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DERIVATION OF ROOF TYPES BY CLUSTER ANALYSIS IN PARAMETER SPACES OF AIRBORNE LASERSCANNER POINT CLOUDS

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ABSTRACT:

The paper describes a method that extracts planar roof faces of building objects from point clouds obtained by a pre-segmentation of airborne laserscanner data. The method utilises a TIN-structure that is calculated into the point cloud. The parameters of every TIN-mesh are mapped into a triangle-mesh parameter space, which is then analysed by cluster analysis techniques. Both the utilisation of a 2-D parameter space (containing only triangle-mesh slope and orientation) and a 3-D parameter space (containing all three plane parameters) are described and tested. By cluster analysis and available knowledge on possible roof shapes, significant planes are derived from triangle parameter space.

Results show that the use of a full 3-D plane parameter space is superior to the analysis of triangle-mesh slope and orientation only. Well-defined building roof planes can be extracted successfully, while disturbances such as dorms on buildings or geometric discrepancies in laserscanner data strip overlaps may significantly reduce the applicability of the technique.

1 INTRODUCTION

Airborne laserscanner data are nowadays used for multiple tasks. One of them is to acquire information for building reconstruction. In respect to obtaining building parameters, different methods have been published that derive parameters of laserscanner point clouds. Some of them are purely based on laser scanner point clouds and others integrate additional information. The former is more flexible, but less discussed in literature. Such an approach is given by [Maas 1999], who uses invariant moments to obtain parameters of buildings. The method is, as described in the article, limited to simple ground plans. Another technique is presented by [Vosselman 2001]. Here the Hough transform is used on high-density point clouds to derive parameters of roof faces.

This paper will discuss a further method for recognising parameters of roofs that is not bound to simple roof types or to a certain point density. The method uses a TIN-structure that is calculated into a laserscanner point cloud that contains a building. The position of each triangle in space is expressed in spherical coordinates that are displayed in a Cartesian coordinate system. These coordinates are understood as parameters that, consequently, define a 3D parameter space. It is assumed that the distribution of points in parameter space (representing triangles in object space) will offer some structure that can be analysed and understood. As only parameter points, later referred to as triangle points, resulting from roofs are of interest for determining building types, a systematic shall be found that discerns triangle points originated from a roof, from other triangle points. Two approaches, one in a 2D parameter space and one in a 3D parameter space, have been tested to accomplish this task.

2 DATA SET AND PRECONDITIONS

Initially, some preliminary information is provided about the data and the process that derives the parameter space.

The laserscanner data have an average point spacing of 1.2m. This point spacing indicates that smaller features of houses, such as dorms, cannot be mapped. The standard deviation in x and y of the data is about 30 cm and in z 20 cm. As planimetric as well as height errors of laserscanner data are mainly caused by the GPS system on board, laser points within an object of little extent can be understood as correlated. Only the accuracy in z must than be taken into account. This presumption can be made since the mean size of the analysed objects in this study is small (ca. 160m²).

For the study, 310 point clouds, each containing only one building including some surrounding ground points, have been arbitrarily extracted out of a laserscanner data set.

[Hofmann 2002] gives an example for the process of extracting such laser point clouds automatically. The extracted point clouds contain buildings with common roof types such as flat, pent, gable and hip roofs. Some of the buildings have also combinations of them. A flat roof is a plane roof with an inclination smaller than 7 degree. Any higher inclination indicates a pent roof. A gable roof has two roof faces whereby their inclinations must not be the same. A hip roof has four roof faces; two pairs that are 90 degree shifted to each other. Table 3-1 has, among other things, the statistics of roof types. The number of each roof type represents the character of the study.

The local coordinates of the extracted laserscanner points of a point cloud are reduced to barycentric coordinates. In each point cloud a TIN-structure is calculated with a Delaunay triangulation using the module Triangle [Shewchuk 1996]. Figure 2-1 shows an example. To obtain parameters for further analyses, the three points of each triangle are used to calculate a plane that is, consequently, also represented by the triangle. Thus, unique characteristics of each triangle can be derived from this plane. The following parameters were used: Slope, Orientation and the minimal distance of the plane to the origin, below referred to as Distance.

The next chapters will discuss the analyses of these parameters. In a first step Slope and Orientation alone (2D) and in a second step including Distance (3D).

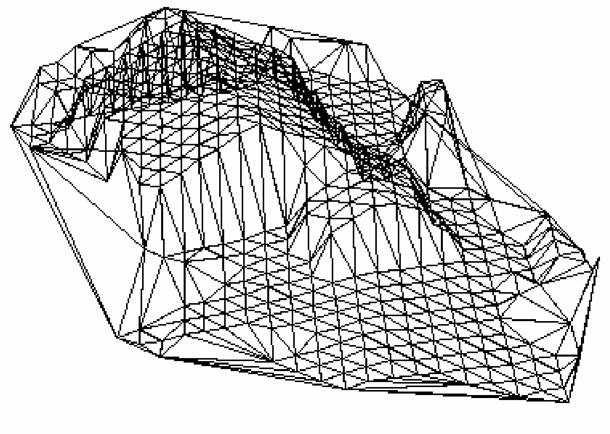

Figure 2-1. A building's point cloud with TIN-structure

3 2D CLUSTER ANALYSIS

The following triangle parameters Slope and Orientation were analysed. The upper image of Figure 3-1 shows the distribution of these triangle parameters for the building of Figure 2-1. The ordinate represents the slope values (0 to 90 degree) and the abscissa the orientation values (0 to 360 degree). Within this 2D space two clusters with roof properties can be made out at a first glance. Consequently, getting characteristics, such as mean slope and orientation values, for those clusters, the mean roof inclination and orientation is known as well. Furthermore, it can be presumed that certain cluster patterns will be obvious for different roof types such as pent roofs, hip roofs or complexes. This chapter will explain what information cluster analysis can derive from the slope and orientation distribution of triangle points in parameter space.

3.1 Conditions of roof clusters

The minimum number of points of a cluster representing a roof face was derived by defining the minimum detectable size of a roof face (4x4m²) and the assumption of outliers within the laserscanner points. Also the number of points of a roof cluster must be distinguishable from other randomly existing clusters.

If the laser points are faultless, then all triangles of a 'perfect' roof face have the same parameters. Due to the error of the laserscanner data in height and the microstructure of the roof, triangles on the roof do not have the same parameters such as slope and orientation. The variation of the triangles in slope and orientation is a function of the roof inclination. Both vary the most for a moderate steepness. For slope values of smaller than 10 degrees the orientation values can vary by more than 70 degrees and no real clusters can then be found. Consequently, flat roofs cannot be detected by the applied error definition.

The variation of the triangle parameters within a roof face causes the roof cluster to spread. The maximal dimension of a roof cluster, and so the maximum allowed distance between triangle points, is to calculate via the maximum laser point error in height for a moderate roof inclination. It is used for the whole laserscanner data set. In addition, the number of points per laser point cloud must be taken into account. The larger the data set, the more triangle points and the higher the likelihood of spread points. Then, the distance between the points must be decreased to separate real clusters from noise.

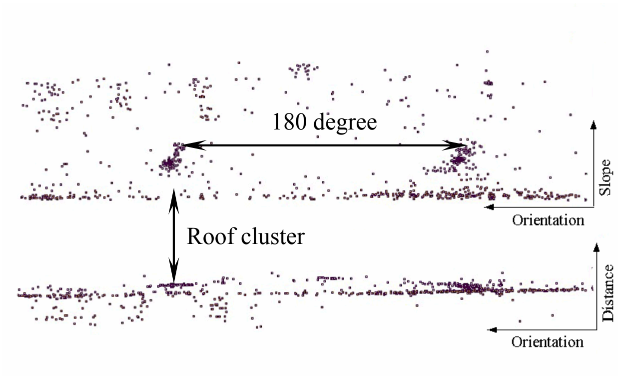

Figure 3-1. Example of a building's 3D parameter space

3.2 Clustering

Several basic clustering techniques, such as partitioning, hierarchical, divisive, agglomerative or k-means methods are described in either [Kaufmann 1990] or [Anderberg 1973]. For this study it was decided to apply an agglomerative approach using single linkage. That means the size of the clusters is not limited in any direction and so-called snake clusters can be generated. This is necessary, as the sizes of the clusters vary with the laserscanner data accuracy in z and with the roofs inclination and position to the origin. The exact algorithm is explained below.

The applied cluster algorithm searches for dense point groups. The procedure is as follows: Starting from a randomly chosen seed point the distances to all direct neighbours are calculated. If one distance is smaller than the maximum allowed, then the point is grouped to the seed point. This search is repeated until no direct neighbour of any point that belongs to the group is found. A new seed point is chosen and its neighbours are checked. Each point is treated only once. A cluster is only accumulated if a sufficient number of points are collected. The shape as well as the extension of the clusters is not relevant. As indicated above the maximum distance between parameter points is to be adjusted with the number of laser points in the dataset. So, the number of points per cluster is checked. If more than 80% of all points belong to one cluster, then the distance value is reduced. This happens if the dataset inherits a huge number of laserscanner points that do not necessarily belong to the roof. By decreasing the maximum allowed distance between points, it is intended to find the actual roof clusters. The minimum reasonable distance between cluster points is 4 degree.

3.3 Analysis

The found clusters of a data set were then analysed by their absolute and relative position in the parameter space. A decision tree was built up considering that the mean slope of the clusters represents the roof inclination:

- If no cluster is left, then no roof could be recognised.
- If one cluster with a plausible slope value (>7 degree and <75 degree) is left, then a pent roof is supposed.
- If two clusters with reasonable slope values and a difference in orientation of about 180 degree are left, then a gable roof is identified.
- If more than two clusters remain, they are searched for pairs whose orientation is around 180 degree different and whose slope values are similar. Each pair represents then a gable roof. The shift in Orientation of the pairs stands for the angle between the ridges of the roofs.

3.4 Results

As indicated above, the algorithm has been applied to a large number of laser point clouds. The datasets have been chosen without any prior knowledge of the extracted buildings. It, therefore, reflects a condition as it happens in practice. Still, for this collection, the analysis shows sub-optimal results (Table 3-1). Gable roofs have best results with 30% correctness. Flat roofs could not be detected since bottom triangles and roof triangles cannot be separated from each other. Any detection would be random. If more than two clusters exist, the association and grouping of the clusters to a roof is not explicitly possible. Only assumptions can be made. Thus, it also could not be discriminated between hip roofs and e.g. L-shaped buildings.

A main problem of the analysis is the optimal number of points per cluster that definitely represents a roof face. The optimal minimum number of points per cluster was found with 11. Still sometimes too many clusters were located and the object type was not recognisable. Thus, the minimum number of points per cluster was increased, in doing so smaller objects could not be identified anymore. An example is a large building with a smaller cover that belongs to it. Also problems arose regarding smaller pent roofs; a single small cluster may not indicate a roof. It could also not be concluded that a higher number of points, in terms of triangles, results in more dense clusters, as a roof combination or multiple inclinations per roof face can occur. Changing the distance parameter for bigger laser point clouds offered some potential for the analysis, but could not give sufficient aid. For best results this parameter must be set manually.

In summary, results show that individual roof faces and thus the roof type cannot be detected reliably in a 2D parameter space. The main reason is the obviously missing third dimension that would enable the detection and separation of real and different roof clusters. For instance, multiple gable roofs (Figure 4-1.a shows) cannot be separated in the 2D parameter space.

Roof Type	Number of	Correct	Passable	False
Flat	3	2 (67%)	0 (0%)	1 (32%)
Pent	17	11 (65%)	6 (35%)	0 (0%)
Gable	240	70 (29%)	83 (35%)	87 (36%)
Hip	17	4 (22%)	8 (44%)	5 (33%)
Combination	33	6 (18%)	5 (15%)	22 (67%)
Summary	310	93 (30%)	102 (33%)	115 (37%)

Table 3-1. Results of 2D Cluster Analysis of the laserscanner data

4 3D CLUSTER ANALYSIS

In the previous chapter it was concluded that an analysis of three parameters should improve results. Thus, in addition to the slope and orientation parameter, the O-distance was included. The O-distance is defined as the minimum distance of a plane that is calculated in the triangle from the origin. The range of values of the O-distance varies with the extension of the laser point cloud and with the position of triangles in the local coordinate system. With this third dimension multiple roof faces with the same orientation and slope can be made out by their spatial position, as Figure 4-1.a shows. To tell roof clusters apart from other clusters the distribution in the O-distance is analysed. If laserscanner points are faultless, all triangles of a roof face should have the same orientation, slope and O-distance. The dispersion of O-distance values for a roof face is a function of the roof face slope and the distance from the origin. That is to say: the steeper the slope, and the greater the distance, the greater the scattering. For a typical roof face, the range of the O-distance values is about 2m.

This procedure can be compared to the Hough-transformation based technique proposed by (Vosselman, 2001): While Vosselman works on unstructured point clouds and generates an entry plane in a 3-D Hough space for every point, the method proposed here is based on a point cloud in a TIN structure, where every TIN-mesh produces one entry in a 3-D parameter space.

4.1 Clustering

The clustering method applied in this 3D parameter space follows the same rules as utilised for the 2D analysis, but was alternated to save computation time. The clustering method is still agglomerative, but starts with a coarse clustering that is later refined. For the coarse clustering a 3-D grid is projected into the parameter space and the number of points per box is counted. The extension of the grid boxes must, of course, be adapted to the properties of the clusters to be found. It was mentioned before that the variation of slope and orientation increases with decreasing inclination. The variation of O-distance values mainly increases with the plane's distance to the origin. Thus, the proportions of the boxes edges have to take these findings into account. The optimal size of the boxes must also take into account the fact that boxes that are too large could inherit two clusters that cannot be separated later. Boxes that are too small will increase the computation speed cubically; in addition, too many clusters would be found. The optimal size for the boxes was empirically found with 7 degree in slope, 10 degree in orientation and a O-distance of 2m. Due to the pancake-like appearance of the cluster, they are seen as lines when projected in the orientation/distance plane. So it is necessary to increase the search area by the standard deviation of the mean roof face cluster. In consequence, each point is assigned twice. Possibly doubly found clusters are later merged. The size of the boxes is, as well, a function of the accuracy of the laserscanner data and has to be altered for other laser scanner data sets.

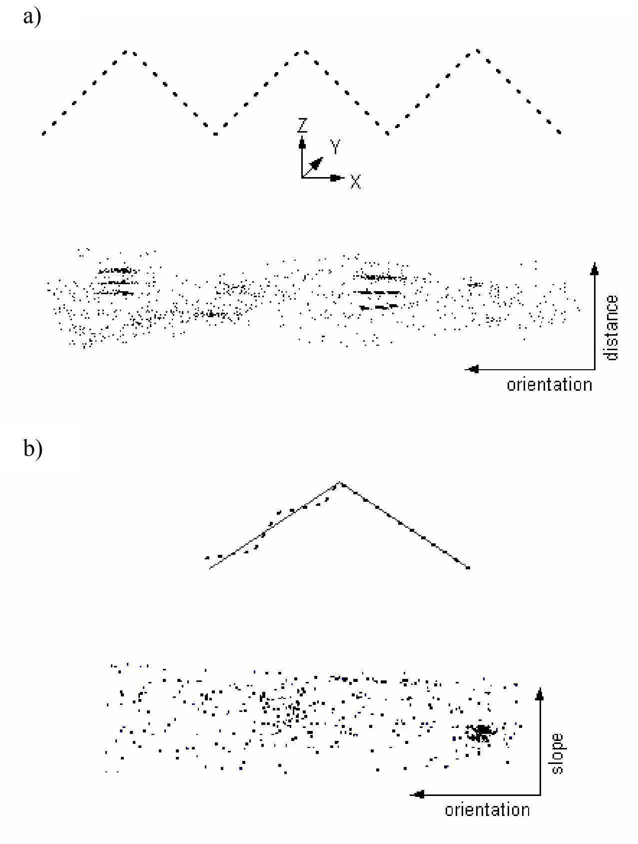

Figure 4-1. a) Multiple gable roofs

b) Effect of laserscanner data errors onto the parameter space

The number of points per box is gathered; now referred to as density. If the number of points exceeds a certain threshold, then the neighbouring boxes are checked for their number of points. By neighbouring boxes it is meant only the boxes that are the direct neighbours in the slope/orientation plane and not in the orientation/distance plane. The grouping process of the boxes is a simple region growing technique as explained in chapter 3.2. Single standing boxes with a number of points above average are understood as group as well. The found box groups represent then coarse clusters.

As not only roof face clusters, but also other sometimes randomly existing clusters are found, the boxes need to be analysed and coarse clusters refined. First points that do not belong to the cluster, but are within the box are removed. That is, for each point within a group the number of close points (within certain distances in slope, orientation and O-distance, depending on the coarse cluster mean slope) is determined. This number of points represents a weight, which is used to calculate the mean of the cluster. Thus, if there are no close points then the weight is 0. The calculated cluster centres are the basis for the membership assignment of each point to each cluster in the parameter space. The distance in slope, orientation and O-distance determines the membership value of each point to each cluster. Whereby the single parameters are treated upon their behaviour in the 3D parameter space. Setting a threshold for standard deviation of the O-distance values eliminates clusters not resulting from roof triangles. A value smaller than 1.3 is evidence of a roof cluster assuming the cluster horizontal positioned in the parameter space.

4.2 Analysis

As explained before, the number of clusters should give evidence of the number of roof faces and the cluster arrangements an idea of the roof type. Again, a decision tree was used for classification algorithm. In a preliminary step all clusters that have a negative O-distance value (that are below the centroid) and a slope smaller than four degree are eliminated. Clusters that have a mean slope value of higher than 76 degree are also not considered as roof clusters, but are understood as wall clusters.

- If no cluster is left, then no roof could be recognized.
- If one cluster with a Distance greater than zero and a plausible slope value is left, then a pent roof is presumed.
- If two clusters with reasonable slope values and a difference in orientation of about 180 degree are left, then a gable roof is identified.
- If more than two clusters remain, they are searched for pairs whose orientation is around 180 degree different and those slope values are similar. Each pair represents then a gable roof. If there are four clusters that make two pairs, this indicates two gable roofs. A direct relationship between clusters based on the same mean distance value cannot be concluded, as this assumes the origin needs to be under the ridge of the roof.

4.3 Results

Table 4-1 shows the results of the 3D analysis. Again it shall be emphasised that Table 4-1 displays results that were obtained for randomly extracted buildings of a laserscanner dataset. Results are nonetheless poorer than expected. The number of correctly clustered and classified objects is only about 49%. A correct clustering and classification exists, if all clusters that represent roof faces, and only those, have been found and interpreted properly. The clustering is called passable, if at least half of the roof faces of the object have been detected. Any poorer clustering results are called "false clustered".

The identification of flat roofs is also in the 3D parameter space more-or-less by accident, given that the triangle points spread more than 90 degree in orientation. That means flat roofs cannot be identified for sure.

The derivation of pent roof parameters should have shown better results. It is the roof itself that mainly caused problems here. Analysing the laserscanner point cloud, a higher number of roof points does not fit the roof. That can be caused by dormers or wet areas. Triangles connected to these points will not occur within the actual roof cluster. The roof cluster might not have enough points then and is not accepted as cluster at all.

Roof Type	Number of	Correct	Passable	False
Flat	3	1 (33%)	0 (0%)	2 (67%)
Pent	17	6 (35%)	2 (12%)	9 (53%)
Gable	239	135 (56%)	67 (28%)	37 (16%)
Hip	18	0 (0%)	6 (29%)	12 (71%)
Combination	33	9 (27%)	15 (46%)	9 (27%)
Summary	310	151 (49%)	90 (29%)	69 (22%)

Table 4-1. Results of 3D cluster analysis of all laserscanner datasets

A considerable amount of gable roofs has been recognised. Still, there are a quite high number of insufficient cluster results. One reason is the effect as described for pent roofs. Another reason is that for some objects the laser points come from different flight stripes that have a shift in z and possibly also in x and y. The laser points at the object show then a typical waviness for at least one roof side that results in a strong influence on the triangle slope. This waviness of the points results in either two clusters for one roof if it is a symmetric waviness, or in case of a random waviness, in a less dense cluster with fuzzy borders (Figure 4-1.b). Sporadically, a single laser point row was calculated incorrectly and perturbs the cluster as well. The same problems occurred also for houses with multiple roof inclinations per roof face; again the clusters are then either divided into two smaller ones or stretched. Anyway, these clusters are not detected, unless there are still plenty of dense triangle points. Altogether, about 16% of the datasets have at least one of these nuisances.

Table 4-1 also confirms that hip roofs are barely detectable within the parameter space. At the small roof faces only few laserscanner data points are available and therefore no big enough clusters are generated. Also, the hip roofs of the study area have the characteristics of having a continuous change in inclination for the lower roof part. Thus, the roof cluster is spread and is not identified anymore. The detection and identification of roof faces of combined roofs is as interesting as it is tricky. Usually, those data sets are large in size. That means there is a higher signal to noise ratio in the parameter space. In addition, the previously described error causing effects shape the parameter space as well. Hence, it is not very likely to detect all roof faces, especially smaller ones. Another issue is: If two or more gable roofs are too close to each other, as illustrated in Figure 4-1.a, then their spacing in O-distance might be too small, and they might be not separated and identified as two clusters. Table 4-1 confirms these issues.

The statistics is provided in Table 4-2 that show the success of the algorithm on perfect datasets. That means, all datasets that cannot be analysed with the algorithm, for instance those that are too small to be identified or that have laserscanner effects or those that have disturbing features such as dorms have been excluded. Here, results appear to be passable with about 63% correctly clustered and classified roof types. Still, this rate must be improved especially for buildings with roof combinations. This could be accomplished by amending the cluster analysis in terms of variable parameter settings.

Roof Type	Number of	Correct	Passable	False
Pent	13	8 (62%)	0 (0%)	5 (38%)
Gable	157	109 (69%)	40 (25%)	8 (6%)
Hip	4	0 (0%)	4 (100%)	0 (00%)
Combination	23	8 (35%)	14 (61%)	1 (4%)
Summary	197	125 (63%)	58 (29%)	14 (7%)

Table 4-2. Results of 3D cluster analysis of laserscanner datasets expected to have good results

In general, the following statements apply to the analysis: Buildings smaller than 4x4m² cannot be detected with this method at the given point density. The larger the roof the less does the missing or false laserscanner points matter. Poor laserscanner data accuracy in z hinders the cluster analysis, as the triangle points scatter too much to form a cluster. Point clouds including a larger surrounding beside the house are also hard to analyse in parameter space, as there is too much noise in the vicinity of the searched roof clusters and their borders are blurred.

5 CONCLUSIONS AND OUTLOOK

The described method yielded interesting preliminary results. The amount of correctly clustered data sets was expected to be higher, especially for gable and combined roofs. Regarding the clustering technique, it will be also of interest if an improved technique will show better results. A method that adapts parameter settings automatically shall also be developed. Beside, it was realised that the laserscanner data quality as much as the evenness of roofs is of importance for the cluster analysis. Systematic errors will prevent a successful clustering, but single outliers will not affect the cluster analysis. A prior knowledge of the data set accuracy is therefore of importance.

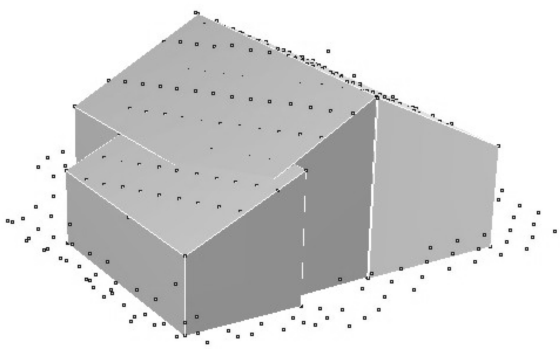

Figure 5-1. Building primitive reconstructed from the 3D cluster analysis information

Next step will be to use the acquired roof information identify laser points that belong to a roof face either by cluster membership assignment or by a region growing technique that is based on the mean cluster information. Both would provide laser point groups that belong to roof faces. Whereby the latter one should be more accurately since parameter points that belong to the cluster by chance would not influence the analysis. Based on this, building primitives, as demonstrated in Figure 5-1, could be generated by interpolating planes in the point groups.

Future work will also continue to explore the presented approach with regard to improving the results for the 3D parameter space. It will be checked out if the set thresholds can be optimised and what clustering method is more efficient. Investigation shall be made if using 1-stripe data will enhance results. It is also of interest to continue building reconstruction based on extracted roof planes.

6 ACKNOWLEGMENTS

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