TOWARDS AUTOMATIC FEATURE LINE MODELLING FROM TERRESTRIAL LASER SCANNER DATA

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ABSTRACT:

For the representation of objects or scenes different representation forms are utilised. While for some tasks a point cloud representation or a triangulation of the point cloud is sufficient, a boundary representation or a wireframe model is necessary for other applications. For these the determination of feature lines is essential. In the past the generation of feature lines was a manual task. Nowadays, many research activities for the automated extraction of feature lines from digital images (e.g. roads and other infrastructure networks) can be found. In contrast to these activities, the extraction of feature lines based on terrestrial laser scanner data is rather at the beginning. This paper presents, after a short summary of the status of research, an approach for the automated feature line modelling. This approach consists of two main steps. In the first step feature line segments are automatically detected, whereas in the second step the modelling of the whole feature lines is performed. Within this approach also, the determination of quality parameters for the extracted feature lines is possible. Practical results of the presented methods are presented. They demonstrate the feasibility of the automatic determination of feature lines from TLS data and provide insight into shortcomings of the presented method.

1. INTRODUCTION

For the 3D representation of objects or scenes different representation forms (e.g. point cloud, wire frame model, surface model, volumetric model, etc.) are available. While for some representation forms and applications feature line information is dispensable (e.g. for visualisation tasks), for others, like the wire frame model, feature lines are one of the main basic geometric entities.

Lines can be directly observed within one step by the manual selection of a sequence of representative points in field in the case of total station surveying, in photogrammetry and terrestrial laser scanning (TLS) the determination of relevant features is done in a two step process. In the first measurement step a permanent record of the scene within the field of view of the sensor is acquired. Afterwards, in the second step, the relevant features are observed within this record (i.e. in a photo or a scan). For the interpretation of the scene in the second step a certain knowledge base is essential. This interpretation can be done manually by a human interpretor by identifying linear features in the permanent record or automated procedures can be utilised.

In the last years a lot of research work in the field of photogrammetry and computer vision was done in the area of automated feature extraction based on image data. For some applications these algorithms already allow a highly automated line reconstruction, but still often human interaction is essential in the case of complex scenes. With the advent of TLS sensors a similar need can be observed in the area of automated reconstruction based on TLS point clouds. However, the development of methods for the determination of feature lines based on TLS data is nowadays rather at the beginning (cf. section 2).

This paper focuses on the extraction of feature lines from TLS point clouds. After a short section that summarises the status of research, the paper presents a process for automated feature line modelling. This approach consists of two main steps. In the first step automated feature line segments are detected, whereas in the second step the modelling of the whole feature lines is performed based on the automatically determined line segments. Within this step different kind of feature line types, such as break lines, step edges, form lines and boundary lines, can be considered. Additionally, this section discusses the determination of quality parameters for the extracted feature lines shortly. Furthermore, the paper demonstrates the application of the presented algorithms for automated feature line extraction and modelling with the help of practical examples. These examples demonstrate the potential for automated fea1ture line modelling based on TLS data and show up current limitations. At the end of the paper a discussion of the limitations of the approach and an outlook into future work can be found.

2. STATUS OF RESEARCH

Algorithms for the determination of feature lines from point cloud data in the research field of computer vision and computer graphics are typically based on previously generated triangular irregular networks (TIN, cf. Hubeli and Gross (2001) and Lee and Lee (2002)). These methods usually consist of two

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main steps. In the first step, geometric characteristics that indicate a feature line are determined for each point of the TIN based on the point neighbourhood defined by the TIN topology. Subsequently, in the second step, algorithms are utilised that allow to determine entire, connected feature lines. Furthermore, in order to exclude the influence of measurement noise or other errors present in the point cloud the TIN is usually smoothed prior the determination of the geometric attributes. The result of these approaches is typically a set of feature lines that is described by a sequence of vertices (typically already available points of the acquired point cloud). Finally, for the surface representation the TIN is refined by the integration of the determined feature lines into the TIN. Within this step a local re-triangulation, where the lines act as constraints (constrained triangulation), is performed. One of the main disadvantages of these approaches is that they typically do not consider sensor specific measurement characteristics (e.g. the rounding off of edges due to the spatially extended footprint of TLS systems). Furthermore, no stochastic information is usually provided and the previous smoothing of the TIN may introduce a too high rounding off of the determined feature lines.

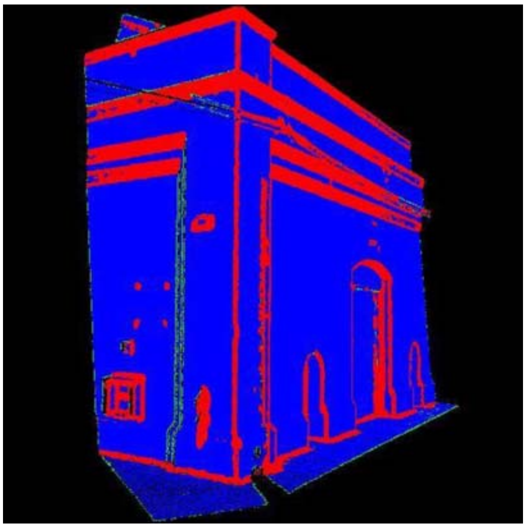

Figure 1:Classified point cloud; Blue: points representing surfaces; Red: Points representing edges; Green: Points representing boundaries. (Belton and Lichti, 2006).

Next to these approaches, specific approaches for feature line extraction based on laser scanner data were introduced. However, while several algorithms were published for airborne laser scanner data (ALS; e.g. Brüglmann (2000), Briese (2004), Brzank et al. (2005)), the number of introduced methods for TLS data is rather low. Recently Belton and Lichti (2006) and Gross and Thoennessen (2006) proposed approaches for the classification of points into the classes boundary point, edge point and surface point (cf. Figure 1). They perform covariance analysis of each acquired point by analysing the eigenvalues of the symmetric 3 by 3 matrix containing the centralised 2nd order moments (cf. Medioni et al., 2000). As can be seen in Figure 1 this approach reliably allows to classify the points near linear features. However, instead of a set of 3D lines that represent the linear features, the result of this local analysis utilising a certain neighbourhood size is a certain band of points along the lines (the points lie in the vicinity of the line on one or the other side of the linear feature). The classified points indicate the presence of a line in the neighbourhood implicitly, but an explicit delineation of the line would require further processing steps.

In contrast to the previously mentioned methods for fully automated feature line detection, Briese (2006) introduced a semi-automated method for feature line modelling. Instead of detecting a sequence of points along the feature line automatically, this approach utilises a feature line growing approach based on one manually set start-point resp. start-segment. Based on these initial line information, the whole feature line is reconstructed (cf. Figure 2).

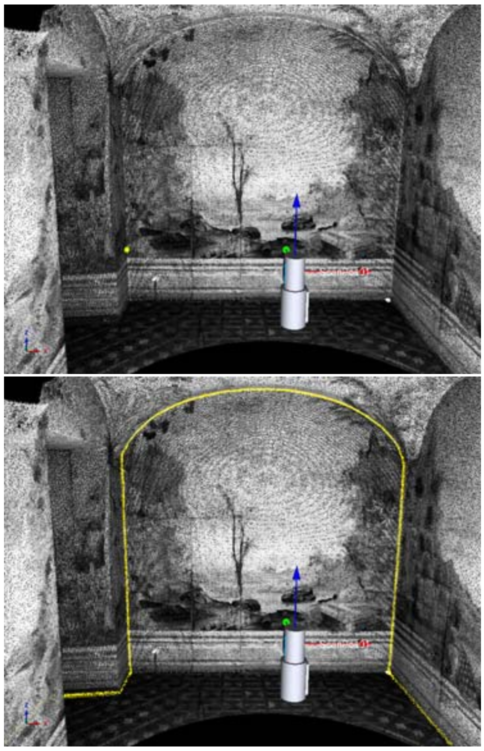

Figure 2:Feature line growing based on one start-point. (Briese, 2006).

3. AUTOMATIC FEATURE LINE MODELLING

The following method for automatic feature line modelling is based on the feature line modelling scheme presented in Briese (2006). However, in contrast to that semi-automatic approach based on manually digitised start-points resp. start-segments the presented workflow allows to determine feature lines based on TLS data fully automatically. The approach for the automatic feature line modelling consists of two main steps. In the first step feature line start-segments are determined automatically (section 3.1). Subsequently, the detected start-segments are used to perform the modelling of the whole lines (section 3.2). Within this step only a few adaptions to the process presented in Briese (2006) where necessary. Furthermore, this section deals with the description of the quality of the determined feature lines (section 3.3).

3.1 Feature line detection based on an adjusted quadric

In contrast to the publications mentioned in section 2, this paper proposes to perform the feature line detection based on a robustly estimated quadric *q*:

$$q = F(x,y,z) = \sum_{i+j+k\le 2} a_{ijk} x^i y^j z^k = 0 \tag{1}$$

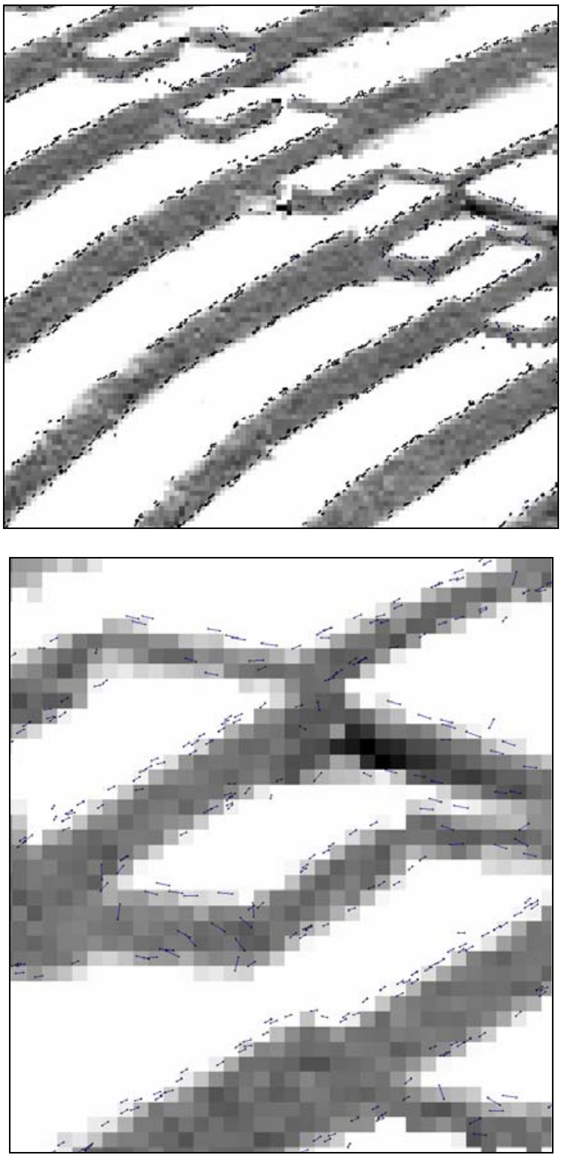

Figure 3: Result of the feature line detection of a staircase. The background image shows the polar TLS data domain from one stand point with a "pixel size" of 0.03° at a distance of about 65m from the sensor. It is displayed as a shading of the 2.5D surface model determined from the polar observations. The feature line detection is based on quadric analysis. Next to the detected 3D location of the feature line (symmetry point) the feature line direction (represented by the second point) was estimated; Upper part: overview; Lower part: detail.

Based on the resulting quadric the presence of a feature line can be determined with the help of the principal axis transformation. In that way the main curvature values can be estimated. Based on the curvature values a classification into feature line and surface point can be performed. Additionally, in contrast to the methods relying an covariance analysis, this approach allows to refine the position of the local feature line segment by the determination of the symmetry point, i.e. the point of maximum curvature. Furthermore, next to the refined position and to the main curvature values, the principal axis transformation provides the main curvature directions. Therefore, next to a representative point, the direction of the local feature line direction can be determined. It can be set to the local minimum main curvature direction.

A result of this approach can be inspected in Figure 3. All resulting symmetry points of the estimated quadric with a significant curvature are displayed. They are connected to a further point indicating the local feature line direction. The determination of the quadrics was performed for each acquired TLS point. For the estimation of the quadric parameters a neighbourhood of 20 points (closest points in the polar domain) was chosen in this example.

Compared to the approach based on covariance analysis (cf. section 2) the determination based on the quadrics has the advantage that the position and direction of the local feature line can be estimated within each patch. The disadvantage of this approach based on the quadrics compared to the covariance analysis is that due to the increased number of parameters the adjustment needs more computational effort. Below, some remarks are provided that show up how the effort for feature line detection based on the quadrics can be reduced.

3.2 Feature line modelling based on robust surface patches

For the feature line modelling the basic concept presented in Briese (2006) is proposed. This approach allows to perform a semi-automated feature line growing of different feature line types (cf. Figure 4) based on one manually set start-point resp. start-segment. The modelling of the lines is performed with the help of different (depending on the feature line type) robust surface patches. This allows the usage of the originally acquired point cloud in the vicinity of the line and off-surface points (measurement errors or points on small objects in front of the line) can be eliminated from the local line determination (cf. Figure 3a).

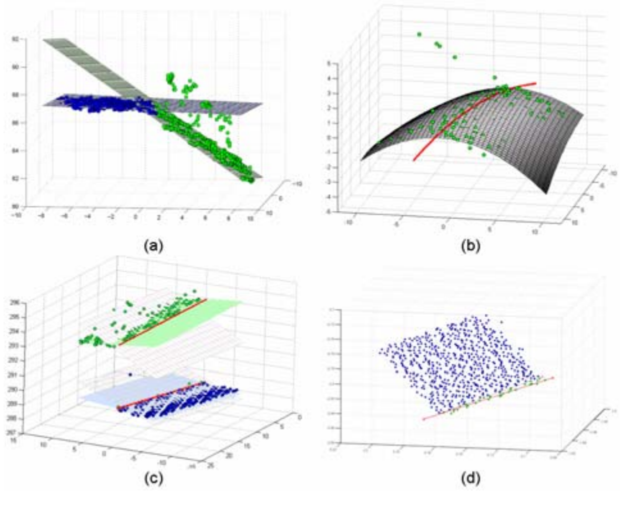

Figure 4: Practical examples for the modelling of different feature line types; break line with 2 intersecting robust planes (a), form line determination based on a robust quadric adjustment (b), step edge modelling with 2 non-intersecting planes (c), and boundary line based on just one plane and missing data on the other side of the line (d). (Briese and Pfeifer, 2008)

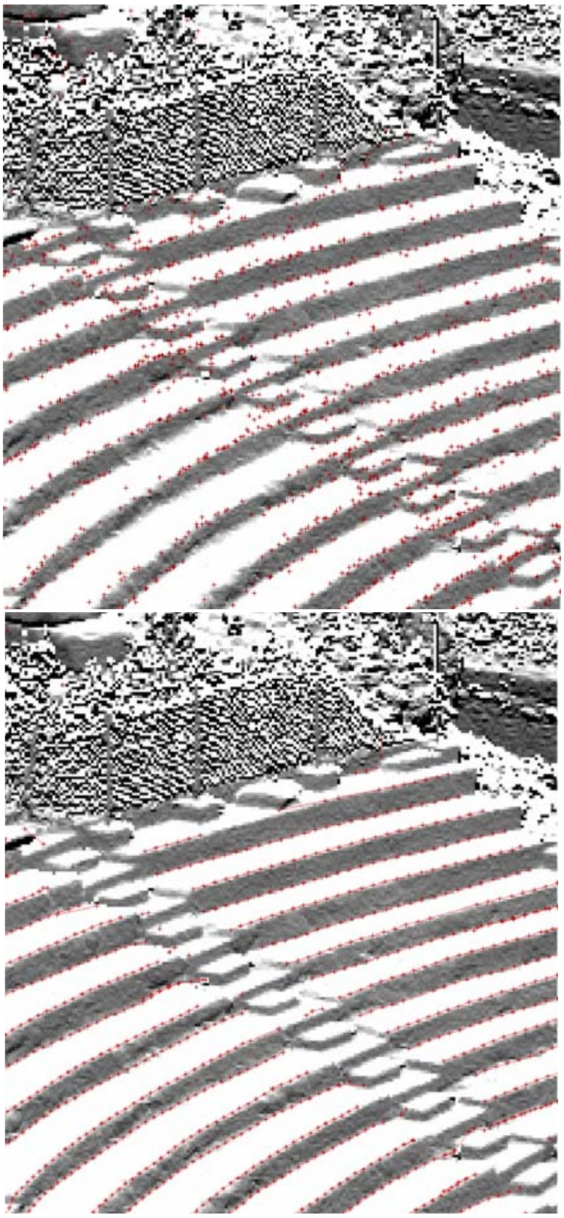

Figure 5: Shading of the 2.5D surface model derived from the polar observations overlayed with vector data; Upper image: automatically extracted start-segments (every twentieth TLS point was analysed); Lower image: automatically extracted feature lines with the proposed approach.

For the application of this approach in the presented full automatic workflow the process has to be extended in order to handle multiple start-segments of the same feature line. Within this first application of that approach this is done by storing already determined feature lines in a data structure that allows a fast access to the stored geometric information. Based on the already stored extracted feature lines prior to the modelling of a segment with the help of line growing it is tested if a feature line in the vicinity of the new start-segment (distance threshold) was already extracted before. If a feature line can be found near the segment the start-segment is dismissed and the modelling process proceeds with the next segment.

3.3 Quality parameters of feature lines

It has to be mentioned that the chosen approach for feature line modelling allows, next to the delineation of the feature lines, the determination of quality parameters. This originates in the adjustment proecure used for determining the plan pair (or other surface types). A detailed discussion about the deliverable data quality parameters of the modelling process can be found in the paper Briese and Pfeifer (2008). Within this paper only the result of the estimation of the error ellipsoid for one break line point is sketched (cf. Figure 6). However, next to the error ellipsoid further quality parameters can be determined, e.g. sigma of the adjustment, percentage of outliers, intersection angle (describing the significance of a line), etc.. These values allow a detailed control of the modelling process.

4. EXAMPLE

In order to test the previously described procedure, TLS data from the theatre in Ephesos was available. The TLS data was acquired with a Riegl LMS-Z420i. The surface was sampled with an angular sampling interval of 0.03°, from a distance to the ranks of approximately 55-80m (cf. also Figure 3). The result of the modelling process for one scan position can be inspected in Figure 5. While in the lower part of the figure the resulting feature lines can be found, in the upper part of the figure the detected start-segments are displayed. In contrast to Figure 3 the number of detected start-segments is significantly lower. This is caused due to a reduction of the number of points were the quadric parameters were analysed. Instead of estimating a quadric in each point, only each twentieth point was chosen. However, due to the subsequent line growing concept this reduction of start-segments does not have a negative influence onto the result (for the growing process just one start-segment per line is necessary). It can be seen that most of the significant feature lines could be determined precisely. Only smaller feature lines on the small stairs could not be determined. In these areas the growing fails, because the number of points on the vertical staircase surface is too low. In order to model these lines manual input (adaptation of parameters and/or manual line approximations) would be necessary. A further discussion about the approach and its first results follows in the subsequent section.

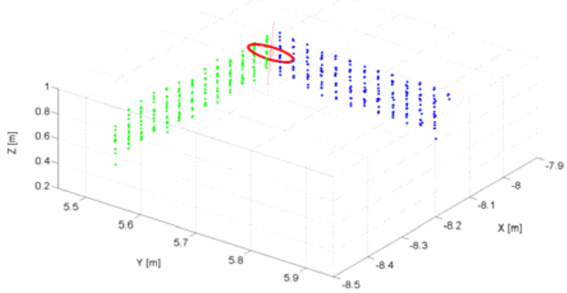

Figure 6: Covariance ellipsoid for one break line patch; Red: resulting break line (dotted line), representative point on the break line (diamond) and corresponding error ellipsoid (principle axis: 0.014m and 0.007m enlarged by a factor of 3); Green: TLS points of the left patch; Blue TLS points of the right patch. (Briese and Pfeifer, 2008)

5. DISCUSSION

The whole process for automated feature line modelling as presented in section 3 has a number of advantages:

- The feature line must not be represented as a whole after the automatic detection procedure. The whole line is generated in an independent subsequent modelling process (line growing).
- Within the process of feature lie growing further geometrical criteria (e.g. the intersection angle) can be used in order to analyse the significance of a certain feature line.
- If the determination based on one start-segment fails, another start-segment can be used for the delineation of the same line.
- The line direction is already provided by the feature line detection process and can be used for the feature line growing process.
- There is no requirement that the whole feature line has to be detected in the first step. Just one initial start-segment per line is sufficient. This allows to reduce the efforts for the detection process, e.g. it is not necessary to determine a quadric for each observed TLS point, the sampling for the quadric determination just has to be dense enough to determine one start-segment per line (e.g. only each twentieth points can be used). This helps to speed up the first step significantly).
- Next to the feature lines, the precision of the modelled feature lines can be estimated (as demonstrated for break lines, cf. Figure 6)

Thus, there is a number of distinct advantages over the approaches summarized in section 2 which only analyse and classify each point, but not look at the line as such. Additionally, the formal line model allows deriving quality parameters and checking the validity of the model. Still, there is a number of possibilities to further increase the reliability, completeness and quality of the process:

- The current approach hinders the usage of a start-segment when a feature line is already present in the vicinity, but during the growing process it is not analysed if the newly delineated line segment is identical to a previously determined feature line. Therefore, double lines can occur if the result of the first growing process of a line does not reconstruct the line in its entirely length and a further start-segment in the unreconstructed area initiates a further line growing step of the identical line.
- Currently, the process of feature line modelling can only automatically determine the feature type of break lines (default type) and step edges. For the other line types (form and boundary line) manual input is requested in the current implementation.
- The topology of the resulting set of feature lines could be considered, too. Currently, each line is treated independently and no qualified intersection of the lines is performed automatically.
- As mentioned before, within the modelling process the lines are determined one after another. No information about neighboured lines is considered. This hinders the introduction of additional constrains in-between neighboured lines (e.g. parallelism, constant distance, etc.).

Next to the previously mentioned possibilities for improvements a combination of the feature line detection based on covariance analysis and the detection of the symmetry point and the main curvature directions with the quadric might be useful und should be studied in the future.

6. CONCLUSIONS

This paper presents, next to a short summary of the status of research, a full automatic procedure for the determination of feature lines from TLS data. The suggested approach consists of two steps and differs significantly from other approaches that try to detect points along the whole lines which are subsequently linked together. In the first step of the presented workflow, local feature line segments (point and line direction) are automatically extracted. In the subsequent step these detected start segments are used as input for the feature line modelling and growing based on robust surface patches. This approach, presented in Briese (2006) is extended to the usage of multiple start-segments per feature line. Within this paper the first promising results of this process are demonstrated. However, it should be noted that a fully automated workflow from the data acquisition to all feature lines required for a complete model is currently not achieved. In order to integrate the delineated lines into final representation forms of a object or a scene a manual improvement of the results (line intersections, determination of missing lines, etc.) is necessary.

The proposed process has a number of advantages (cf. section 5), but in order to built a highly automated workflow a lot of further improvements are suggested. In the future, next to an automated determination of the feature line type, constraints in-between neighboured lines will be introduced. Furthermore, this automatic approach will be adapted to the 2.5D usage with ALS data. Finally, it has to be mentioned that the accuracy of the estimated lines has to be analysed with external control data in the future.

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