Combination of Different Surveying Methods for Archaeological Documentation: the Case Study of the Bronze Age Wooden Chest from Mitterberg

Hanke, K.[1], Stöllner, T.[2], Kovács, K.[1], Moser, M.[1]
[1] Institute of Basic Sciences in Civil Engineering, Surveying and Geoinformation Unit, University of Innsbruck, Austria
[2] Institute of Archaeological Science, University of Bochum and German Mining Museum, Bochum, Germany
{klaus.hanke, kristof.kovacs, michael.t.moser}@uibk.ac.at, thomas.stoellner@bergbaumuseum.de

The international research program HiMAT (History of Mining Activities in the Tyrol and adjacent areas) is dedicated to the research of mining in the Eastern Alps. There is only a limited number of specific regions (e.g. Mitterberg) that provide the possibilitie to investigate the former mining expansion. Within this multidisciplinary project, the Surveying and Geoinformation Unit analyses the archaeological sites and finds of the HiMAT key areas with different surveying methods.
This paper presents the exact combination of terrestrial laser scanning and close range photogrammetry to obtain a photo-realistic 3D model of one of these major finds, the Bronze Age wooden chest from Mitterberg. The applied workflow consists of four steps in this case study: 1. Point cloud processing, 2. Meshing of the point clouds and editing of the models, 3. Image orientation and correction, 4. Model texture.
Additionally, a short range laser scanning survey was organized before the conservation process of the wooden boards. The aim of this project was an all-side data collection and 3D model creation. This detailed documentation helps to maintain more accurate research opportunities for these wooden objects. This paper demonstrates also some analysis opportunities of the wooden chest's fine structures.

Keywords: Documentation, Analysis, Terrestrial laser scanning, Close range photogrammetry.

1. Introduction

In 2007, the special research program HiMAT (History of Mining Activities in Tyrol and adjacent areas) was established at the University of Innsbruck as an interdisciplinary project. The aim of this international research is the analysis of the impact of mining activities on the environment and human society.

During the HiMAT program, the continuous documentation of the archaeological excavation sites and finds is a fundamental requirement (HANKE *et al*. 2009). The more than 3000-year-old wooden chest was one of the most important finds in 2009.

In this paper we present a case study combining different surveying methods, such as laser scanning and close range photogrammetry, to assign an objective digital documentation of the Bronze Age wooden chest. Firstly, we provide information about the planning and data acquisition at the site. Then we bring into focus the post-processing methodology, e.g. point cloud registration and segmentation, meshing, image orientation and object texturing. After the presentation of this workflow we will discuss the results.

Finally, we describe the short range laser scanning survey and the results of this thorough documentation. The patterns of the wooden boards' shaping are one focus of this paper. The analysis of these fine structures gives important information about the construction process of this unique wooden chest.

2. Description of the site

In the frame of the HiMAT-Special research program the Mitterberg Project Part (PP07) was able to continue its excavations in this industrial area alongside the famous main load mining area at Mitterberg. This mine can be considered as one of the largest Bronze Age mining districts in Europe. Aside the mining depressions an extensive area of ore-beneficiation is known (STÖLLNER 2008). The excavations uncovered in 2008 and 2009 an area of wet beneficiation and an ore-washery. In the centre of these installations we were able to discover a fully preserved wooden chest, in which ore was washed and perhaps heavier, fine grinded ore residua were concentrated. While the wooden chest is singular and outstandingly preserved a complete documenting using different scanning devices was desirable.

When the archaeologists found this wooden structure, the condition of the object was unrivaled. The geometry of the chest seamed undamaged, therefore it was possible to investigate the Bronze Age mounting techniques of the wooden boards. The three-dimensional documentation of this site was a top priority, because later investigation of these mounting methods will be impossible after the excavation of the find.

Next we present the significant information of this documentation as a case study.

3. Planning and data acquisition at the archaeological site

The terrestrial laser scanning (TLS) data acquisition at the site was accomplished with a Trimble GX 3D Scanner in October 2009. The earliest and the final stage of the archaeological site have been measured. The first documentation was managed, when the approximately 1.5 m × 1.5 m wide and 0.5 m high wooden structure was found. The second data acquisition was done before the beginning of the conservation process. The resolution of the two excavation layers was 2 mm but the surrounding was scanned with resolution of 20 mm. At an average scanner to object distance of 5 m, the accuracy was about 3 mm. These parameters qualified the three-dimensional documentation of the excavations with the Trimble GX 3D Scanner (MOSER *et al*., 2009). Each attitude of the instrument must be carefully planned to ensure complete coverage of the object. The two excavation situations were scanned during two days from a total of 14 different positions. The volume of the raw dataset was in the order of 14 million points.

The wooden chest was recorded also with a Nikon D200 calibrated digital camera accompanying the TLS surveys (Figure 1). The resolution of the eighty photos is 3872 × 2592 pixels, which provides accurate image data for texturing the object.

4. Methodology

The applied workflow can be summarized in four steps:

1. Point cloud processing
2. Meshing of the point clouds and editing of the models
3. Image orientation and correction
4. Model texture

Figure 1: *First data acquisition at the site.*

4.1. Point cloud processing

The raw data was captured from every scanning position in a local coordinate system during the TLS survey. Spherical targets were used to transform the different point clouds of various standpoints in a common master coordinate frame. These artificial targets were scanned from all positions outside the archaeological excavation. The centers of the spheres were used afterwards as reference points during the registration process. Finally the maximum residual between homologous reference points was less than 2 mm.

4.2. Meshing of the point clouds and editing of the models

This step includes data triangulation and the different processing techniques, e.g. filling small holes and model filtering.

The aim of the 3D digital documentation is the objective survey of the objects. That means the maximum efficiency of the well defined automatic methods during the model creation, and implies minimum manual work. We had to reduce the ponderousness of the editing with well selected parameters during the meshing process to reduce the number of resulting holes in the surface. This was the most difficult part of the workflow because the characteristics of the various point clouds, e.g. roughness and point density, differ throughout the excavation.

The point clouds of the wooden chest and its environment were triangulated and processed primarily with automatic methods (Figure 2). The final 3D models of the two excavation stages consisted of 5.5 million triangles. Finally, the number of triangles was reduced by ninety percent without significantly changing the geometry of the wooden boards. The creation of an optimal data volume for model texture was the reason of this step.

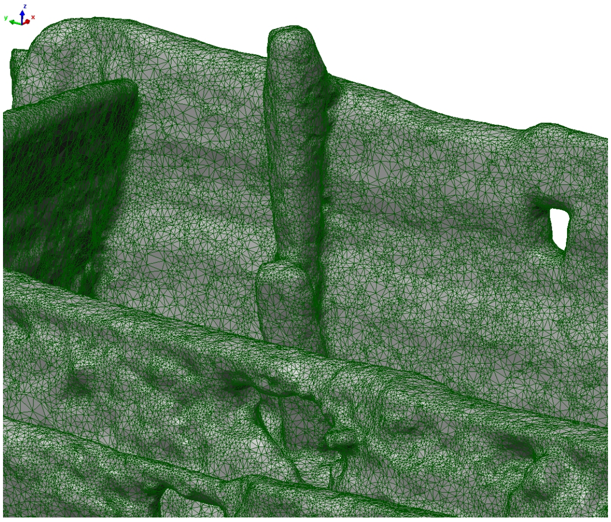

Figure 2: *Detail of perspective view of the wooden structure with wireframe overlay.*

4.3. Image orientation and correction

The interior orientation parameters were accurately known, because we worked with an in-house calibrated Nikon D200 DSLR camera. The relative orientation was determined using homologous points in all images.

The spherical targets were used to transform the two photogrammetric projects into the coordinate system of the 3D models from laser scanning (Figure 3). Another important step was the color correction of the images. The adjustment of brightness parameters was carried out manually. The result was a fine photorealistic texture.

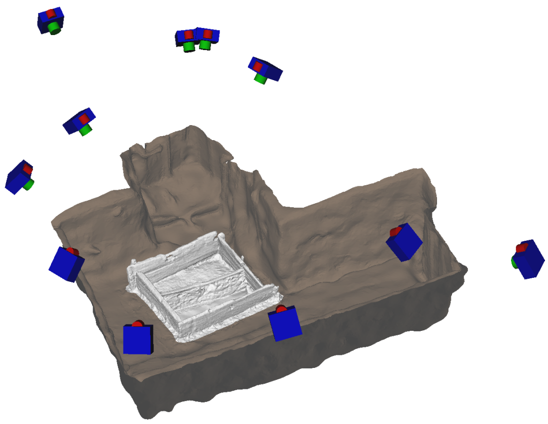

Figure 3: *The last stage of excavation, positions of the digital cameras after their relative and absolute orientation.*

4.4. Model texture

Because the relationship between the object space (model) and the image space (photos) was determined in the previous step, it was possible to do the texturing with a visibility analysis (DORFFNER *et al*., 1998).

The quality of the texture material depends mainly on the difference between surface normal and camera axis direction. The threshold of this angle tolerance is a fundamental parameter of the texture quality. If the surface does not face any picture within this angle tolerance, then the model texturing is unfeasible. If the surface of the model is multiple visible within this tolerance, then the photo textures have to be blended. This threshold was set to 80°. The modification of brightness parameters reduces the significance of the blending process. We accepted a medium blending factor, to get smooth transitions between the different photos.

The textured 3D models of the wooden chest were exported in OBJ file format with 5000 × 5000 pixels TIFF material file (Figure 4).

Figure 4: *The photo-realistic 3D model of the Bronze Age wooden chest.*

5. Documentation of the wooden boards with a short range laser scanner system

To obtain an overall high-resolution digital documentation of these excavated wooden boards, the Surveying and Geoinformation Unit organized a short range laser scanning survey with a FARO Laser Scanner mounted on a FARO ScanArm in March 2010. This seven-axis ScanArm also provides the exterior orientation of the measurement instrument. The aim of this assignment was an all-round data acquisition and digital model creation.

5.1. Technical preparation and data collection with the Faro ScanArm

The short range laser scanning survey was organized in a mine entrance area near Bischofshofen. The external conditions, such as temperature and air pressure, must stay constant during a high precision documentation, because the smallest deformation of the object surface or the measurement system will produce error sources. This was the main reason why we worked in the mine entrance area where the external conditions were absolutely constant during the data acquisition (Figure 5).

The seven wooden objects were scanned during three days and the amount of the raw dataset was in the order of 440 million points. The resolution of the 1.5 m long and 0.5 m wide wooden boards was selected at 0.25 mm.

In the following secction we describe the most significant information about the model creation from this data source.

Figure 5: *The close range laser scanning (left) and the archaeological drawing (right) of the wooden boards.*

5.2. Digital model creation from short range laser scanning dataset

The first step was once more the point cloud processing. However, the registration process was accomplished without artificial targets in this case. We used the "Best Fit Alignment" technique to adjust the different sides of the wooden objects in a common reference system. After the registration, the main distance between the overlapping areas was less than 1 mm.

The next step was the meshing and model editing. The point clouds of the wooden boards were triangulated and processed principally with automatic methods, whereas the filling of small holes was achieved manually. The number of holes was significantly higher at the micro wood cracks because the data collection was unfeasible at these complex areas.

As a result, we received the high-resolution 3D digital models of the wooden objects.

6. Development of an analysis method for the micro-relief investigation of surface morphology

Today several surveying techniques provide more information about surface morphology, e.g. micro-relief changes, than ten years ago. The investigation of the small-sized alterations offers new research opportunities in the field of archaeology, as well.

The condition of the more than 3000-year-old wooden chest was outstanding when the archeologist discovered the object. The signs of the wooden boards' shaping were clearly visible on the wooden chest, and these work traces preserved a Bronze Age construction method. In order to detect and study these manufacturing traces we completed the high-resolution short range laser scanning survey.

In the next chapter, we present the study of these fine structures with the help of the geographical information system (GIS). One of the main methods to store data in a GIS is the raster. This data type comprises columns and rows of cells, each cell storing a single value. The micro-relief changes can be analyzed on a large area with the comparison of the raster values.

7. Work traces investigation in GIS environment

The applied techniques were similar to the practices well known for digital terrain model surface analysis (e.g. calculating slope).

7.1. Importing the raw dataset

The coordinates of the point clouds come from the orientation of the short range laser scanner system. The XYZ axes of our model space were determined during the import process in the GIS environment, and the values of the raw datasets were ordered to this well-defined model space before the interpolation. Defining the horizontal axis and the vertical direction meant the most important preparation of the dataset.

7.2. Surface interpolation

The second part of the workflow was the surface interpolation. There are numerous studies about various techniques, which calculate unknown coordinates of interested points by referring to spatial information of neighboring points. In the following, we introduce one of the worthwhile processes that could aid to get an exact surface model.

The first step was the creation of a Triangulated Irregular Network (TIN) from the imported point cloud. The raw spatial coordinates were stored in this TIN model and the surface was represented by triangles between the imported mass points. The generation of an accurate digital model was unfeasible at the narrow wood cracks because the depths of these micro holes were unknown.

TIN, which is a vector based surface representation, has less analysis facilities than a raster data type, therefore the TIN model was converted to a raster format. The selected parameter of the cell size was 0.25 mm as the scanning resolution of the close range laser scanning survey was also 0.25 mm. The cell values of the raster were calculated by linear interpolation of the TIN triangles. Linear interpolation considers the triangles as planes and every interpolated cell is assigned to a height by finding which triangle falls in and calculating the location of the grid center comparative to the triangle plane.

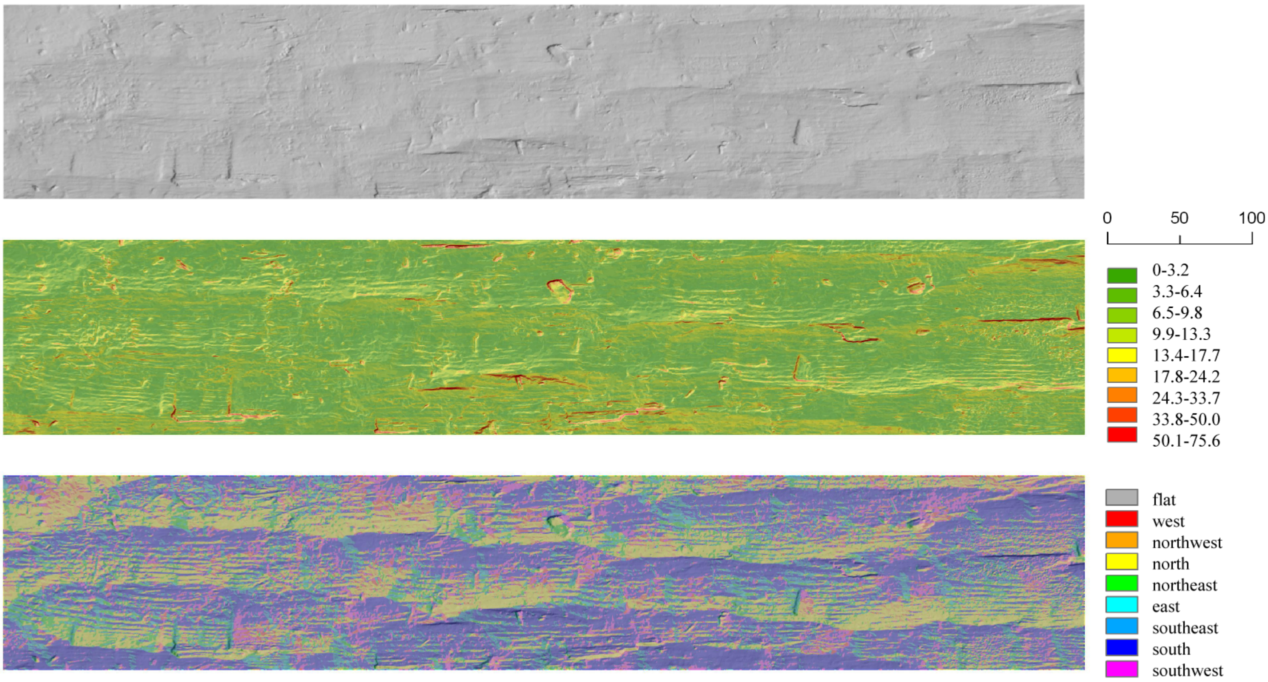

Figure 6: *Surface analysis of the wooden boards in mm (up: hillshade model, middle: slope analysis, down: aspect analysis).*

7.3. Surface analysis

After the conversation process, the third part of the methodology was the raster surface analysis. Three different techniques were utilized to investigate the work traces: hillshade tool, slope and aspect calculations (Figure 6).

Hillshade function means the illumination of the surface by defined illumination values for each raster cell. The azimuth and altitude parameters of the light source specify the shading effect. Two different light sources were defined in this study. The values were in the first case: azimuth 315 degrees and altitude 45 degrees. In the second case the parameters were: azimuth 45 degrees and altitude 45 degrees. Perpendicular azimuth directions were applied since the characteristic of the morphology could be visualized in more detail after the blending of these different hillshade images (KOVÁCS, 2009).

The second technique was the slope calculation, which determines the maximum change in Z-direction of each raster cell. The shape of the more than 3000-year-old working tool was recognizable on the surface model of the wooden boards. The slope analysis of the work traces helped understand the tool's movement forming the wooden boards. The direction and the length of the different manufacturing traces were visible in the GIS environment after the slope calculation.

The aspect values (the slope direction of the surface) were calculated in the third surface analysis method. The parameter of this raster presents the "compass direction" in degrees. The evaluation of the aspect showed to be the best tool to determine the patterns of the traces because the regularity of the shaping movement could be analyzed based on the direction and the depth of the micro-relief forms. The accurate separation of the wooden boards' forming movements from the rest of the micro-topography was feasible after this step.

Discussion

After the close range laser scanning documentation, it was possible to do a digital reconstruction of the wooden chest. The photorealistic model of the second terrestrial laser scan was the basis for the reconstruction process. Based on this framework, it is possible to include the new high resolution models into the different wooden structures (HANKE *et al.*, 2010).

The object surface morphology analysis proposes new research potentials in the field of archaeology, as well. After a high resolution survey, the fully preserved finds can be evaluated with digital methods.

The different digital analysis methods can be separated in two parts. The first is the computer aided design (CAD) environment, where the reverse engineering and modeling represent exact geometrical digital rebuilding and object comparison opportunities. The second part is the geoinformation system (GIS) environment, where the vector and raster utilizations provide a large scale of surface analysis tools.

It would be ideal though to have the advantages of these two analytical environments merged within one software package.

Conclusion

This case study demonstrates the combination of laser scanning and close range photogrammetry for archaeological documentation. The wooden chest from Mitterberg was accurately surveyed. The original position of all wooden boards was completely scanned in the first and the last stage of the excavation. Images were also taken during the TLS measurements with a calibrated DSLR camera. During the applied workflow, the different datasets were accurately merged together. As a result, we obtained a photo-realistic, three-dimensional digital model of the Bronze Age wooden chest.

Through the archaeological documentation, the Surveying and Geoinformation Unit ensures the future analysis of this important find in the HiMAT program.

The development of the analysis method was accomplished for micro-relief investigation of the wooden boards. The separation of the wooden boards' forming movements was feasible after the utilized methodology.

The geoinformation systems allowed the application of exceptional laser scanning dataset processing methods. The hereby utilized GIS analysis techniques showed significant research opportunities. Hillshade tool, slope and aspect calculations assisted the understanding of the Bronze Age wooden chest construction.

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