3D-RECONSTRUCTION & RE-PRODUCTION IN ARCHAEOLOGY

M. Ioannides [a], A. Wehr [a]

[a] Higher Technical Institute, P.O. Box 20423, CY-1521 Nicosia, Cyprus - gammat@cytanet.com.cy
[b] Institute of Navigation, University of Stuttgart, Breitscheidstr.2, D-70174 Stuttgart, Germany - wehr@nav.uni-stuttgart.de

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ABSTRACT:

First an imaging 3D-Laser Scanner (3D-LS) will be presented and its functioning will be explained. The scanning mechanism of the 3D-LS is realized by two Galvanometer Scanners. Using such a scanning device it is possible to program various scanning patterns depending on the application. Therefore, the scanner can be applied for the digitization of small sculptures as well as for digitizing interiors of rooms. It has been shown that the 3D-LS is an excellent tool for 3D-Reconstruction. However, using laser scanners for digitizing comprehensively archaeological items means that several hundreds of Megabytes must be efficiently processed. This problem will be addressed in the second part. It will be shown, how laser scanner data must be processed to obtain NC-programs for re-production in archaeology. Here the Advanced Surface Modeling Software Package (ASMOS) developed by the University of Stuttgart and the Higher Technical Institute is applied. Also the problem reconstructing solids by using 3D-LS data from different overlapping views will be addressed and examples will be presented. Various examples will demonstrate that 3D-LS can be well applied in 3D-reconstruction and re-production if sophisticated and powerful software packages are available for processing the 3D-LS image data efficiently.

1. INTRODUCTION

In the last years 3D-Laser Scanners (3D-LS) have been used more and more in 3D-reconstruction and reproduction, because very precise 3D-data can be measured in very short time intervals. Due to the high point density not only 3D-surface models can be generated but also real 3D surface images can be derived if intensity data are available.

In the beginning of 3D surface digitization either with photogrammetric means or tactile machines a modeling of the surveyed surface was required, because the number of measurement points was very limited. Today the problem is vice versa. The user obtains a huge amount of data which very often contains redundant information. 3D point clouds containing more than a million measurement points are typical for laser scanner data sets. In order to reduce superfluous data again surface models must be generated. This means sophisticated processing software is necessary to obtain valid data for CAD modeling or even rapid prototyping. As soon as CAD data are available 3D-reconstruction can be carried out by commercially available CAD software. In this processing level reconstruction of volumes are also possible. Therefore, in this paper main emphasis will be laid on the modeling postprocessing algorithms and software respectively. However, before all sorts of algorithms and procedures are discussed and analyzed, a 3D-LS developed by the Institute of Navigation will be explained. The scanning pattern can be customized by software modifications. Therefore, the 3D-LS covers a large field of applications as e.g. scanning of sculptures, small objects and interiors of rooms.

2. 3D-LASER SCANNER

Over the past years the Institute of Navigation of the University of Stuttgart has developed several imaging 3D laser scanners using continuous wave (cw) semiconductor lasers as transmitters and carrying out the slant range measurement by

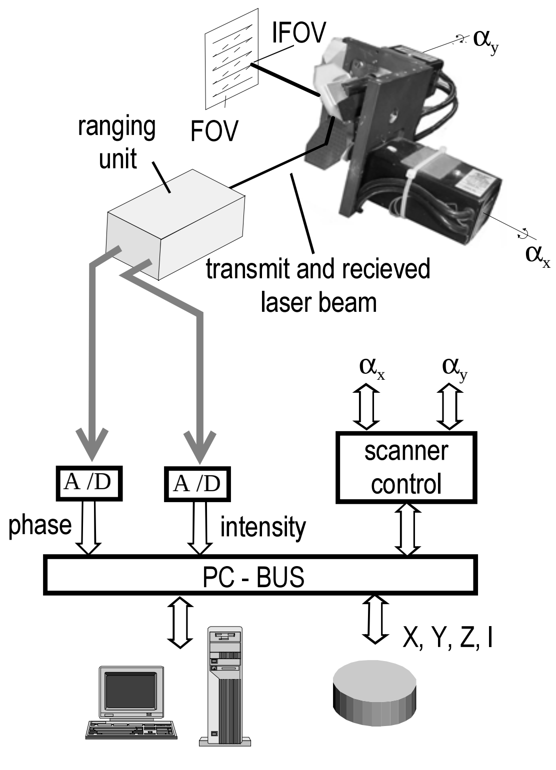

Figure 1. Principle 3D-LS Setup

applying the phase difference measurement principle which is also known as side-tone ranging. Here the intensity of the light of the cw-semiconductor laser is modulated by the drive current with high frequency signals. As the phase difference between the transmitted and from the object surface backscattered laser light is proportional to the two-way slant range depth information can be directly measured. Using high modulation frequencies of e.g. 314 MHz resolutions down to the tenth of a millimeter are possible. Knowing the actual laser beam´s orientation for each measurement point, three dimensional surface coordinates can be determined (s. Figure 1). Besides the depth information, the 3D-LSs of INS sample the intensity of the backscattered laser light with a 13 bit resolution synchronously. This means, the user obtains grey scaled 3D surface images. Figure 2 shows a typical 3D-LS measurement result in 3D-projection. A more detailed description of 3D-LS is given in Wehr, 1999. The technical data of 3D-LS are compiled in Table 1.

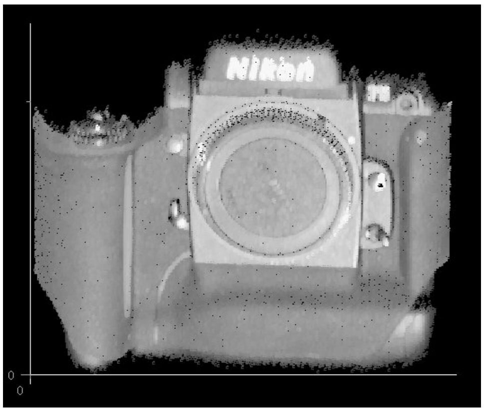

Figure 2. Typical 3D-LS image in 3D Parallel Projection

optical laser power	0,5 mW
optical wavelength	670 nm
instantaneous field of view IFOV	0,03° (transmitting aperture 3,5 mm)
total field of view FOV	max. 30°×30°
receiving aperture	17 mm
standard scanning	2-dim. line scan
number of pixels	typ. 200×200, 400×400 or 800×800 Pixel
max. range	<10 m
slant ranging accuracy	0,1 mm (for diffuse reflecting targets with 60% reflection at 1 m distance)
slant range error	±1 mm (0 ≤ range ≤ 5 m and 50 dB intensity dynamic)
side tones	10 MHz and 314 MHz
sampling rate	2 kHz (1-side tone), 800 Hz (2-side tones)
scanning time for one image with 200×200 pixels	40 s (2-side tones)

Table 1. Technical Data of 3D-LS

2.1 Scanning Patterns

Figure 1 depicts that 3D-LS uses two galvanometer scanners which are mounted orthogonally to each other. This setup allows for deflecting the laser beam in two dimensions. In standard setup mode the 3D-LS moves the laser beam in horizontal line over the object´s surface (s. Figure 1). However, using galvanometer scanner drives it is possible to address randomly points within the field of view (FOV) which is 30°x30° for 3D-LS. These drives are controlled by software. Therefore, it is possible to adapt the scanning pattern to the actual applications. The standard scanning pattern (s. Figure 1), the TV line scan, is normally used to digitize object surfaces. The number of points along the line and the line spacing is also programmable. The minimum spacing is determined by the resolution of the galvanometer scanners and the scanning control unit respectively, which is 10 arcsec. In this scanning mode the user obtains a 3D image of one view. When scanning surfaces which are larger than the FOV of 3D-LS, several images must be taken in order to obtain a comprehensive data set. This means that after scanning, the different views must be merged by sophisticated software programs. Taking several views is also required if solid volumes, closed interiors, surfaces and volumes with undercuts are sampled. Surveying procedures and merging will be explained in the preceding chapters.

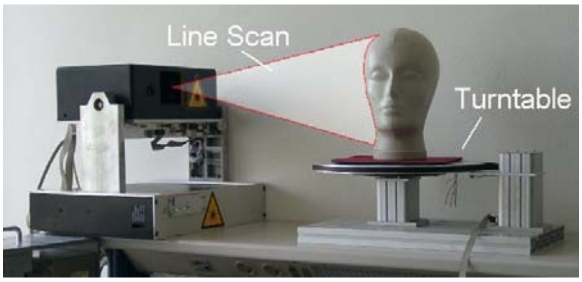

Figure 3. Digitizing an Object on a Turntable

Figure 4. 3D-LS on Turntable

Sampling axially symmetric solids, like vases, cups etc. which should be described as volumes may be digitize by mounting the object on turntable and using a vertical line scan (s. Figure 3). After each line scan the turntable is moved by a defined angular step. Turntable and 3D-LS are controlled by the same computer. The setup turntable and laser scanner must be well calibrated as well as the exact orientation between the coordinate systems of the turntable and the laser scanner must be known.

When scanning extended concave surfaces across a hemisphere like vaults or interiors of rooms, a setup depicted in Figure 4 is of advantage. Here the 3D-LS is mounted on a turntable and a vertical line scan is applied. After each line scan the turntable is

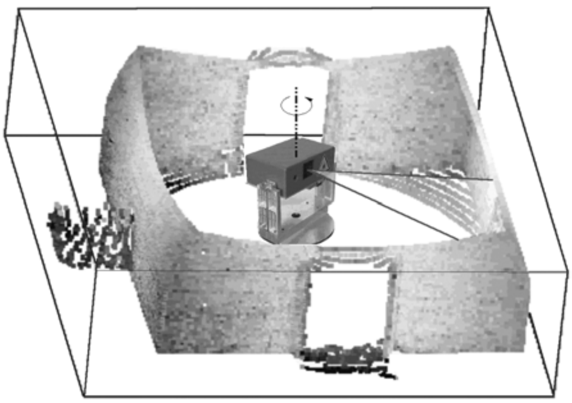

Figure 5. Scanning Interior Rooms (one belt)

moved by a certain angular step in azimuth. After a turn of 360° a belt with a vertical FOV of 30° is sampled (s. Figure 5). To obtain a hemispherical coverage the 3D-LS must be moved in elevation. This is carried out by an additional stepping motor drive (s. Figure 4). For nadir an image scan is advisable. These selected examples make clear that the optimum scanning pattern is very dependent on the applications and commercially available laser scanners are limited to one scanning pattern realized by optimally designed opto-mechanically setup; e.g. the Cyrax 2500 of the company CYRA features a two-dimensional line scan where as the LMS-Z210 of the RIEGL company carries out a vertical line scan. The 3D-LS of the INS was developed for scientific studies, to derive critical design parameters for the optimization of future laser scanners and measurement procedures.

3. SURVEYS WITH 3D-LS

With regard to the different scanner setups typical surveys will be presented and discussed.

3.1 Object on a Turntable

Figure 6 shows the digitization result of a glass head. As the scanner did not sample information on the top of the head the solid was not surveyed comprehensively. However, most of the object can be described by a well ordered point cloud directly after the survey. This means the data were sampled volume oriented.

3.2 Digitizing of Rooms

In the historical "Maerzenbierkeller" in Polling, Bavaria (Germany), which was built in 1745/46 by Michael Fischer, two

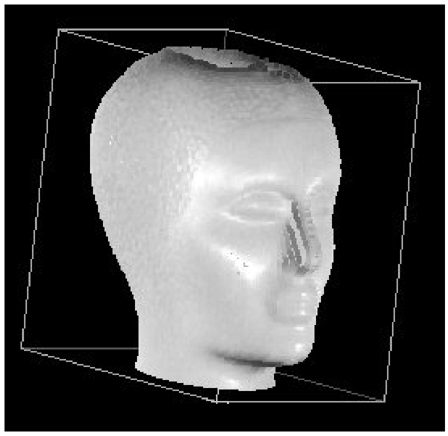

Figure 6. Glass Head

neighboring caves were scanned with the setup shown in Figure 5. The rooms had a quadratic plan form of 7.2 m x 7.2 m. The maximum height was 4.35 m. The vertical laser line comprises 40 measurement points. The 360° in azimuth were subdivided in 500 steps. Seven belts were scanned with elevation angles of 0°, 9°, 22°, 36°, 49°, 63° and 76°. At the nadir a complete image of 200x200 points were taken. One cave was surveyed in 1.5 hours. The data sets of both caves were sampled independently. The data sets were merged using identical points

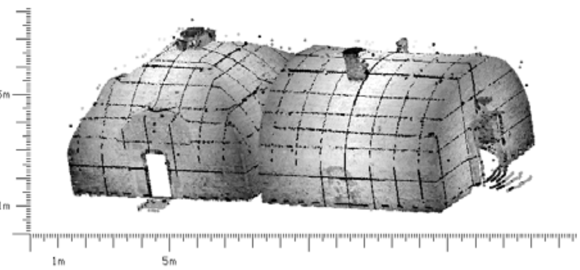

Figure 7. 3D-Projection of Caves

in both sets and adjustment methods. This was possible, because the two rooms were connected by a door. Figure 7 shows a look from the outside. The survey comprises 360000 points.

3.3 Using the Imaging Scanning Pattern

Two typical examples for using the imaging scanning pattern will be regarded. First a copy of a relief from the famous master builder Schinkel with the dimensions width 80 cm, height

Figure 8. Relief

40 cm and depth 9 cm was scanned at the "Bauhof" in Berlin, Germany. The relief exhibits some undercuts. Therefore, two views must be taken with the 3D-LS. The final result of the merged data set is shown in Figure 8. The side view clarifies that the undercuts were well digitized.

A very challenging device was a dinosaur skeleton of a Diplodocus carnegii at the Museum of Nature Humboldt -

Figure 9. 3D-Projection of Diplodocus carnegii

University of Berlin. The skeleton had a length of 25 m and was 5 m high. 21 laser scanner images were taken. These independent data sets were transformed into one common coordinate system by adjustment procedures. Figure 9 shows the final result in 3D-projection. The skeleton is imaged by 861021 laser measurement points.

4. PROCESSING OF LASER SCANNER DATA

The presented examples make clear that laser scanners generate point clouds with a large amount of data which cannot be processed by standard CAD programs. This chapter addresses the problems of processing the data so that they can be input into CAD software packages and of generating NC-programs for re-production in archaeology. Solutions for merging effectively independent laser scanner images into one common coordinate system will be presented.

4.1 Procedures for Merging Laser Scanner Images

The previous chapters clarified that several independent laser scanner images must be merged when the object is larger than the field of view of the laser scanner or the object exhibits undercuts. A very straightforward solution is using identical points in the overlapping area of neighboring images. This requires that these points appear with high contrast. In cases where identical points cannot be identified on the object itself so called reference spheres can be applied (Wehr, 2001). Using these aids very precise results can be yielded.

The Cartesian coordinates that are the result of the digitizing of freeform objects by the 4D-LM are transformed into object coordinates by a special software postprocessor. The coordinates may now be processed as either NC-commands for copymilling (duplicating milling) and rapid prototyping machines or in the data format for the sculptured surface modeller.

4.2 Postprocessing of Object Coordinates for Copymilling and Rapid Prototyping Machines

A special software functionality is developed for the calculation and determination of loop contours out of the digitised data. Figure 10 and 11 illustrate the method for the estimation of the contours for the front digitised view of the glass head in figure 6. In further steps of research while analyzing NC-programs of copymilling machines, we found out that the coordinates of the cutter center point represent a set of loop contours. This means that the calculated contours could be transformed directly to NC Programs.

This method presents a simple way of how even non experts in CAD/CAM systems could generate and produce a 3D-modell.
A more advanced method is to carry out the merging after surface modelling.

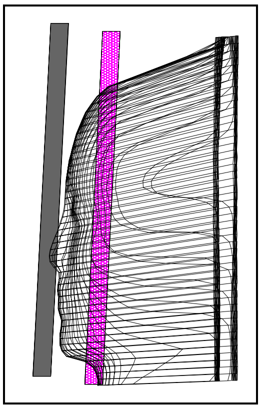

Figure 10. Estimation of the contours

The tooling and moulding industry currently models the work pieces mathematically through Computer Aided Design/Computer Aided Manufacturing- (CAD/CAM) systems. Unfortunately the analytical description of such objects is not sufficient for practical applications. Here the computer space and time complexity must be increased to achieve the approximation and interpolation necessary.

Digitizing a sculptured surface results in a very high amount of data (Giga Bytes of space in the main memory system). The computation performance of existing CAD/CAM-systems is

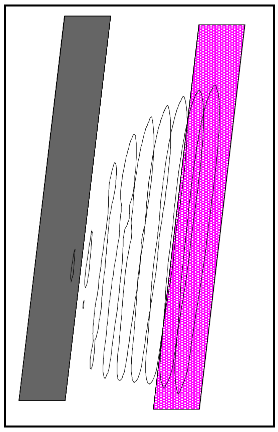

Figure 11. Estimation of the contours

insufficient for the processing of this data.

A data reduction is required to solve this problem. A data reduction of more than 80% can be achieved depending on the complexity of the workpiece by computing spline -curves and -surfaces using the following algorithms

- bicubic Bezier,
- polynomial representation (Coons),
- B-Spline,
- Non Uniform Rational B-Splines, (NURBS) representation.

These computed internal representations of the digitized object is obtained by the Advanced Surface Modelling Software

Package (ASMOS) developed by the Institute for Control Technology for Machine Tools and Manufacturing Systems (ISW) at the University of Stuttgart and the Higher Technical Institute in Nicosia, Cyprus.

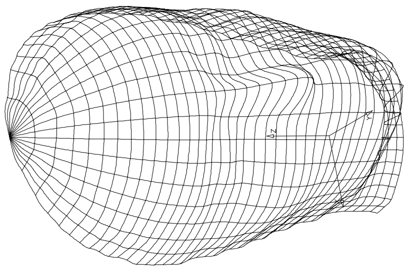

Figure 12. Generated Surface of the front digitised view

The output of ASMOS can be processed by all 2D / 3D-oriented CAD/CAM-systems. For the data transfer within CAD -systems the following interfaces are available

- IGES,
- VDAFS and
- STEP.

Figure 12 shows the generated surface of the front digitized view of the glass head and figure 13 illustrates the manipulation of the structure of a special part of the spline surface.

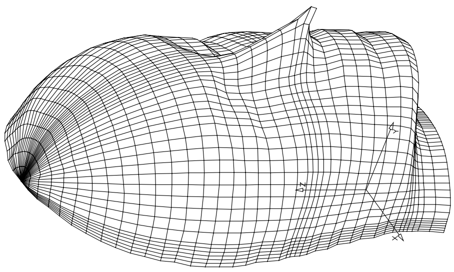

Figure 13. Structure Manipulation

4.3 Volumeoriented Digitalizing Approaches

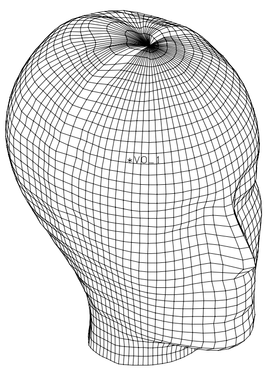

Figure 14. Reconstructed Glass Head

When the digitalized object is measured not only from one side but from different overlapping views, it is then possible to reconstruct the entire object (Volume, Solid) by using specially developed algorithms which are also integrated in ASMOS.

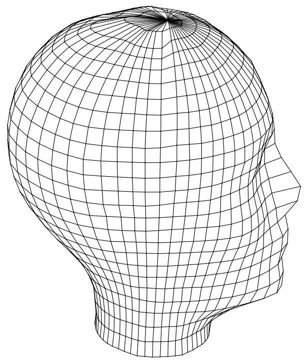

Figure 15. Volume Model

Figure 14 shows the results of the reconstructed glass head (as volume structure). Figure 15 (volume model) and 16 illustrates the reconstructed head of a mummy (from Cyprus).

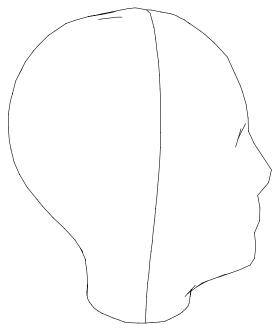

Figure 16. Reconstructed Head of a Mummy

5. LASER SCANNING FOR CONSERVATION

The 3D-LS was applied to support the conservation of a wooden epitaph from a church at Rothenstein in Germany. This

Figure 17. Backplane of the Painting
(Photo: DANKA Office Imaging)

400-year-old crucifixion painting was badly damaged by insect damage. Originally the supporting structure was 2 cm thick. Now, in some areas only a wafer-thin layer remained. The supporting structure should be rebuilt by honeycomb paper boards drenched in phenolic resin. The surfaces of these boards must be shaped so that they fit perfectly to the backplane of the painting´s structure which shape is determined by the worm-eaten wooden surface (s. Figure 17). The 3D-LS was applied to digitize remotely the backplane of the painting(s. Figure 18). The laser scanner data were used to generate NC-data for milling the honeycomb paper boards. These boards were finally glued on the backplane with a special adhesive. This conservation project was led by the Fachhochschule Hildesheim / Holzminden Germany.

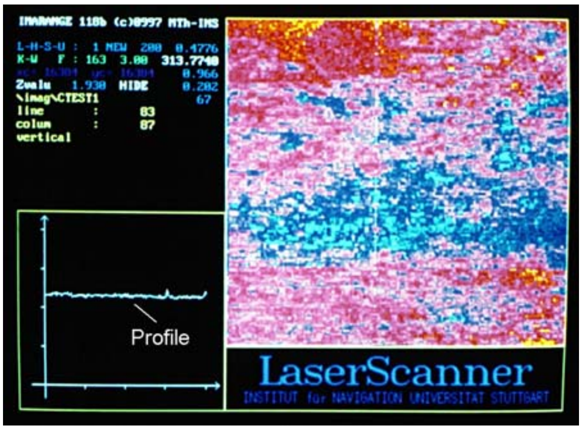

Figure 18. Colour Coded Range Image of the Backplane

6. CONCLUSIONS

It was explained that 3D-Laser Scanners can be well used as a data acquisition tool for 3D-reconstruction and reproduction in archaeology. It was worked out that scanning patterns must be selected independence on the application. The 3D-reconstruction and Re-production process was tested with various objects and showed robust and precise results. The experiment carried out together with the Fachhochschule Hildesheim showed that laser scanning combined with advanced production engineering opens the application field of conservation.

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