Quantity versus Quality in Cultural Heritage Documentation

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Abstract: In June 2010, the Dwelling Unit 7 of the Terrace House 2 in Ephesus, Turkey, was scanned from 172 scanning positions covering the object completely. Altogether, approximately 10 billion laser scanning points and a set of control points were acquired. In order to enable a global registration of the given datasets, we applied a robust 3D filtering method on the individual scans to reduce the amount data. After the registration, the points were merged to one point cloud by means of the same 3D filtering process. The main task of the project was the determination of 2D floor plans and sections and the generation of scaled projections of numerous walls for further archaeological interpretation. For this, we applied manual as well as automated methods. Within this contribution, we discuss the differences in quality and quantity of the two approaches. Special focus is drawn on the qualitative benefit of manual methods with respect to the quantitative benefit of the automated processing methods. While the manual analysis is based on commercial software tools, the automated processing is realized by innovative methods for data selection, projection and filtering in order to achieve the expected results. Additionally, hybrid approaches aiming at introducing as much automation as possible to support the manual work while ensuring high qualitative results are discussed. The conclusion of this contribution is that if large scale documentation of archaeological sites is to be performed, automated data processing is preferred over manual documentation for economic reasons, as long as certain restrictions on the achievable quality are acceptable. Automated processing serves as a reliable foundation for subsequent large scale interpretation of archaeological sites and higher repetition rates.

Keywords: Laser scanning, prospection, automation, mapping, 3D modeling.

Introduction

“To Reach and Unveil the Hidden Spirit of the Town” was the motto of the 16th Conference on Cultural Heritage and New Technologies in Vienna. Replacing “town” by “excavation site”, this motto represents the core idea behind any archaeological excavation aiming at finding new insights about the past based on previously invisible or hidden objects (e.g. DONEUS et al. 2008; CRUTCHLEY 2010). In order to preserve the findings which may become visible for a short period only – this fact is of crucial importance in the case of rescue excavations in urban areas – a proper documentation has highest priority for any archaeological scientist. Especially, as such a documentation represents the foundation for the subsequent interpretation and scientific work.

Manually generated line drawings produced by hand and photographs are the fundamental documentation methods in archaeology (KRINZINGER 2010). The major advantage of these technologies is the fact that
they are like to be carried out by the scientists themselves (easy to use) and they allow for in-field classification, generalization and interpretation – i.e. “From which viewing position should images be taken?”, “Which richness in detail should be achieved when producing a line drawing?”, and similar decisions are already drawn during the data acquisition. Additionally, everyone is familiar with these products. The application of 2D plans is part of our everyday life and photographs preserve the real appearance of objects as they are seen in nature. 

Within the past decade, laser scanning emerged as a new technology for the determination of the geometric surface structure of objects (e.g. BARTOS et al. 2011; STUDNICKA et al. 2011). By means of current Terrestrial Laser Scanner (TLS), up to one million points per second are determined in a dense pattern representing the object. Although established in many areas such as reverse engineering, industrial surveying, modeling for visualization purposes, and many more, laser scanning is still not entirely accepted for many archaeological applications. The reasons for that are manifold including additional costs, requirement for an experienced operator and the respective equipment, and, especially, a lack in automated data processing fulfilling the expectations of archaeologists.

Within this contribution, we present automated methods for processing TLS point cloud data in order to support the scientific analysis of archaeological sites. The basis for all documentation products is a robust thinning of the raw point cloud, in order to significantly reduce the amount of data while preserving richness in detail and high accuracy. Due to the high degree of achievable automation, it is possible to process huge datasets and thus to document large sites at comparatively low cost and in a short time. Results are presented, based on data of Dwelling Unit 7 of Terrace House 2 in Ephesus, Turkey. The achievable quality as well as quantitative aspects are discussed with respect to results generated interactively based on the same TLS data.

**Methodology and Related Work**

TLS instruments can be categorized according to the distance measurement principle used. Instruments based on the pulse roundtrip distance measurement emit a laser pulse and determine the distance based on the runtime of the pulse from the sender to the object and back to the detector. Such instruments typically have sampling rates of up to 150.000 points per second and they allow for measuring distances up to kilometers. For distances at the range of some 10 meters, the single point accuracy is smaller than 5 mm. TLS based on the phase-shift measurement principle allow for a slightly better accuracy (smaller than 2 mm), and for higher sampling rates (up to 1.000.000 points per second) but at smaller maximum distances (up to 100 m but achieving the highest quality up to 10 m only). The highest accuracy (smaller than 0.1 mm) may be achieved by close range scanners which in general project a light profile or a pattern on the object’s surface and determine the shape of the surface based on this pattern recorded by CCD-cameras and evaluated using the photogrammetric stereo-matching principle. Economically it is generally not feasible to use such scanners for huge objects due to their restricted field of view (typically up to 40 by 40°) and their restricted maximum measurement distance (some meters).

We propose the application of phase-shift TLS as they allow for high point densities due to their high sampling rates. This enables increasing the achievable accuracy by means of averaging neighboring points.
For this, we propose a highly robust method, called 3D filtering in the following, aiming at reducing the measurement noise significantly while preserving richness in detail. The method is based on the computation of local normal vectors for each point by using its neighboring points. Subsequently, the position of each point is shifted to the position which has the highest probability of being closest to the actual surface, i.e. the mode of the local point density (NOTHEGGER and DORNINGER 2009).

This filtering is applied to every scan. Afterwards, a global registration of the scans is applied. This approach is based on the Iterative Closest Point (ICP) algorithm (RUSINKIEWICZ and LEVOY 2001), minimizing the average distances of overlapping point clouds. Additionally, a network of control points may be considered within a conditioned adjustment calculation in order to assure a consistently high accuracy for the whole dataset. The application of such a network of known (i.e. by tachymetric measurement), possibly signalized control points is advantageous for two reasons: It ensures a global accuracy given by the accuracy served by the network itself, and those points are applicable to determine a good estimation of the global registration by means of manual or semi-automated processing of the data. I.e., knowing three points within each scan allows determining the parameters required for the transformation of local scans into a project coordinate system. Based on this preliminary result, the ICP based approach operates properly.

For the documentation of walls, typically orthogonal projections (i.e. rectified images or ortho images) of the current situation representing the surface structure are used. Such so-called wall views are traditionally generated from line drawings or from geometrically rectified photographs at a target scale (e.g. 1:20) and a target resolution for reproduction (i.e. printed publication). Figure 1 shows typical examples of such documentations as they are commonly used for further archaeological interpretation.

As a matter of fact, scanning data represents a surface based on individual points. The achievable resolution defining the maximum scale hence is dependent on the resolution of the given point cloud data and the footprint. Hence, reducing the resolution of the point cloud by means of filtering as proposed may reduce the achievable reproduction-resolution. To overcome this, we propose to assign the given (filtered) points to a grid and thus enabling a mapping of the given point cloud data to a full (i.e. without white pixels) raster representation.
Results and Discussion

We tested the applicability of the proposed methods on TLS data acquired at Dwelling Unit 7 of Terrace House 2 in Ephesos, Turkey. The building was excavated by the Austrian Archaeological Institute (ÖAI) from 1960 to 1985. The insula with 7 dwelling units situated on three terraces was built in the first century AD in the center of the city on the northern slope of the Bülbüldagh. After several reconstruction phases, it was abandoned after an earthquake in 263 AD. Today, it is the best maintained antique building in the eastern Mediterranean region. It gives an extraordinary insight to the way of living of the upper class people at Ephesus in the second and third century AD. To preserve this building complex, a modern roof construction was built to protect Terrace House 2. Figure 2 shows Terrace House 2 including the roof construction (left), a photograph of a typical room of the Terrace House (center) and the floor plan of the northern part of the Terrace House containing Dwelling Unit 7 (right, shown in purple).

The data acquisition took place in June 2010 using a Zoller&Fröhlich Imager 5006i phase-shift laser scanner. Altogether 172 scans with approximately 60 million points per scan were taken. This was done by one operator within a week. Additionally, a network of signalized control points was measured using a tachymeter. The complete point cloud consisted of approximately 10,000 million points covering the archaeological site and its roof construction. For further processing, it was necessary to eliminate the points representing the roof construction. This was done applying a height threshold and by eliminating the remaining points interactively. The left panel of Figure 3 shows a shading of the point cloud after the registration based on the control points has been applied.

In order to improve the quality of the registration locally, a conditioned adjustment using an ICP based approach for minimizing the discrepancies of overlapping scans locally while considering the control point network was applied. For this task, filtered point clouds have been used in order to reduce the computation time. For further processing, we finally generated two point clouds with different resolutions. For local investigations a high density point cloud with 500 million points was generated. For global investigations, i.e. if it was necessary to process all points at once, a point cloud with 100 million points was generated additionally. As described above, robust local normal vectors are a by-product of the 3D filtering process. Based on those normal vectors, points at vertical structures can be determined. The right panel of Figure 3 shows those points height coded.

Fig. 2 – Left: Terrace House 2 with modern roof construction; Center: Photograph of a typical room of Terrace House 2; Right: Floor plan of the northern part of the Terrace House containing Dwelling Unit 7 (shown in purple).
For numerous archaeological applications, floor plans are required. Typically such plans are derived from tachymetric measurements. For this, a horizontal profile at a defined height-level is measured in-field. However, several problems may occur: The definition of relevant structures being represented by the plan is done in-field (i.e. generalization) and there is no possibility for validating the correctness during post-processing or to modify the plan later on. The example shown in Figure 4 is representative for those shortcomings. On the one hand, the outline of the biggest room in this scene cannot be determined at one distinct level. The northwestern wall is only visible at 16.20 m (left panel) while the southern structures become visible at higher levels (right panel at 16.60 m). Further on, a discrepancy between the floor plan (violet polygon) and the point cloud (color coded raster profile) occurs in the upper left region of the shown figures. While the rest of the polylines shown have been digitized based on the point cloud, this polyline is part of a previous, tachymetric measurement. Obviously, there was a lateral shift, but at the current situation it is impossible to fix this problem based on the tachymeter measurements alone.
Fig. 5 – Wall views automatically determined from filtered point clouds. Top: Intensity image. Middle: Shaded relief. Bottom: Distances to a best fit plane.
Additionally to the geometric shape of the object, for each point a respective reflectivity measure, often referred to as intensity value, is determined by TLS. The top panel of Figure 5 shows a wall view of
reflectivity values derived from the filtered point cloud. Compared to the original points, the resolution of the filtered point cloud is reduced and hence may not serve the requirements to generate a continuous image (i.e. without “white” areas) at the dedicated output scale. Anyhow, by defining a respective grid size and by mapping the given points to the grid pixels enables generating continuous representations of the thinned points as well. A shaded relief and a distance map representing the distance of the points to a best fit plane are shown in Figure 5 middle and bottom. To increase the expressiveness of the automatically generated wall views, we calculated combinations of these three layers. The results are shown in Figure 6 (middle: Intensity & shaded relief; bottom: Intensity & shaded relief & distance). A manually generated wall view, based on the original, high density point cloud is shown in Figure 6, top. For this result, all points of the respective scans were selected manually, and a combination of intensity values and shaded relief was computed. In this case, the points were not assigned to a grid representation. This, on the one hand, allowed for a more detailed representation in some local areas where an extremely high point density was available. Anyhow, a more homogenous impression is achievable by means of the automatically, raster based generated wall views.

Despite the qualitative differences between results generated interactively and automatically, we compared the achievable quantity by analyzing the amount of data that can be processed in a given time budget. Table 1 gives an overview on the time required to generate results such as the presented (i.e. floor plans and wall views) interactively and automatically for the whole scene acquired of Dwelling Unit 7. For the floor plans, the difference is not significant. But, the TLS based processing has the major advantage that it enables a verification of the results at any time. For the generation of the wall views, the effort may be significantly reduced by means of automated processing (i.e. from 40 hours to some minutes for the whole scene). It has to be mentioned that in some cases, the automatically generated wall views lack in quality, as disturbing artifacts caused by objects not related to the excavation site (e.g. cables, people passing by, etc.) may not be eliminated properly. This has to be considered either during data acquisition (i.e. during the scanning process) or an interactive “cleaning” of the data has to be performed prior to the automated processing.

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<tr>
<th>Horizontal Profiles (Floor Plans)</th>
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<tr>
<td><strong>Interactive Processing</strong></td>
<td>Automated Processing</td>
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<tr>
<td>24 hours Field work (tachymeter)</td>
<td>8 hours Digitizing first version</td>
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<tr>
<td>8 hours Post processing</td>
<td>8 hours Archaeological adaptations</td>
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<tr>
<td><strong>Result</strong> 1 profile; not verifiable</td>
<td><strong>Result</strong> Multiple profiles at different heights; verified by point cloud</td>
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<th>Wall Views</th>
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<tr>
<td><strong>Interactive Processing</strong></td>
<td>Automated Processing</td>
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<tr>
<td>40 hours 20 rooms with 4 walls each</td>
<td>0.2 hours Digitize start- and end-point</td>
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<tr>
<td>selection of points from individual scans and map projection</td>
<td>Automated processing to generate results</td>
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<td><strong>Result</strong> 80 wall views</td>
<td><strong>Result</strong> 80 wall views</td>
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Tab. 1 – Quantitative comparison of interactive and automated data processing.
Conclusions and Outlook
We demonstrated a set of highly automated methods for processing TLS point clouds for further archaeological interpretation. Based on a processing chain enabling registration and robust filtering of the original scans, the discussed methods are applicable at pre-processed point cloud data, hence making the generation of a surface model (e.g. a triangulation) unnecessary. We compared the automatically generated results with interactively generated ones and showed that there is a very high potential to increase the quantitative output using appropriate data processing methods.
Nevertheless, the local quality of individual products such as wall views may be slightly better if the data is interactively prepared. For example, full automation does not allow for the elimination of locally disturbing objects such as cables or visitors passing by during the data acquisition and therefore, some artifacts may remain within the scene hence impeding the subsequent interpretation. Additionally, it turned out that the interactively generated products match the traditional documentation products like photographs more closely, as the operator may optimize the respective parameters (lightning, color coding, etc.) in order to achieve more pleasant looking results compared to the automated process. Hence the acceptance of interactively generated results is most likely better.
However, the proposed methods have major advantages. As demonstrated by the floor plan example, the proposed, TLS-based approach enables a more selective determination of plans (e.g. using different height levels) and it allows for further interpretation based on the point cloud while direct in-site measurements using a tachymeter do not allow for later on quality validation. Therefore, methods such as the presented ones should be investigated in order to generate new or at least adapted products instead of aiming at the regeneration of traditional ones. Furthermore, the results are more objective as the methodologies and parameters applied are similar for the whole site compared to subjective generalization and selection applied by an operator during interactive data processing.
Summarizing it can be stated that for huge excavation sites such as Ephesus, methods like the proposed ones allow for a significant increase in quantity (i.e. mass production) of documentation, albeit at a slightly decreased quality compared to interactive data processing. Hence, they are well suited for an overall documentation of huge areas while selected regions of special interest should be investigated based on interactively prepared data, at least partially. For urban archaeology, this increased quantity (i.e. fast availability of products) and especially the objectivity with respect to the application of the methods at various sites and carried out by various operators are favorable.

Acknowledgements
This work is funded by the Österreichische Forschungsförderungsgesellschaft FFG under the project number 2127585 (project leader: P. Dorninger) and by the Austrian Science Fund FWF under the project number 22102-G19 (project leader: E. Rathmayr).
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