Geometrical Approximation and Segmentation of Laser Scanning Point Clouds

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SUMMARY

Feature lines are substantial means for the segmentation of measured point clouds, especially if a surface model has to be generated from the data. In this presentation, methods for the automated extraction of feature lines from measured or scanned point clouds will be described. It allows a complete scanning also of the inner geometry of a complex geometrical structures. A geodetic computation of point curvature values is used.

These methods can be applied to points from Laser Scanning since they do not require sorted or edited data sets. The mathematical basis for the feature line extraction, experimental results and the limits of the methods will be presented based on the track geometry computation.

ZUSAMMENFASSUNG

Die Erkennung der Konturen ist von großer Bedeutung bei der Segmentierung von gemessenen Punktwolken, insbesondere wenn Oberflächenmodelle aus den Daten generiert werden sollen. Der vorliegenden Beitrag beschreibt Wege zur automatischen Extrahierung von Konturen aus gemessenen Scanpunktwolken. Somit erhalten wir eine Vorstellung zu der inneren Geometrie komplexer geometrischer Körper. Geodätische Methoden zur berechnung der Krümmung werden angewandt.

Wichtig ist das diese Methoden an Laserscandaten anwendet werden können ohne das ein editieren und sortieren der Daten notwendig ist. Der Mathematische Hintergrund
Ein Beispiel zur Schienenoberkannten-Eerkennung wird presentiert.

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1. INTRODUCTION

For the most engineering problems using the laser scan method for the data acquisition the main objective is then measuring and analyzing the dense discrete point data to derive the 3D models. Typically the measured data are large point clouds up to millions of points in the case of laser scanners with varying densities.

One class of reverse engineering methods is based on the segmentation of the point cloud intopolygonal regions to fit an individual surface to each region. To avoid undesired smooth surfaces in regions with edges, edges of the scanned part (together with additional boundaries) should form the boundaries of each polygonal region.

Since in current program systems this segmentation has to be done manually, the subject of the paper are methods for the automated extraction of feature lines - strips end lines, real and theoretical edges. To be independent from special 3D scanners, no order information of the point cloud will be considered - the point cloud will be regarded as totally unsorted scattered data.

2. CLASSIFICATION OF FEATURE LINES

The different types of feature lines for engineering applications are:

- Step Edges: They appear due to scanner insufficiencies. Optical scanners only can measure, what can be seen from outside the part. In the case of holes and channels, normally only a few points at the beginning of these geometrical features can be recorded and step edges appear.
- Fold Edges: They are characterized by discontinuities in the first derivative across the edge and will be generated with separate surface patches in CAD modeling.
- Smooth Edges: By modeling of parts fold edges do not appear as often as commonly expected. Especially in the case of design surfaces, edges will be often modeled as smooth edges and the surface and edge modeling will be done with strip surfaces with a small radius of each strip. The smooth edge itself will be represented by four entities then: Two strips end lines, the edge line on the part and additionally a theoretical edge line "above" the part

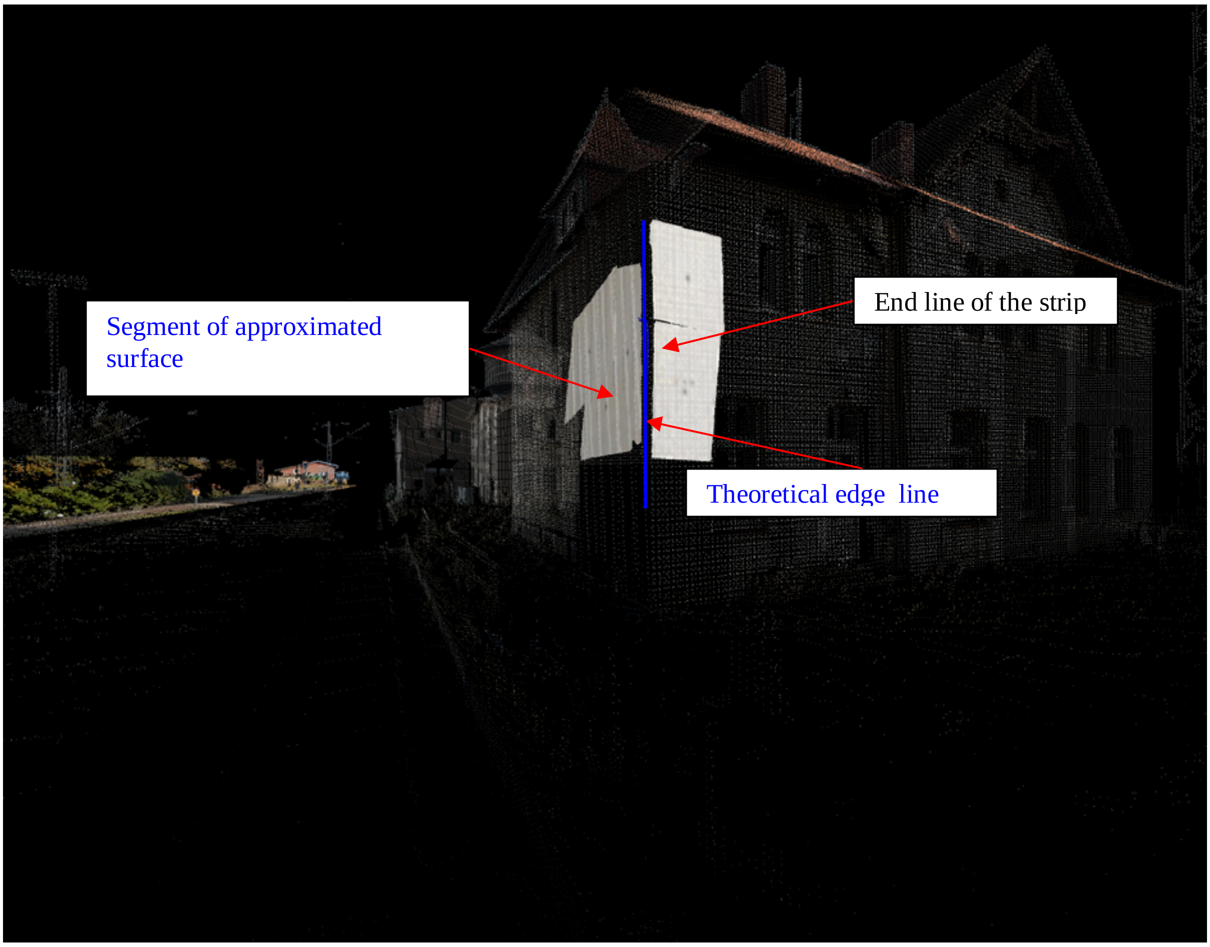

Figure 1: Feature lines for adjacent approximated surfaces

3. DATA PROCESSING

Two methods for the feature lines extraction:

- Automatic extraction of sharp edges based on robust curvature analysis of the whole point cloud. This is the high end solution and needs very powerful hardware.
- Interactive extraction of sharp edges and/or smooth edges (semi-automatic method).

In the latter case strip end lines, the edge on the part and the theoretical edge line can be computed (see figure 1). The user will be requested to mark a region on the point cloud, where the algorithm will extract the feature lines. Here, the benefit of user interactions will be, that with a pre-segmentation of the point cloud the feature extraction can be done in real-time. Besides, the raw location of feature lines can mostly be seen by the user in the visualization of the point cloud. Optimized user interactions through rough marking of the edge to be detected, allow accurate detection of the strip end lines, the edge on the part and the theoretical edge, even if the accuracy of the cloud would be rather poor (noisy clouds).

Figure 2: Semiautomatic selection of feature lines

3.1 Computation of Point Curvature Values

Once the neighbors of each point *pi* of the point cloud within the search radius *R* have been determined, best fit planes *Ei* in each point depending only on the neighbors of *pi* can be computed.

With Taylor's theorem, the best fit plane *Ei* can be interpreted as being a local approximation of the surface near the point *pi*. The normal vector of the plane *Ei* can then be interpreted as an approximation of the normal surface vector of the measured part. Fitting planes to point data is a well-known problem and is normally solved using least-squares methods (Rietdorf 2004). These methods are used here but are not explained in any detail. Once the normal vectors *nj* for the relevant points within the search radius *R* have been computed, point curvature values will be determined by applying a formula which gives an approximation of the average curvature of the surface of the part (Fig. 3). To apply this strategy, the orientation of the normal vectors of the neighbored points must be homogenous. This must be ascertained first, because the calculation of point normal vectors with the best fit planes *Ei* does not automatically result in a homogenous orientation of the normal vectors.

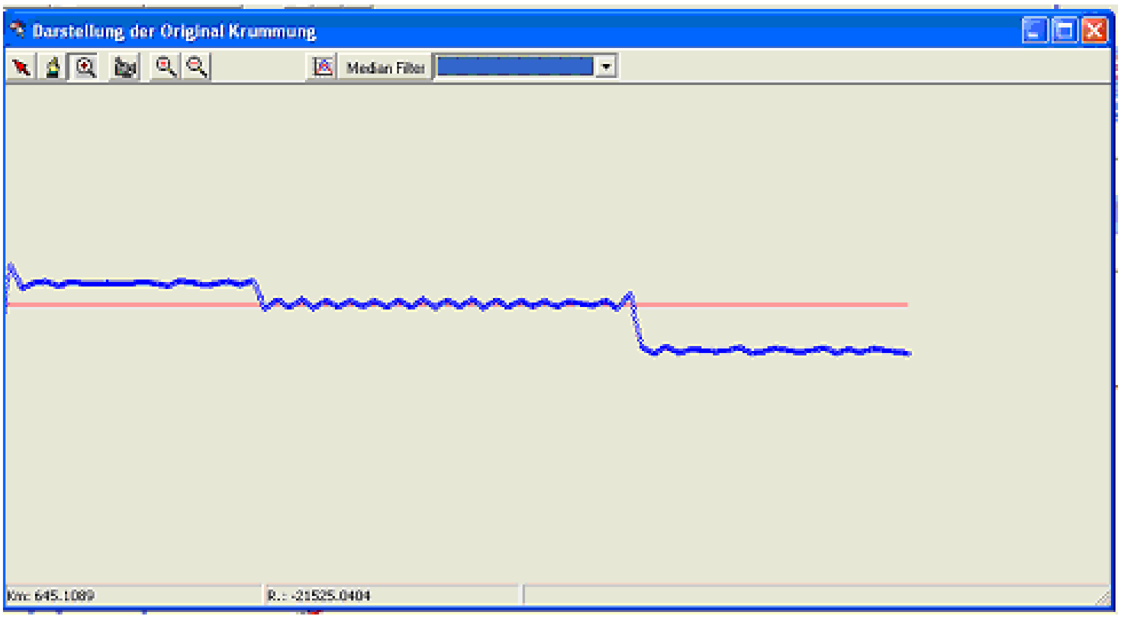

Figure 3: Curvature values to obtain the criterion for the location of strip end points

3.2 Construction of Strip Surfaces Based on Feature Lines

Regarding the presented conventional workflow, the need for an automation of the described steps is evident. The method described below is intended to be as automated as possible with special attention for producing results of high quality in means of accuracy to the measured point cloud and smoothness of the resulting feature lines.

The method computes the following vector elements:

- Two strip end lines in NURBS representation for each region, where a strip should be recomputed(Milev 2004).
- A theoretical edge line (NURBS representation), which specifies the position of the intersection curve of the extended surfaces, adjacent to the strip to construct. Of course the input for the method consists of the measured point cloud only; the adjacent surfaces to the strip need not to be generated before.
- An edge line on the part (NURBS representation). This line normally would not be needed for the construction of the strips. The edge line on the part can be used, if not a strip, but a sharp edge should be modeled, especially in the case of strip with very small radii.

Figure 4 shows each of the feature lines to be extracted.

After the strip end lines and the theoretical edge line were computed, two or more adjacent surfaces can be constructed using the theoretical edge line as a common boundary. Analogously the computation of the segment strips can be done using the two strip end lines as boundaries with existing strip generation and calculation tool. It's also possible, to use existing functions to compute normal blending surfaces instead of a special strip generator then, since the boundaries of the blending surfaces are determined by the strip end lines. Another possibility will be to use constrained surface fitting algorithms; then the segmented points will be fitted and the strip end lines can be considered as the constraints.

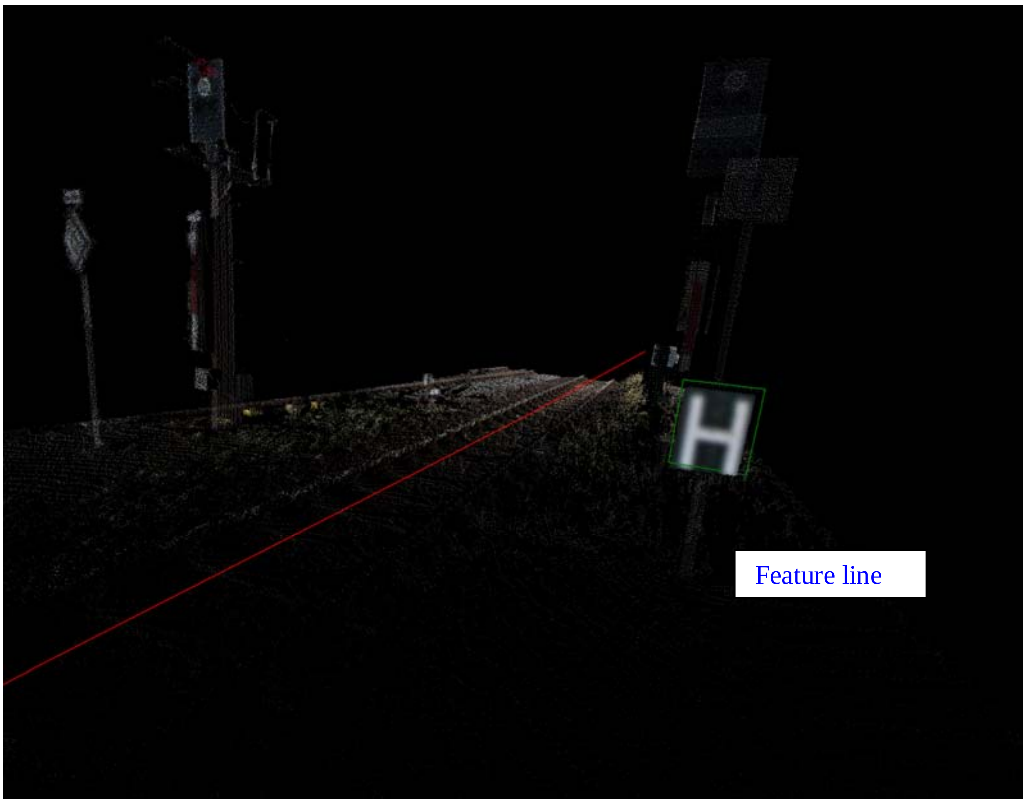

Figure 4: Semi automated extracted feature line on the surface

4. SURFACE PARAMETRIZATION

Interpolation of data, which might have been gathered by measurements of a physical quantity, or by sampling a function at scattered or periodic points of several variables, is a problem that occurs in many areas of science and engineering. Laser scanner, for example, measure the surface of a engineering object and these data are then used to construct a contour map of a region on this object with the same curvature. Especially in cases where the data are sampled by measurements, they are scattered, which means that the positions of the data points do not obey any regular pattern. Generally, a discrete set $X = \{X_1......X_n\}$ of points in d-dimensional space $\Re^d$ and real valued data f_i, i = 1,… n, are given, and the task is to construct a continuous or sufficiently differentiable function s* : $\Re^d \to \Re$ that satisfies the interpolation equations:

$s^*(x_i) = f_i$;   i = 1….. n

4.1 Automateof Multiple Spline Fitting for Curvature Analysis of Cross Section Points

Especially for automated multiple spline fitting, a well-known problem arises: On the one hand, the resulting spline curve should be accurate respectively to the cross section points, means the distances of the points to the fit curve need to be checked and should be rather small. On the other hand, if the resulting spline curve would follow the cross section points too closely, oscillations appear in the spline curve, if the scan data would be noisy (and it always is). The amount of oscillations of the spline curve normally will increase(fig. 6), if the distance to the points should decrease, but oscillating spline curves can be used for curvature analysis only with great difficulties. There is no real solution out of this classical reverse engineering paradox, but it can be (approximately) solved as good as possible.

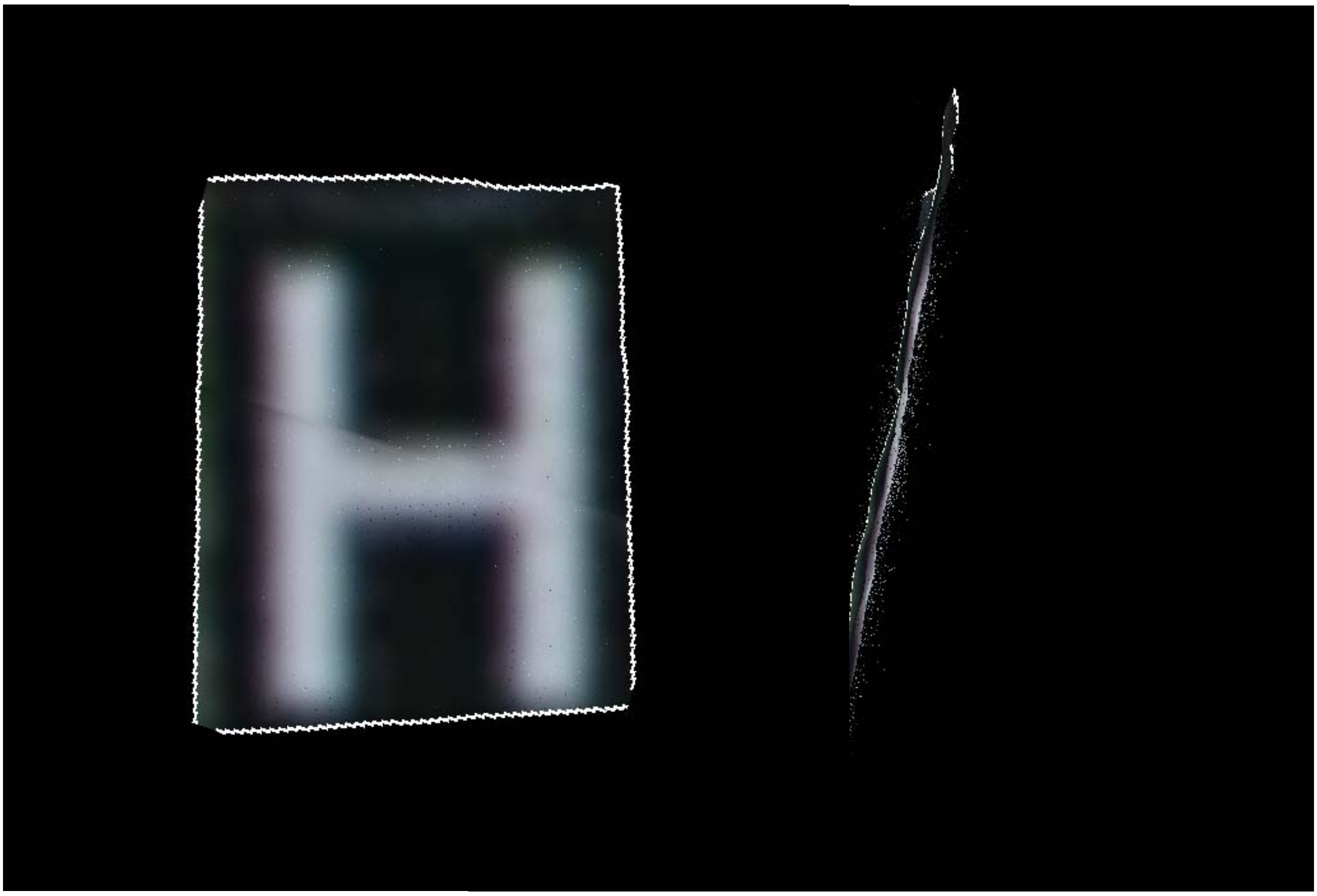

Figure 6 : Approximation of free-form surfaces via NURBS

5. CONCLUSIONS

Automatic feature line detection is an important tool for engineering applications. With the described algorithms the workflow for computing of strip surfaces in 3D scanner data will be automated. The method can handle even dense huge point clouds in real time. It can be expected to halve the operating time for engineering jobs in the case of multiple strips to be constructed.

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BIOGRAPHICAL NOTES

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