As-built Documentation and Reverse Engineering Derived from Laser Scanning

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SUMMARY

In the paper new ways of merging laser scanning data from different measurement sessions, and of recognition and extraction of objects will be derived.

The merging of different sessions is based on identical natural features. The strategy of efficient multi-level object extraction will be described. Another valuable tool which has been developed is the export of the derived surfaces to CAD systems.

ZUSAMMENFASSUNG

Der vorliegenden Beitrag beschreibt neue Wege der Orientierung und Zusammenführung mehrerer Scanner- Standpunkte sowie Möglichkeiten der Objekterkennung und Extrahierung.

Die Zusammenführung der Standpunkte basiert auf natürliche Erkennungsmerkmale Bestandteile der Objekterfassung. Beschrieben wird die Strategie der mehrstufigen Objektbildung. Ein weiterer Schwerpunkt ist der Export der erkannten Flächen in CAD Systeme.

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1. INTRODUCTION

Terrestrial laser scanners are very powerful measuring instruments. They may serve as a basis of the next revolution in surveying the data acquisition for architectural, industrial, transportation etc. purposes. But like a lot of other modern technologies, they are black-boxes, in as much as all their important functions are inaccessible to the user.

Black-boxes are dangerous for two reasons: on the one hand, they are easy to use, and on the other hand, because of their complexity, it is difficult for users to estimate the accuracy of the resulting measurements.

Laser scanners contain in principle more components which are subject to error than most conventional surveying equipment, and therefore will require extensive calibration and testing (Rietdorf 2004).

The scan session is typically followed by computer processing. This provides suitable results and output from the downloaded measurements. Thus scanners can provide all the essential data to describe an object as seen from one point. It is easy to come to the conclusion that the laser scanner provides almost the complete information the surveyor needs when measuring certain object types. It is, however, necesary also to estimate the precision and reliability of the derived results wich are not equivalent with the point cloud.

Another objectives of the present contribution are the preprocessing strategy of the extremely huge amount of raw data (high data density measuring method) and the extraction of object parameters and constructive values for third engineering parties. The visualization is definitely not the main propose of using such expensive equipment.

2. OBJECT OF MEASUREMENT – THE NEW PALAIS SANSSOUCI

For rehabilitation proposes of the Big Colonnade – New Palais in the Park Sanssouci (city of Potsdam) test measurements had to be done which were performed by the IVD engineering company based in Schwerin and the Technet GmbH - engineering, programming and consultancy company based in Berlin with the support of the RIEGL LMS Company Horn - one of the leaders in innovative laser scanner manufacturing. The north Pavillon (Fig. 1) has ben captured. Damages during the second world war, poor maintenance in the least 50 years and partial restoration attempts in the GDR time are responsible for the bad condition of this heritage building. For the upcoming restructuring and restoration process a complete structure documentation for static computations, reverse engineering of building parts, and orthophotos for preservation of monuments and historic buildings specialists had to be prepared. A feasibility study in the preliminary stages of the rehabilitation was performed for the record. A RIEGL LMS Z340i environment scanner was used for the measurements.

Figure 1: North Pavilion of the big Colonnades

3. DATA PROCESSING

The laser scanner ensures normally homogeneous and constant adjacency precision provided the reflecting properties of the object do not change abruptly. Typical problems are associated with the reflector lens when measuring in rooms and corners. The main problems are still the hidden parts and the limited measuring range with respect to the object for which reason multi-station measurements are used in surveying. This provides also redundancy in the data sets and has to be managed in the right way. The transformation to a common reference frame is based on identical marks - reference point on the object or in the nearest environment measured in a classical way prior to the scan.
This solves the problem with the transformation into a unified frame but does not take into account the adjacency rule. The regular distribution of identical points smooth this problem but increases the time and costs. The processing software can take this also into account.

3.1 Scanner Position Linkage by Using Corresponding Surfaces

The station linkage using added (additional) nonnatural control point objects like cylindric and spherical bodies can be optimized by using primitive geometrical parts of the objects. They must be recognizable at least in two scans. If the same object regions are partially or completely measured, they can be used to connect the scans (Fig. 2). The advantage of comparing object references and fitting target bodies is in saving time in field. For the automated extraction of object references the same reliability as when using the fitting spheres cannot be easily achieved. The normalized repetition factor is lost. In this case the usable regions are defined manually. (Fig. 2).
The corresponding fitting planes can be manually connected through the definition order in the two scans or automatically after the definition in the first scan. The automated sequential plane adjustment follows.
The residual equations for the adjusted plane with the normal vector n and reduced coordinates are:

$$\upsilon_i = \hat{n}_x(w)x_i(w) + \hat{n}_y(w)y_i(w) + \hat{n}_z(w)z_i(w) - 1 \qquad (2.1.1)$$

where i in 2.1.1 means the number of points that are adjusted. A „data snooping" algorithm eliminates automatically the outliers. The Gauss-Helmert model with additional conditions between the unknowns is used for the adjustment. Condition equations are derived from the plane equations with point coordinates $\mathbf{x}_g$ and plane parameters $\mathbf{x}_E$ as arguments (Rietdorf 2004).

$$\begin{aligned} n_g \cdot x_g - d = 0 \\ f(x_g, x_E) \end{aligned} \qquad (2.1.2)$$

3.2 Object References and ICP Algorithm

Methods using reflecting targets are very common. This principle is based on the signal intensity of the reflected laser. A fine scan can be used for better detection of the target center but this is not necessary if reference objects like spheres, in the right size, are used. Artificial objects have in most cases a regular geometry or are typical geometrical parts. Thus the reference object properties can be used to compute the orientation parameters between the point clouds (Kern 2003).
For identical object parts a proportional extension in all main directions of the measured object, as given by the ICP-Algorithm (Iterative-Closest-Point-Processing) for the so called „Registration" (Besl, Mckay 1992), can be successfully used. The good approximate orientation of the point clouds is a precondition. To generate these approximate values, at least three identical points in both scans should be used. A definitely better and mathematically stable way for this computation is the method described in section 3.1 .

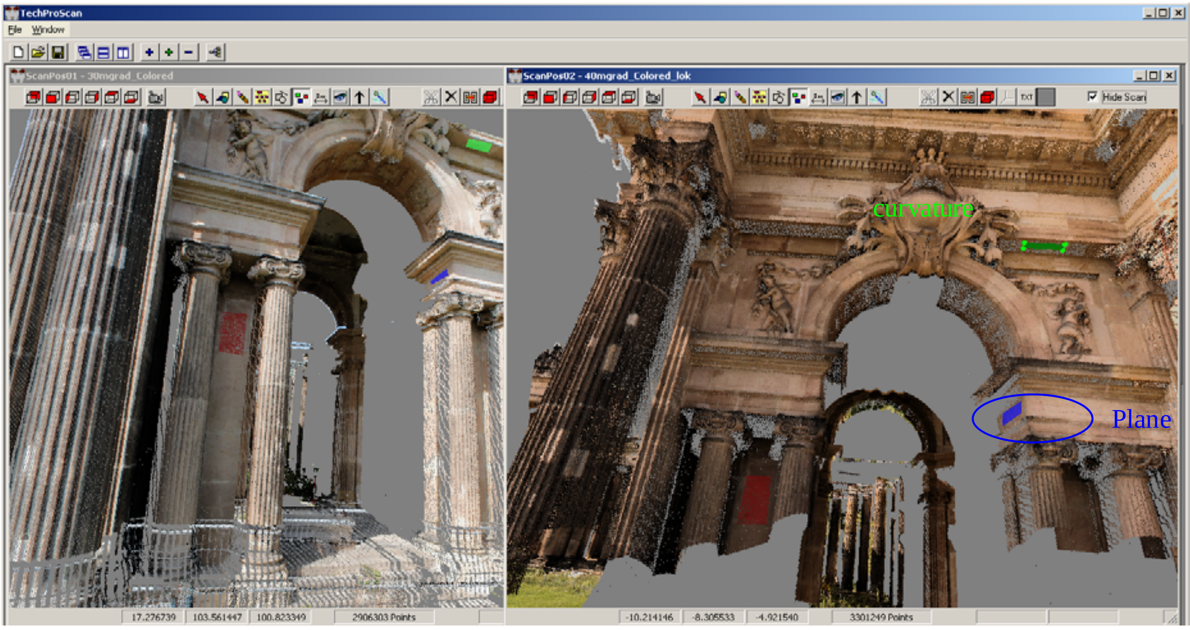

Figure 2: Selection of linkage surfaces

4. REGULAR AND FREE-FORM SURFACE PARAMETRIZATION

While testing of some photogrammetric systems can sometimes be carried out using objects of regular shape, the problem with laser scanners is that they are suited for measuring very large objects, and it is rather seldom for such objects that they are built precisely to standard geometric shapes.
The real data processing follows after the unified orientation of the single point clouds. There are several ways to realize this. Two of them are presented below.
The export of the point clouds in the common CAD environments allows the generation of profiles, area calculations, and mass calculations for mining purposes. This 2D concept for data processing has a lot of restrictions and leads to permanent switches between the 2D process layer and the 3D view layer. This working flow is used when planning and surveying companies. In this case, having in mind the scanner measuring speed, alternative low cost methods can be applied. (Scherer 2004).
The use of strictly 3D data processing leads to a sequential parameric description and smoothing of the object surface. Systems for the generation of „as built“ documentation in industrial and plant acquisition are based on this principle.
In most cases the fitting tools are solve the subjects in order:

- fitting of primitive geometrical shapes like line, circle, ellipse, plane, sphere, cylinder
- incomplete point clouds fitting of arcs, spherical segments, part of cylinders, cone obtuse
- fitting of cover elements for circle, sphere and parallelepiped
- fitting of weighted smooth free-form functions (NURBS)
- comparison between the point cloud and fitting element with deflections measuring against CAD

4.1 Non-Uniform Rational B-Spline (NURBS)

Non-Uniform Rational B-Splines, are mathematical representations of 3-D geometry that can accurately describe any shape from a simple 2-D line, circle, arc, or curve to the most complex 3-D organic free-form surface or solid. Because of their flexibility and accuracy, NURBS models can be used in any process from illustration and animation to manufacturing
A **NURBS** curve is defined by a set of weighted control points, the curve order and a knot vector. NURBS are generalizations of both B-splines and Bézier curves, with the primary difference being the weighting of the control points which makes them *rational* (non-rational B-splines are a special case of rational B-splines, in practice most NURBS curves are non-rational).

The NURBS geometry possesses a number of important advantages:

- There are several industry standard ways to exchange NURBS geometry. This means that customers can and should expect to be able to move their valuable geometric models between various modeling, rendering, animation, and engineering analysis programs. They are excellent for storing geometric information. Years later additional information can be extracted on the basis of these models (Schmälzle 2001).

- NURBS have a precise and well-known definition.

- NURBS can accurately represent both standard geometric objects like lines, circles, ellipses, spheres, and tori, and free-form geometric objects like car bodies and human bodies.

- They are invariant under affine as well as perspective transformations;

- The amount of information required for a NURBS representation of a piece of geometry is much smaller than the amount of information required by common faceted approximations.

- The NURBS evaluation rule, discussed below, can be implemented on a computer in a way that is both efficient and accurate.

To date, a 3D CAD model is usually derived from an existing physical part firstly by canning the physical part with a 3D scanner, e.g. laser triangulation scanner, a coordinate measuring machine (CMM), or strip light projectors and then measuring and analyzing the dense discrete point data in order to obtain the 3D CAD model. In the case of laser scanners with varying density, e.g., the measured data is typically in the form of large point clouds made up of millions of points. One class of reverse engineering methods is based on the segmentation of point clouds into polygonal regions to fit an individual surface to each region (Fig. 3). To avoid undesired smooth surfaces in regions with sharp edges, the boundaries of each polygonal region should be formed by the sharp edges of the scanned part (together with

additional boundaries). NURBS curves are easily generalized into NURBS patches.
As this segmentation must be carried out manually in current CAD systems, the advantage is that one deals mainly with methods for extracting feature lines from scanned point clouds automatically. In order to be irrespective of special 3D scanners, no point cloud order information will be taken into consideration – the point cloud will be regarded as totally unsorted scattered data. Data structures will be presented capable of handling even huge point clouds efficiently.

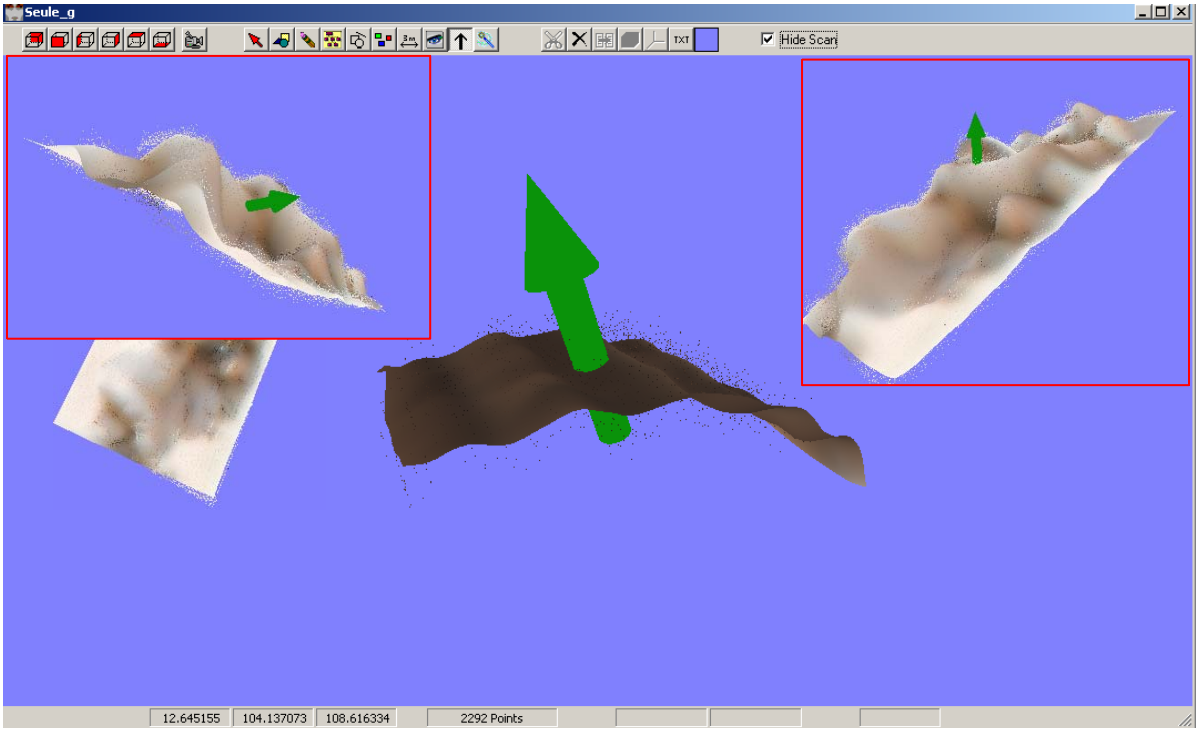

Figure 3: Free-form surface patches based on a scanned pylon and

The algorithms for automated feature-line extraction attempt to find locations where surface normal vectors suddenly change their direction (Fig. 4). This seems to be a contradiction as normal vectors cannot be determined until the surface has been computed, but normal vectors are required so that the boundaries of the surface may be calculated first. However, algorithms for the robust approximation of normal vectors have been developed and will not be described in this paper. As the direction change of normal vectors represents the curvature of the partial surface, the feature line extraction will therefore be based on these point curvature values(Wani 1994).

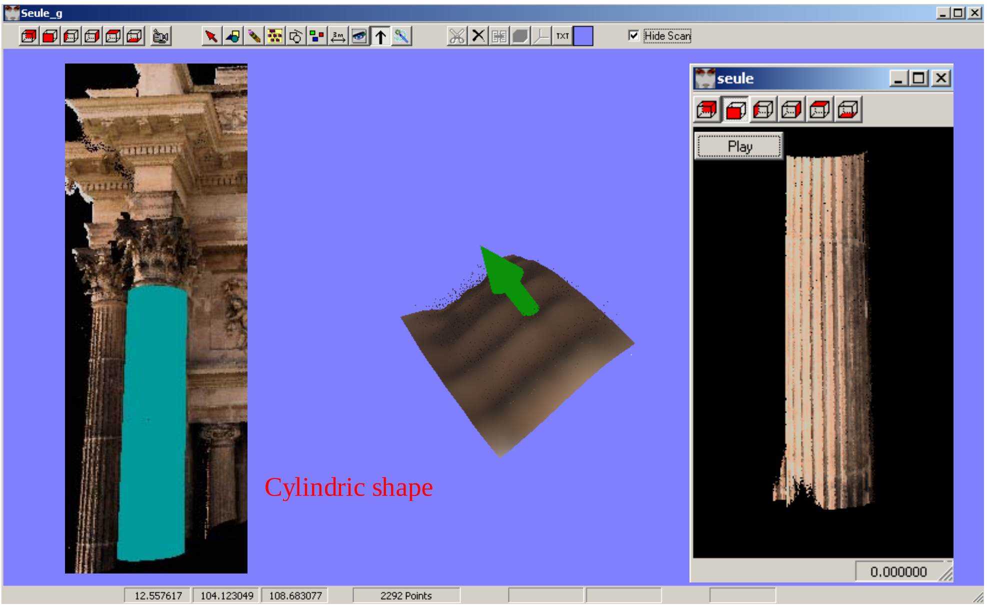

Figure 4: Approximation of free-form surfaces via NURBS

3 CONCLUSIONS

For processing 3D laser scan data it is important to establish tools capable of solving the following objectives:

- Data reduction and filtering
- Automated calculation of plan views, cuts and profiles
- Transformation of point clouds into an unitary object frame under preservation of the adjacency rules
- Producing panoramas and orthophotos
- Description of regular and free-form surfaces.

These steps allow creating a unique model for reverse engineering purposes. The combination of standard geodetic adjustment algorithms with the advantages of processing CAD-CAM systems provides a new generation software tools based on dense discrete point measurement of physical objects for automated generation of 3D digital models. This approach proves to be powerful and reliable, and even complex reverse engineering problems involving laser scan techniques can be solved today by using modern reverse engineering software tools.

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