geometry between laser and CCD enables simple triangulation to determine the position measurement. The point accuracy is typically 0.2–2 mm and the range 0.1–5 m, making them more appropriate for small-scale projects.

Both terrestrial and close-range laser scanners have been used to generate 3D images of the shaft and galleries in Greenwell's Pit, Grimes Graves, Norfolk.

an extract from The Millennium Map™ which is © getmapping.com plc

Grimes Graves, Norfolk. Greenwell's Pit is marked by a yellow-brown area towards the bottom centre of the photograph.

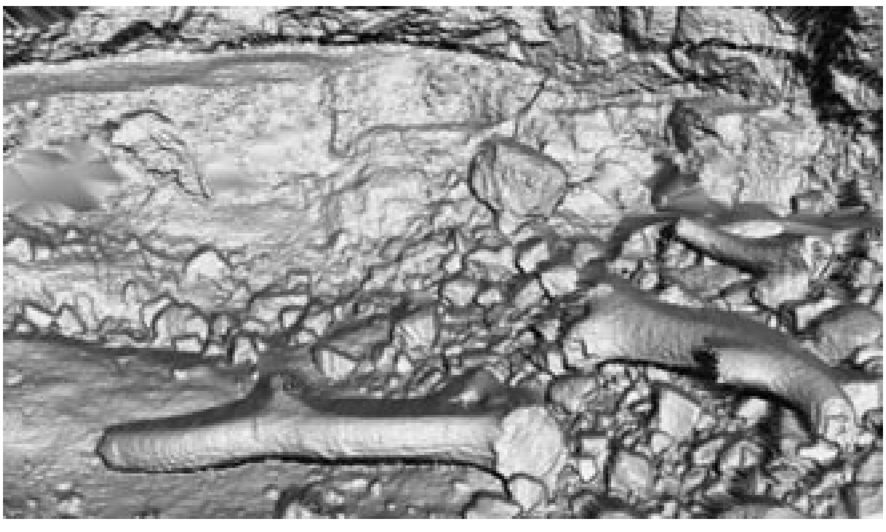
Other survey techniques such as photogrammetry produce the same level of 3D information, but there is no hard and fast rule to follow when selecting a technique. The client must balance the advantages and disadvantages of each technique to match the project requirements.

Application by English Heritage

Since the first terrestrial laser scanner appeared in 1999, the English Heritage Metric Survey Team has studied its application within the historic environment sector. As well as funding a recently completed three-year research project with the Department of Geomatics at the University of Newcastle – *Laser Scanning for Heritage Applications* – our study has included trial scanning on several English Heritage projects including Ironbridge, Shropshire, Chatterley Whitfield Colliery near Stoke-on-Trent, Staffordshire, the 'Seahenge' timbers from Holme-next-the-Sea, Norfolk, and most recently, Grimes Graves, Norfolk.

The area of heathland known as Grimes Graves lies seven miles north-west of Thetford, Norfolk, and is the earliest major industrial site in Europe. These remarkable flint mines, dug by Neolithic miners some 4000 years ago, can still be seen today. There are about 400 shafts across the 40-acre site, many of which are shallow hollows, though some have been excavated and may be descended by ladder.

To enable a detailed study of the extent and scale of the mine, a laser scan survey of the shaft and galleries in Greenwell's Pit is currently underway. The first phase of survey was completed by a consultant in 2002, using a Cyrax 2500 terrestrial scanner. This survey has already provided a substantial amount of 3D and volumetric information about the size, shape and form of the subterranean mine workings. It is currently being supplemented by additional survey using a Minolta VI-900 close-range scanner to record in finer detail the remaining archaeological evidence, including angular irregularities of the chalk surface, shallow indentations in the gallery floors and axe marks left by the Neolithic miners. As well as providing an invaluable management tool to monitor any evidence of collapses within the mine, these surveys may also produce a 3D virtual model of the site. By combining the underground scan survey with the existing DTM of the surface, produced by English Heritage's Cambridge-based Archaeological Investigation Team, it is hoped that remote access will be available, when the project ends in early 2004, for a site too fragile to be opened to all visitors.



© English Heritage. Screenshot courtesy of Archeoptics, Glasgow

Towards a standard specification

Recently, the School of Civil Engineering and Geosciences at Newcastle University completed an English Heritage-funded research project – *Towards a Standard Specification for Terrestrial Laser Scanning of Cultural Heritage* – to produce an addendum to Metric Survey Specifications for English Heritage outlining the requirements for the use of terrestrial laser scanning.

Although the project set out to cover all aspects of the process, including the capture, use and storage of scanned data, the addendum has concentrated on the collection and archiving of 'point cloud' data obtained by terrestrial laser scanning. Though scanning has already been applied to some building recording projects in the last three years, and most scanners now feature some form of vector generation within their processing software, the use of the data has still to be defined in terms of standard products. The production of 3D CAD and meshed models, profiles and cross sections, and animations and visualisations are all potential outputs from scanned data, though their presentation or level of attainment has yet to be specified. For cultural heritage projects, it is worth considering the type of fabric to be surveyed, the potential for voids in the data set, the minimum feature size to be recorded and the minimum ranges available before selecting laser scanning technology.

However, where traditional vector output is required, often for accurate 'edge detection', English Heritage currently considers it more appropriate to use survey techniques such as hand survey, theodolite/REDM survey and photogrammetry, which produce detailed architectural drawings and are included in Metric Survey Specifications for English Heritage.

Future research and development

An agreement must be reached on a common data exchange format for all laser-scanned data. Aerial surveyors have welcomed the recent announcement by the American Society of Photogrammetry and Remote Sensing (ASPRS) of an industry standard for the exchange of LiDAR data between manufacturers, software developers, data providers and users. This 'LAS' format has widespread international support. Further research and development should include informed users such as English Heritage to ensure that proper tools and formats are available for cultural heritage projects. □

REFERENCE

Barber, D *et al* 2003 'Towards a Standard Specification for Terrestrial Laser Scanning of Cultural Heritage', in *New Perspectives to Save Cultural Heritage: CIPA 2003 International Symposium, 30 September–4 October 2003*, 619–24, CIPA / ICOMOS (ISBN 975-561-245-9)

The results of the terrestrial laser scanning project were presented at the CIPA XIXth International Symposium on 'New Perspectives to Save Cultural Heritage', held in Antalya, Turkey, 2003; the addendum is available on request. Further information on the survey work of English Heritage and its use of laser scanning technology may be obtained from the Metric Survey Team (paul.bryan@english-heritage.org.uk). *Metric Survey Specifications for English Heritage* (Product Code 50562, price £15) may be ordered from English Heritage Postal Sales, c/o Gillards, Trident Works, Marsh Lane, Temple Cloud, Bristol BS39 5AZ. Tel 01761 452966; Fax 01761 453408; ehsales@gillards.com.

3D LASER SCANNING	
ADVANTAGES	DISADVANTAGES
Applicable to all 2D and 3D surfaces	Some systems do not work in sun or rain
Rapid 3D data collection – near 'real-time' – requiring substantially less site time	Large, high-resolution 3D data sets require post-processing to produce a useable output
Very effective due to large volumes of data collected at a predictable precision	Difficulty in extracting the edges examples from indistinct data clouds
Ideal for all 3D modelling and visualisation purposes	Output requires manipulation to achieve acceptable recording quality
Both 3D position and surface reflectance generated which, when processed, can be viewed as an image	Does not currently generate an image comparable to those produced by other techniques
Extensive marketing from manufacturers and exposure to technology by clients, through conferences	No common data exchange format – such as DXF – currently in use to allow ease of processing by third parties
Rapidly developing survey technology	Difficult to stay up-to-date with developments
Extensive world-wide research and development currently being undertaken on both the hardware and software tools	With hardware still expensive and sophisticated software required to process data, cost is prohibitive for many projects