3D Scanning Technologies and Data Evaluation in an Archaeological Information System

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Abstract. The use of technological 3D applications for archaeology and cultural heritage has advanced rapidly in the last few years thanks, in particular, to the employment of 3D scanners and high-capacity 3D editing software. These advances have lead to a great improvement in the standard of digital documentation. The ultimate objective is to create realistic, virtual 3D documentation which can be systematically and comprehensively viewed on computer. Specialist archaeological information systems have been developed to accompany excavations and documentation projects. They are capable of presenting complex spatial and historico-cultural relationships in a comprehensible and manageable way. This paper is intended to give an overview of the developments and research projects currently in progress at ArcTron Ltd.

1. Introduction

During the last few years, the development of innovative, three dimensional surveying technologies for the documentation of archaeological and historical goods and monuments has given rise to new occupational fields for specialist service providers within archaeology and related disciplines. ArcTron Ltd. is just such a service provider for engineering services for 3D surveying wit a focus on archaeology and cultural heritage.

ArcTron Ltd. was founded more than a decade ago and, since then, has expanded to become the largest excavation company in southern Germany. From the beginning, ArcTron Ltd. has specialised in electronic surveying techniques and the development of surveying instruments with connected CAD/database information systems for archaeology and heritage. We have employed surveying technologies such as total stations, laser pantographs and 3D photogrammetry for more than ten years and have now diversified into the more innovative 3D scanning technologies.

Since 2000 we have invested heavily in 3D scanning technology and now employ three different scanning systems (Fig. 3) to allow us to provide a comprehensive three dimensional surveying service ranging from the documentation of small finds all the way up to large topographical recordings with areas of several hectares. Of course, all this technology is of little use if the huge amounts of data it produces cannot be easily accessed, evaluated or visualised. For this very reason, ArcTron Ltd. has developed a modular archaeological information system which, when used in conjunction with 3D surveying and scanning technologies, can be used to produce photo-realistic, 3D digital documentation of finds, monuments or indeed entire excavations or historical sites.

2. Terrestrial Laser Scanning

In contrast to airborne laser scanning, terrestrial laser scanning only really became accepted as a surveying technique vduring the late 1990's. In terrestrial laser scanning the distance measurements are carried out either using the familiar phase comparison technique or, more usually, the pulsed time-of-flight technique.

One of the great advantages of laser scanning is that the geometry of any object can be recorded on a scale of 1 to 1 at the push of a button. Nowadays, terrestrial and/or airborne laser scanning (LiDAR) is used to create 3D survey records of the topography of historical sites (Fig. 1) such as ramparts, enclosure complexes, historical masonry etc.

The data can be recorded relatively rapidly and with a comparatively high level of accuracy (depending on the technology from submillimeter to millimeter range).

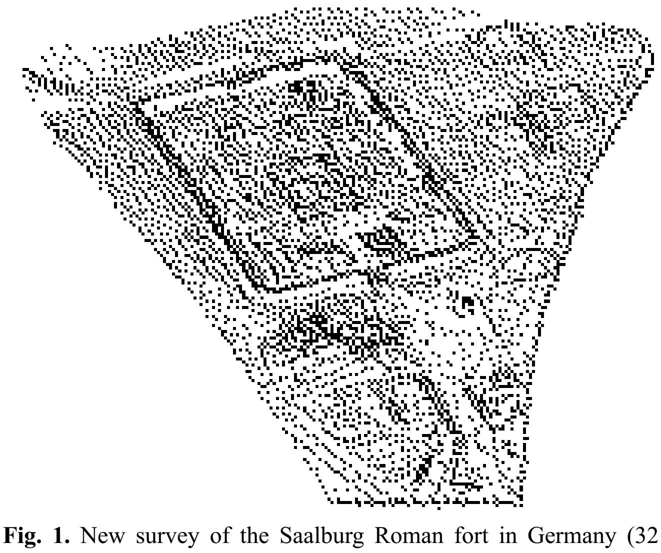

Fig. 1. New survey of the Saalburg Roman fort in Germany (32 hectares) recorded using a combination of total station surveying and laser scanning and displaying an integrated CAD recording of the historical excavation plan for comparison. (© ArcTron Ltd).

Laser scanning is a procedure which can be employed in almost any environment. It allows existing conditions to be comprehensively and reliably recorded, ensuring optimum preservation of evidence.

It is a technique which is very well suited for use in the fields of archaeology and heritage for several reasons. Laser scanning is a hands-free procedure which makes it ideal for documenting poorly accessible or instable objects. It is also ideal for recording complex, amorphous objects which would otherwise be difficult to survey and which crop up with notorious regularity in the fields of archaeology and heritage (Fig. 2).

One of the clearest advantages provided by laser scanning is the reduction in time spent on location. Large and complex areas can be recorded in a very short time and, once data acquisition is complete, all further measurements are carried out on the generated model. With a systematic approach to laser scanning, it is also possible to document the development of complicated, stratigraphic archaeological features in all their various stages of excavation.

At ArcTron we employ two different time-of-flight laser scanners from the Austrian manufacturers, Riegl (Fig. 3,1.2): a panorama scanner and a pan-and-tilt scanner. Both of these scanners can be used in combination with a high-resolution single-lens-reflex camera which is mounted on the scanner and whose calibration and orientation is precisely registered within the system. This combined system is currently the only one of its kind and can be used to generate high-resolution, digital survey images which are ideal for the further addition of photogrammetry recordings. Combining spatial geometries with true-colour information in this way allows the scanned objects to be modelled in three dimensions and realistically textured already during the data capturing process.

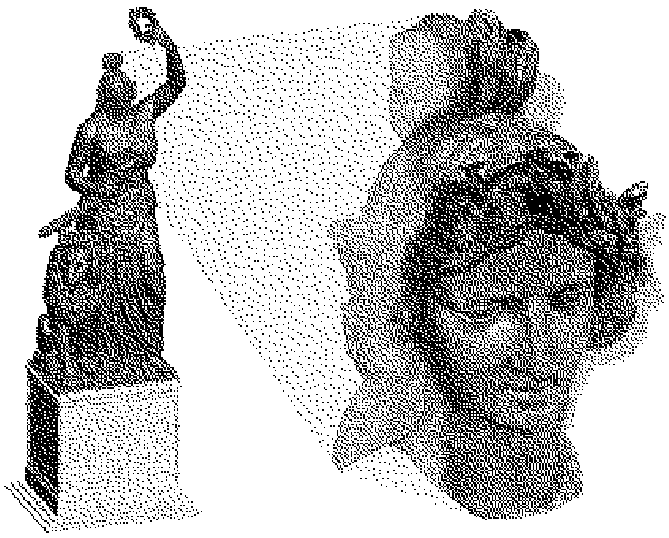

Fig. 2. The Bavaria. A monumental sculpture in Munich. This almost 19m tall bronze was surveyed in its entirety using 3D scanning techniques in 2002. 3D data processing was carried out in connection with a 3D damage mapping system and used to generate a complete, photo-realistic textured model (© ArcTron Ltd; Polygon Technology; Engineering consultants Dr. Koenig).

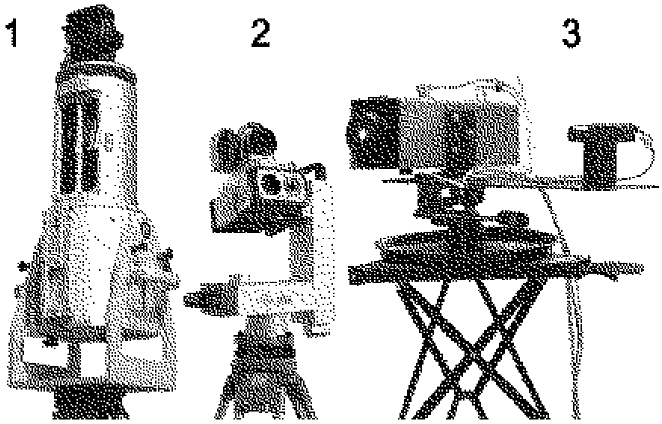

Fig. 3. The three scanning systems used by ArcTron Ltd. 1: Riegl LMS Z-360 with Nikon D100; 2: Riegl LPM 25-HA with Canon EOS; 3: Structured light scanner from the Fraunhofer Institute (Igd).

3. Scanning with Structured Light

Whilst terrestrial laser scanners are well suited to recording topographical and architectural objects, their accuracy and detail resolution are completely inadequate for recording fine architectural details such as complex sculptural features or for recording smaller, intricate finds.

During the last few decades, a host of innovative technologies have been developed which define the surfaces of irregular objects by projecting and recording patterns of light. Such systems have sub-millimetre accuracy and can be used to record even the smallest structures in three dimensions.

Structured light or stripe-light scanners can be used to document architectural details, small archaeological finds and historical artefacts as well as larger items such as life-size statues, reliefs and gravestones etc.

For projects which require a higher level of resolution we use a structured-light laser scanner (Fig. 3,3) which was developed at the Fraunhofer institute for graphical data processing. It is accurate to within a tenth of a millimetre and projects a pattern of structured light over a maximum area of two square metres. As with our terrestrial laser scanning systems, our structured light scanning system uses a high-resolution digital camera to record surface colours during the scanning process. This combination of information can be used to generate a true-colour, photo-realistic digital model of

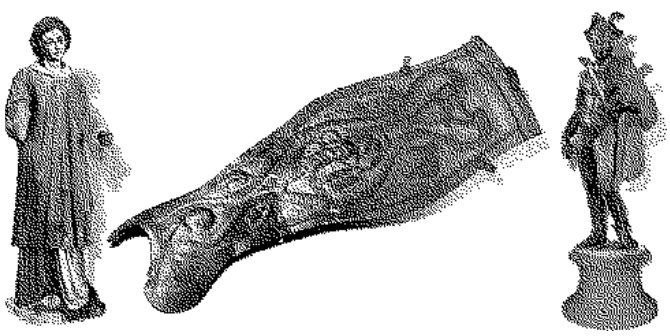

Fig. 4. Examples of various finds (late medieval wooden statue, Roman bronze greave, Roman bronze statuette of Mercury) which were recorded at high-resolution and in three dimensions using the stripe-light scanning system and photo-realistically textured (© ArcTron Ltd).

the original object (Fig. 4) which can be studied on computer from any angle and in any degree of enlargement.

4. Processing 3D Scan Data

3D laser scanning produces enormous quantities of data which must be processed to produce 3D reconstructions of the measured objects. Processing is carried out in the office and is a much more laborious and complicated task than the comparatively simple procedure of scanning the features on site.
The raw data from a laser scan is an unstructured mass of 3D points which require careful classification in the post-processing phase. This can be achieved using filter algorithms, by extracting geometric shapes or by generating polygon meshes. In order for processing to be successful, the software employed must be capable of accurately modelling complex undercuts and edges and be able to generate optimised 3D meshes. Handling such huge amounts of data, which can contain hundreds of millions of scanned points, requires high-capacity hardware and specialist software.
The individual scans are registered and transferred into a common coordinate system. Point cloud data is then purged and refined, filtered and thinned out using edge matching routines and losing as little vital information as possible in the process. The data is then converted into polygon meshes and textured using photographic information to create photo-realistic 3D models (Fig. 5). The survey data can now be analysed and evaluated and used to generate plans, sections, various views, thematic mapping and 3D animations etc.
On excavation, even the most complex, stratigraphic relationships can be modelled if each new planum or feature is recorded as and when they are uncovered. In such models, the base of each layer (working from top to bottom) forms the upper surface of the next and if sections are also recorded, the information can be used to generate digital 3D volume models of the individual strata (Fig. 6).

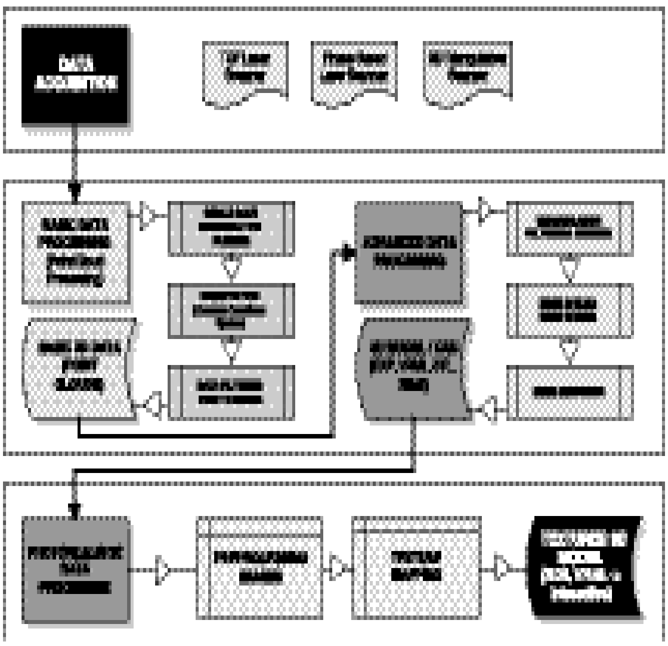

Fig. 5. Sketch of the workflow: Data Processing (© ArcTron Ltd).

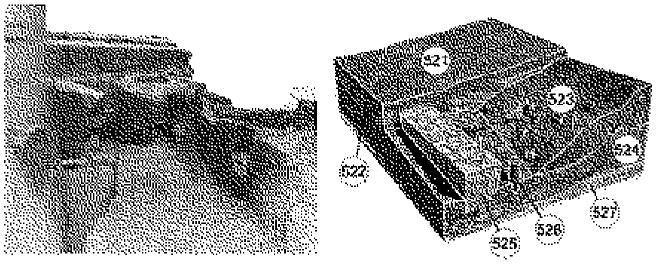

Fig. 6. Left: Clinique St. Joseph, city of Luxembourg. A medieval site with complex architectural remains which has been completely scanned and surveyed in 3D. Right: Archaeological, stratigraphic model. The use of laser scanning technology allows the complex, stratigraphic relationships from archaeological excavations to be recorded in layer-oriented 3D documentation. (© ArcTron Ltd).

5. The Structure of the ArcTron Archaeological Information System

The ArcTron archaeological information system is modular and is based on standard hardware and surveying instruments. It consists of a CAD station with peripheral equipment, laser scanners, digital cameras, our own specialist software as well as software from other manufacturers and a total station for use in basic documentation and surveying. As an authorised marketing partner for Leica Geosystems, we specialise in the use of Leica total stations but, of course, our software packages also provide interfaces for equipment from all other well-known manufacturers.
GPS systems can be employed although they are still relatively expensive and, therefore, are usually only used if no existing survey reference points are available. Digital pantographs may also be incorporated into the system. In 1995/96 we developed our own model, the 3D laser pantograph, ALPHA. This instrument in seldom used nowadays due to the improved performance of laser scanning equipment

6. ArcTron Specialist Software

Our in-house programmers specialise in developing software solutions specifically for use in the fields of archaeology and heritage.
Our extensive software range forms a solid basis for the construction of comprehensive archaeological information systems. Soft and hardware can be combined in various ways, depending on the requirements of the individual project. This flexibility allows us to perfectly tailor our information system to suit each particular task.
Our archaeological information system contains the following specialist programs:

- ArchaeoCAD, the central program of our information system is an AutoCAD 2004/2005 application which automatically processes 3D data from surveying instruments and generates scientifically structured plans.
- aSPECT3D is our software module, integrated into ArchaeoCAD, which allows incoming 3D data from a total station and from 3D-scanners to be visually monitored actually during the surveying process. There are additional

modules which allow the user to work with fully textured complex VRML-models as a result of processing 3D-scanner data.

- ArchaeoDATA is ArcTron's own comprehensive excavation database. It can manage and record all information from excavations of any size.
- ArchaeoMAP is a mapping interface which allows database queries to be realised in CAD plans.
- ArchaeoDTM is a digital terrain modelling program based on AutoTerrain 2004 and was developed in collaboration with EDO Software
- kubit PhoToPlan is a photogrammetry interface which allows the user to rectify individual photographs using surveyed control points to generate a single, overall photographic plan.

7. Reproduction, Rapid Prototyping and Modelling

3D documentation of the type discussed here provides an ideal basis for the reproduction of objects using rapid prototyping, CAD/CAM and CNC technologies or 3D printers (Fig. 7).

This creates manifold new possibilities for model building and marketing in museums with scaled models able to be created directly from computer data in a multitude of different materials and grades of reality. Ink-jet technology has recently been developed which can print colour information such as aged stone or bronze patina directly onto the reproduction 3D model. This allows a level of information to be included which goes way beyond that of a standard 3D model.

Fig. 7. The Bavaria, Munich. Examples of various reproductions generated using Rapid Prototyping techniques. In ABS plastic (left), glass block (middle) and with a coloured surface created using ink-jet-technology (right). (© ArcTron Ltd).

8. Conclusion and Future Works

Laser scanning and electronic surveying have come to be essential tools in the fields of archaeology and heritage. Equally, digital documentation techniques are becoming indispensable for the preservation of architecture, heritage sites and archaeological finds and features for posterity. It is, of course, absolutely fundamental that the data is able to be viewed and evaluated without difficulty. Integrated archaeological information systems which allow various types of documentation and data to be combined, visualised and analysed provide the best solution for managing such a task.

ArcTron is currently involved in a further development and research project whose objective is the creation of a spatial information system for archaeology (VRAIS – Virtual Reality Archaeological Information System).

We are aiming to produce a VR-based, 3D information system which is capable of reproducing geometric, photographic and textural data. The system will be capable of managing the data in a scientifically structured, digital, VR environment and of evaluating it for historico-cultural significance.

Acknowledgements

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