TOWARDS A STANDARD SPECIFICATION FOR TERRESTRIAL LASER SCANNING OF CULTURAL HERITAGE

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ABSTRACT:

The use of terrestrial laser scanning for cultural heritage recording is becoming increasingly popular. Although in some cases laser scanning has been met with a degree of scepticism, scanning has, on the whole, been received with a great deal of enthusiasm. This zeal has ensured laser scanning is now at the forefront of many new projects for the documentation of cultural heritage, leading to the need to standardise the outcome of laser scanning surveys to ensure data is collected in a manner that can produce products useful to the end user. The current Metric Survey Specification for English Heritage, the body responsible for preserving and enhancing England's cultural heritage, contains similar requirements for photogrammetric, non-photogrammetric and topographic survey. This project increases the scope of the specification by introducing terrestrial laser scanning into the surveying workflow. It informs about the advantages and disadvantages of using laser scanning, highlighting the pitfalls of the technique and producing sample datasets that show exemplary practice of laser scanning within the field of cultural heritage recording. Guidelines, for the application of terrestrial laser scanning to cultural heritage, have been formed based on the work.

A number of issues surround the definition of such a specification, such as broad range of scales at which laser scanning can be applied, and the black box nature of some of the instruments. In particular this project deals with objects at the "building scale" range, typically surveyed using photogrammetry or rectified photography. The guidelines have been formulated based on three laser scanning surveys, at different English Heritage sites. In order to remove any bias for a particular instrument it was important that different laser scanning systems were considered. After the completion of each survey the draft document was examined and updated. As it is essential that a specification is also a practical guide to implement outside of test projects it was important that the end users of the specification were properly consulted throughout the process. Therefore, a steering committee, whose members represented a cross section of laser scanning practitioners, surveyors and experts in the field of cultural heritage recording in the UK, was formed to provide guidance during the project. The project does not claim to produce the definitive specification for terrestrial laser scanning in cultural heritage as the subject is particularly complex, however it does provide a useful starting point for future discussion and revision. Although the definition of a specification could smother the development of terrestrial laser scanning, this project aims to guide the development of scanning to meet the needs of the end users (archaeologists, architects, building historians amongst others).

1. INTRODUCTION

1.1 The role of a specification

English Heritage, the national body for the protection and conservation of England's historic environment, has maintained a standard specification, covering all existing types of metric survey for over 5 years. The current Metric Survey Specification for English Heritage (Bryan and Blake, 2001) outlines the current requirements for survey by rectified photography, photogrammetric, orthophotographic, architectural and topographic techniques. These techniques play a key role in the understanding of a heritage site (Clarke, 2001) and the specification ensures that, when required, a repeatable level of geometric precision and narrative recording is achieved. Within English Heritage 82 survey projects have been completed to the defined level to date.

A survey specification is intended to define the standards to which work must be completed. It covers issues ranging from the required geometric accuracy of data to the required format, along with all of the contractual responsibilities of those involved. It ensures that the contractor understands what is required and serves to manage a client's expectations. A specification also ensures standardisation between projects, a vital requirement for organisations such as English Heritage who both commission and advise upon a large number of projects each year and who have a commitment to the tax payer to achieve the best possible value.

The current metric survey specification does not, however, include terrestrial laser scanning (TLS). TLS is an increasingly popular survey technique which has been met with great enthusiasm by many users. There is, however, a need to standardise the technique's processes and deliverables to ensure laser scanning provides the repeatable level of recording that photogrammetry for example currently provides.

Defining a specification for TLS data is complicated by the wide variety of systems and workflows available. TLS can be arranged into two broad groups: the first being close range scanning, operating at ranges of less than two meters and therefore mainly restricted to small objects and artefacts; the second including scanners that operate to ranges of greater than two meters allowing for the efficient survey of building façades and monuments. It is this second group of scanners that most closely resembles instrumentation suitable for the type of survey addressed in the current metric survey specification. Discussion and examples of TLS are therefore limited to this class of system.

1.2 Project design

The project described in this paper has been funded through the English Heritage Archaeology Commission's budget. It aims to produce an addendum to the existing metric survey specification, thus allowing laser scanning to be considered alongside existing techniques within the survey of the 400 monuments directly under the care of English Heritage and many of England's 450,000 listed buildings. It is, however, important to understand that the inclusion of TLS in the specification does not instantly deem it suitable for the replacement of other survey techniques. It is normal that before any survey work is undertaken a project brief is defined. This should describe the variable elements of a particular survey and hence it is the responsibility of this document to define the appropriate technique/s. The specification document produced from this project is simply intended to define the level to which TLS, if appropriate for use, should be applied. The document is also intended as a guide for users. It is not intended to stifle the development of TLS by imposing unrealistic or unnecessary constraints on the application of laser scanning systems. In fact the project explicitly aims to steer the development of laser scanning so that it meets the needs of cultural heritage users, archaeologists, architects and building historians.

An iterative process of specification, survey, consultation and revision was used to define the specification. Based on previous experience an outline project brief was agreed to allow an initial data collection phase to take place. After analysis of this data, a steering committee comprising nine individuals (including the authors), was consulted. The members of this committee were selected to represent both the client and contractor. Contractors were selected from the survey community, including those already offering commercial photogrammetric or TLS services. End users were represented by members of English Heritage, including some from their Centre for Archaeology. After this review a second survey was performed before the initial document was again revised. This draft specification (English Heritage, 2003) was then released for comment to the wider UK survey community before a final survey to confirm the suitability of the document (at the time of writing these two stages are yet to be completed). This extensive process of consultation will ensure the practicality, impartiality, relevance and ultimate value of the final document.

2. OVERVIEW

From the outset it was clear that the specification could be divided into three interrelated segments. These three segments represent the clear logical progression of laser scanning (or indeed any other survey technique): data capture, data use and data storage (or archiving). Although each segment depends on another, for example the methods employed for data collection will implicitly depend upon the intended use of data, using these three broad categories allowed a structured approach to the project.

2.1 Data capture

The capture of data clearly depends on the scanning system in use as this will dictate the workflow and techniques applied. This includes issues such as methods for registration, available/required field of views, the density of data capture and the requirements for any additional information.

2.2 Data use

Although scanning has been used for architectural survey for over three years, standard products have yet to be defined. The use of TLS data was therefore not specifically addressed by the document with the main emphasis placed on the collection and storage of point cloud data. However, in order to make the specification sensitive to the needs of possible end products the following were defined as potential outputs although no specification of how they should be presented, or to what level they should attain, was provided.

- CAD models (by primitive modelling)
- Meshed models
- Profiles and cross sections
- Animations

Work is still required to educate clients who commission TLS that the production of traditional products (such as line drawings) from scan data may not be the most appropriate way of applying laser scanning.

2.3 Data storage

All survey data generated for English Heritage is ultimately deposited in the National Monuments Record, Swindon, UK. The storage of data is therefore a vital part of the specification process. Access to the data must be possible despite the possibility of a number of years passing between data collection and processing. The biggest obstacle to this is the current lack of a standard data format. A standard format for TLS would allow for the efficient transfer of data, improving software development and ensuring the continued use of TLS as a technique to supply archive data. Any standard data format also requires appropriate metadata to allow for long term data storage and management.

3. FIELDWORK

Two separate surveys were performed at Tynemouth Priory, Newcastle upon Tyne in February and May 2003. A further survey is planned for Clifford's Tower, York although at the time of writing the details have yet to be confirmed. Tynemouth Priory has been used on several previous research projects looking at the application of metric survey techniques (Mills et al., 2000, Barber et al., 2002), in addition to being the subject of several phases of survey by English Heritage. As it provides a clear, open and local site it was an ideal location for the first two surveys of the project. Both surveys concentrated on the remains of the priory church (Figure 1), a ruin approximately 92 m x 21 m in size with the tallest structure reaching 22 m in height. During the first visit a substantial survey was performed helping to provide experience and understanding of the type of large scale survey that may, in the future, be performed using TLS. It also provided a basis from which to address important data management issues. A total of 43 scans were collected using a Cyrax 2500 TLS and over 50 control points were used to register data to the local site grid. To ensure the independence of the specification document from any one particular system three different scanning systems were used. In addition to the Cyrax 2500, a Zoller and Froelich Imager 5003 system was used to scan the presbytery (22 m x 14 m x 22 m in size) and, during the second survey, a Riegl LMS Z320 system was used to scan several areas of the church.

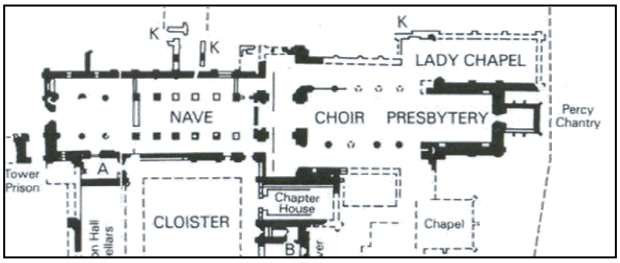

Figure 1. The remains of the Priory Church (solid shading represents standing walls) Hadcock, 1991.

The third survey will validate the specification document by undertaking a "commercial" survey. A project brief will be defined by English Heritage prior to the survey and data then collected to the level described in the specification. The survey data will then be delivered to English Heritage for assessment and comment.

4. DISCUSSION

The following discussion is based on the data collected during the first and second surveys in addition to consultation with the steering committee. It outlines some of the requirements and issues of the specification and illustrates this with examples from the first two surveys.

4.1 Definitions

In order to ensure clarity throughout the specification document a list of definitions was provided. A selection of these definitions are provided below:

- Data voids - Sections within the point cloud, more than twice the point density of the scan in size, which contain no data despite surface information on the object itself.

- Peripheral data - Additional scan data collected during the scanning process not explicitly defined as being required in the project brief.

- Point cloud - A collection of XYZ coordinates in a common coordinate system that portrays to the viewer an understanding of the spatial distribution of a subject. It may also include intensity or colour information. Generally a point cloud contains a relatively large number of coordinates in comparison with the volume the cloud occupies.

- Point density - The average distance between XYZ coordinates in a point cloud. Density can be represented by either a horizontal and vertical separation taken from/to the centre of the footprint at a specified range, or by using angular values.

- Registration - The process of determining the transformation parameters required to transform point clouds onto a common coordinate system.

- Resolution - The smallest discernable unit of measurement.

- Scan orientation - The approximate direction in which the scan is made if the system does not provide a 360 degrees field of view.

- Scan origin - The origin of the arbitrary coordinate system in which scans are performed. When the scan origin is transformed onto the site coordinate system it becomes the scan position.

- Scan position - The location, in a known coordinate system, from which a single scan is performed. If the system does not perform a full 360 degree scan, several scans may be taken from the same scan position, but with different scan orientations.

- Scanning artefacts - Irregularities within a scan scene that are a result of the scanning process rather than features on subject itself. These may be geometric or radiometric in nature.

- Terrestrial laser scanning system (TLS) - Any ground based device that uses a laser to measure the three-dimensional coordinates of a given region of an objects surface automatically, in a systematic order at a high rate in (near) real time (adapted from Boehler and Marbs, 2002).

4.2 Data capture

Before any survey takes place the contractor must supply a method statement detailing the techniques to be used. In the case of TLS this must show the area to be scanned along with details showing that the scanning system to be used is operating correctly. It is considered vital that, for QA purposes, such information is provided. However, as the majority of manufacturers do not provide calibration certificates some other standard is required. Details of a test showing the system is operating to its supplied level of precision and accuracy are required, although, as the exact nature of such a test is likely to vary between users the ultimate responsibility should be on the client to ensure appropriate information is provided.

Accuracy in the recording of cultural heritage consists of geometric accuracy, the closeness of a coordinate to its true value, and narrative accuracy the "correctness" of a particular attribute. From discussion with end users it was clear that each type of accuracy must be specified for. In TLS the two most important parameters for this are the chosen point density and the geometric accuracy of the point measurement. It is necessary to determine suitable values for both. It is possible to assume that point density is mainly responsible for controlling the narrative accuracy of TLS, while point accuracy has the greatest impact on geometric accuracy (although intuitively both point density and point accuracy will effect each type of accuracy).

In previous photogrammetric/topographic specifications the required accuracy of a measurement has been determined by scaling the width of the standard output line width to calculate the required "real-world" accuracy. For example for survey output at a scale of 1:20 and a standard line width of 0.18 mm, an accuracy of 3.6 mm would be required. Originally this was applied when hard copy output was required. However, with most deliverables from survey projects likely to be digital this assumption is less appropriate as data could be plotted at potentially any scale. The use of scale however still provides some control as to the use of the data, providing the user with information relating to the accuracy of the information. Scale was also useful in suggesting the practical dimensions of objects for any particular scale – based on the size of a standard A1 sheet.

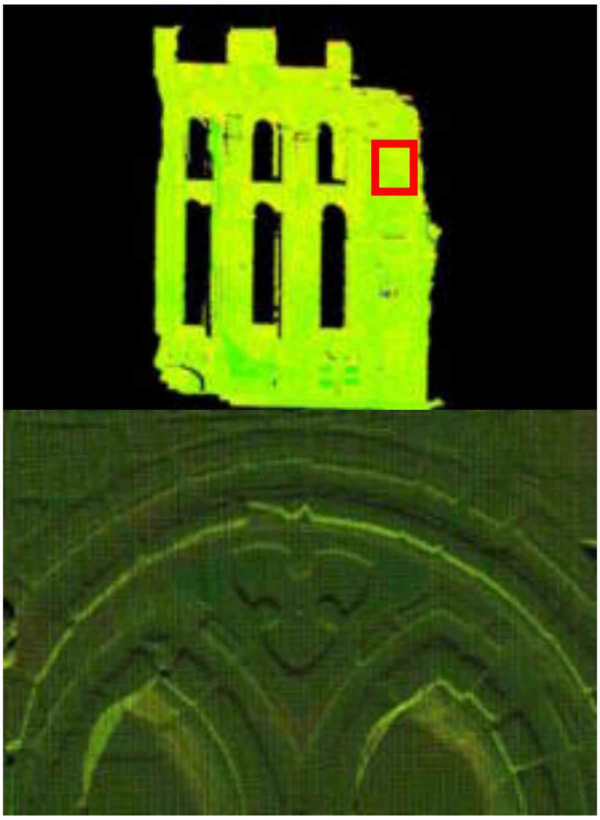

Figure 2 A background scan, top, and a detail scan, below, of the area marked with a rectangle.

The previous metric survey specification however defines a different level of accuracy when using different techniques, despite requesting survey at the same scales. In order to maintain continuity with previous measurement practises it was decided to adopt the same required level of geometric accuracy as that required for building survey. By applying this level of precision to scan data the use of the majority of laser scanners operating over 2 m is unsuited to survey at 1:10 scale, however survey at 1:20, 1:50 and 1:100 scale are all possible. The choice of an appropriate point density is a subjective decision and although it is acknowledged that as high a point density as possible may be desirable this must be balanced with storage requirements.

It was also important that the specification acknowledged the practical constraints on the data that can be captured. For example it is difficult to scan every portion of a complex structure, especially when scanning from ground level where it is not possible to record elevated window ledges or doorways in full. Where such areas are required it should be noted in the project brief and it may be necessary to amend the data collection process or investigate other methodologies all together.

Scanning in heavy rain is deemed unsuitable, mainly due to concerns of having water droplets on the scanning window which may cause diffraction of the measurement beam, resulting in erroneous measurements.

The likely need for two levels of recording is also emphasised. Background scans are appropriate for the spatial location and orientation of areas of detail which are scanned at a higher resolution, Figure 2 gives an example of using detail and background scanning using a Cyrax 2500.

The process of registration differs between each TLS on the market. Some systems opt for the conventional survey approach of using a known reference object and known instrument position while other systems use a resection solution as performed in photogrammetry. It is necessary to specify for both methods of registration as each has a valid pedigree. For resection calculations the residuals of the estimated parameters are required to meet the accuracy of individual scan point measurements. Where registration is performed using a known scanner location and a known RO the precision of the scanner coordinates must be shown to equal the standard requirement of 4 mm for an XYZ control point as defined in the current metric survey specification for English Heritage. Cloud matching routines are deemed suitable, providing additional targets are used to confirm the accuracy of the procedure meets the specification.

A particular feature of TLS, especially for cultural heritage survey, is the amount of additional information captured during the survey process. This includes imagery, sketches and notes. Copies of any data captured on site to aid the survey process are required on delivery to ensure any subsequent processing has all the available information. Where specific additional information is required it will be noted in the project brief. Imagery showing the scanned area is required for all surveys and to ensure any imagery is useful for interpretation this must have a resolution of at least 1500 x 1000 pixels.

As most sites in the UK under the care of English Heritage are open to the public, the safety of visitors is vital. Lasers have a justifiable reputation for being dangerous. A set standard is required to define the necessary precautions that should be taken. The specification adopts the classification and requirements of IEC 60825 (IEC, 2001). All laser classifications should be quoted to this standard. It is noted that at least three different specifications for laser classification exist; the European IEC standard; BS 60825:1994 and the American ANSI standard (ANSI, 2000). Classification between these specifications is not consistent and it is important that users are aware of the class of their instrument in the required classification.

4.3 Data storage

No specific data format or standardised set of metadata exists for TLS. It is not within the scope of this project to define a suitable format and supply the necessary management requirements. A brief overview of the issues involved however would benefit discussion of the topic. The LAS format (LAS, 2002) has recently been adopted by the ASPRS as a standard for airborne laser scanning (ALS). Although ALS and TLS share some common features and that the LAS format could be easily adapted to store TLS data it is suggested that a new format should be developed to ensure full compatibility with all future software systems. Any such format should be universally accepted by software developers and users. The following issues should be considered in any format definition:

- To maintain simplicity a single file should represent a single scan position (header files could be used to group together individual scans).
- Storing information in an arbitrary system would seem good practice but transformation parameters are also required so a single scan may be viewed together with other scans in a "real world" coordinate system.
- Support must be provided to store intensity and/or RGB values for each point.
- Optimum compression of the data should be possible. The data volumes provided by the available systems vary, with the Z+F Imager 5003 providing up to 1GB from a single scan position. A compressed binary format is therefore preferable.

As no format is currently available it has been necessary to adapt the specification to allow for a variety of formats with the emphasis being placed on the ability to transfer data between software systems. The transfer of data between software systems would be best facilitated through the application of a standard level of metadata, both for individual scans and for a project as a whole. For raw scan data the specification requires the following metadata:

- File name of the raw data
- Date of capture
- Scanning system used (with serial number)
- Company name
- Monument name
- Monument number (if known)
- Survey number (if known)
- Scan number (unique scan number for this survey)
- Total number of points
- Point spacing on the object
- Filename for control data
- Weather during survey
- The file name of an image, located at the point of collection, showing the data collected

This metadata should be contained in a digital file and in hard copy in the post survey report. The post survey report should also include the standard requirements found in the current metric survey specification such as details of control point coordinates and accuracies.

Although the generation of this information may at first seem like additional work for the contractor it is envisaged that in future all metadata would be generated semi-automatically. Most systems for manipulating and processing scan data now accepted control and image data in addition to scan data. This could also be extended to contain notes and sketches. Such data management systems (DMS) would make metadata generation easier and in the long term these DMS may become full GIS systems which advanced 3D spatial data analysis tools. Such DMS may even become actual deliverables themselves.

It is common to find users stating that decimation of data was required before any viewing/processing could be performed. It may be necessary to define appropriate decimation procedures to allow for this if required. As the standard computer specification increases the impact of this limitation maybe reduced.

4.4 Common faults

Finally the specification aims to limit some of the common faults of laser scanning surveys. These include:

- Data voids - These are normally caused by temporary/permanent occlusions of the measurement beam by vehicle or pedestrian traffic (Figure 3) or obstruction by the building itself. Where it is not possible to prevent such occlusions it will be necessary to provide sufficient overlap between scans to fill such voids.

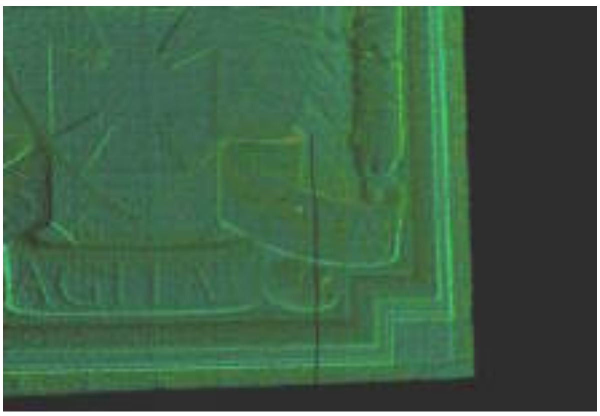

Figure 3 A data void caused by a passing vehicle.

- Scanning artefacts – These are the result of selections made during the scanning process. For example, by choosing to use a higher point density in the horizontal axis than in the vertical axis a point cloud can wrongly emphasise vertical linear features. A second artefact is the cropping of a scan scene so that important parts of the subject/scene are not visible. This may be a particular problem with tall buildings. In worst cases a viewer looking at only the point cloud could misinterpret such cropping as actual geometric features, Figure 4 shows an example of the problem.

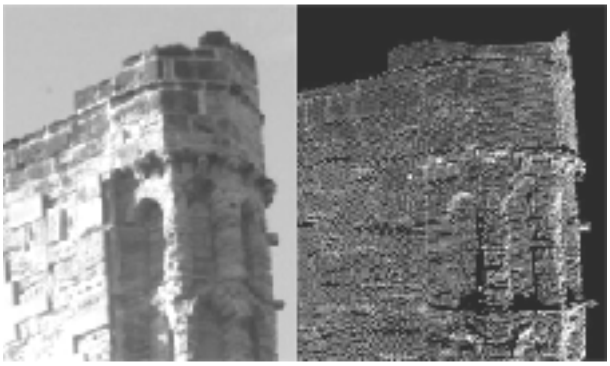

Figure 4 Example of cropping a scan scene

5. SUMMARY AND CONCLUSIONS

The definition of a specification for the collection of point clouds using TLS is a major step in the adoption of laser scanning as a standard survey technique for cultural heritage. The use of a standard specification has advantages for both client and contractor in addition to focusing the needs of a particular technology.

The specification has been divided into three segments: data capture, data use and data storage; however each segment is clearly interrelated and has been considered in relation to each other. Standard point densities have been defined in addition to the required accuracy for point measurements. Definitions for terms used in scanning surveys have also been outlined.

A major theme of the discussion has been ensuring the impartiality of the document from any one particular scanning system. Three different systems, each representing a particular type of laser scanner, were used. The use of multiple systems ensured the workflows employed by each were considered. A notable difference was seen between systems that used a known station location and those that relied on a resection calculation.

The specification defined as a result of this project does not claim to be the definitive standard but does provide a basis for future discussion and revision. The paper presented here has provided an outline of the issues covered by the specification, illustrated with examples of some of the problems faced. As the technology continues to develop it is anticipated that the specification will evolve. The results reported in this paper represent the initial experiences of the project. Readers are recommended to consult the final addendum once the project has been completed. This will report the requirements of the specification in full.

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