FROM POINT CLOUD TO SURFACE: MODELING STRUCTURES IN LASER SCANNER POINT CLOUDS

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Commission V, WG V/3

KEY WORDS: Laserscanning, Photogrammetry, Feature Extraction, Segmentation, Modeling, Software Development.

ABSTRACT:

The automatic modeling of precise structures from randomly distributed laser points derived from laser scanner data is a very hard problem, not completely solved and problematic in case of incomplete, noisy and sparse data. The generation of polygonal models that can satisfy high modeling and visualization demands is required in different applications, like architecture, archaeology, city planning, virtual reality applications and other graphics applications. The goal is always to find a way to create a computer model of an object which best fits the reality. Polygons are usually the ideal way to accurately represent the results of measurements, providing an optimal surface description. While the generation of digital terrain models has a long tradition and has found efficient solutions, the correct 3D modeling of closed surfaces or free-form objects is of recent nature, a not completely solved problem and still an important issue investigated in many research activities.

In this paper we develop an approach for converting a laser scanner point cloud into a realistic 3D polygonal model that can satisfy high modeling and visualization demands. Close range photogrammetry deals since many years with manual or automatic image measurements. Now laser scanners are also becoming a standard source for input data in many application areas, providing millions of points. As a consequence, the problem of generating high quality polygonal models of objects from randomly distributed laser points is getting more and more attention. After reviewing some results in this context, we will describe a full approach for turning a usual unstructured point cloud into a consistent polygonal model. Finally, the polygonal model is turned into a hierarchical nodes network similar to VRML. A novel laserscanning processing tool, LSM3D (Laser Scanner Modeling 3D), has been developed and tested over different examples related with architectonic buildings.

1. INTRODUCTION

The automatic 3D modeling of precise structures from randomly distributed laser points is a problem which has been approached in several ways in computer graphics and computer vision literature and which has currently produced a growing interest in close range photogrammetry due to the emergence of terrestrial laser scanner. The generation of polygonal models which can satisfy high modeling and visualization demands is required in different applications, like architecture, archaeology, virtual reality applications and other graphics applications. The goal is always to find a way to create a computer model of an object which best fits the reality, remember that the models, if they are even very accurate, are idealizations of the reality. Polygons are usually the ideal way to accurately represent the results of measurements, providing an optimal surface description. While the generation of DTMs has a long tradition and has found efficient solutions, the correct 3D modeling of closed surfaces or free-form objects is of recent nature, a not completely solved problem and still an important issue investigated in many research activities.

Several methods and approaches have been developed for the recognition of object surfaces in laser scanner point clouds. Following the proposal of (Vosselman et. al., 2004), methods for the extraction of surfaces can roughly be divided into two categories: those that segment a point cloud based on criteria like proximity of points and/or similarity of locally estimated surface normals and those that directly estimate surface parameters by clustering and locating maxima in a parameter space.

The first approach shares large similarities to the image segmentation problem, so equivalent techniques and algorithms of image processing could be extrapolated and adapted. For example, an important type of 2D image processing operators and filters like neighborhood, labeling, skeletonisation or even morphologic operators could be adapted for the detection of three dimensional linear structures and boundaries: (Palagyi and Kuba 1999), (Jiang and Bunke, 1994) and (Sithole and Vosselman, 2003) are several examples where scan line segmentation and growing surfaces methods could be comparable in strategy to the split-and-merge methods and region growing algorithms in image segmentation respectively.

In this line, polygonal meshes, volume grids and parametric piecewise functions NURBS (Non Uniforms Rational B-Splines) are others alternatives to obtain a final description of the surface: (Polis and McKeown, 1992) and (Oda et. al., 2004) develop several methods for creating simple polygonal meshes linked to surveying applications; (Chew, 1997), (Shewchuk, 2001) and (Watson, 1981) present several approaches based on 3D polygonal meshes; finally, (Han and Medioni, 1996) develop several parametric piecewise functions based on NURBS. Nevertheless, one of the main drawbacks of complex polygonal meshing is that requires high rates of computing time and do not always represent the wealth of information contained in the original points cloud.

On the other hand, regarding the second category of methods, these are more robust but can only be used for modeling basic primitives supported by a few parameters. There are several authors (e.g. (Krishnamurthy and Levoy, 1996), (Curless and Levoy, 1996), (Pottmann et. al., 2002) and (Vosselman et. al., 2004)) who have developed automatic methods and algorithms for polynomial 3D modeling, but only applied to structured or small points clouds corresponding to independent objects. In these approaches, the use of a parameter space based on the generalized Hough transform (Ballard, 1981) and Gaussian Sphere (Barnard, 1983) have been the most successful techniques for modeling basic primitives such as plans, cylinders, spheres, etc. Nevertheless, the main disadvantage of these methods is its high computational cost, as well as the presence of outliers. Outlier detection in point clouds is not a trivial task since there are: geometrical discontinuities caused by occlusions, no prior knowledge of the statistical distribution of points, existence of noise, and different local point densities.

The approach that we propose follows a combination of both categories, since segmentation and clustering techniques are applied over unorganized laser scanner dataset. In order to avoid outliers, RANSAC robust estimator (Fischler and Bolles, 1981) has been adapted before the fitting step.

The complete full pipeline process in 3D modeling structures from laser scanner dataset is illustrated in Figure 1.

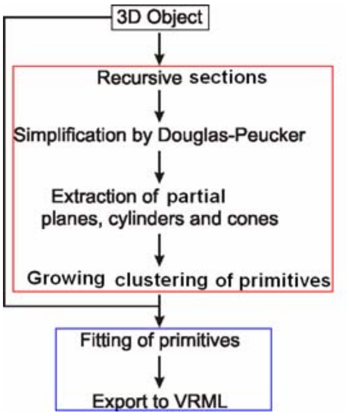


Figure 1. Full pipeline process.

The paper presents the following structure and organization: after this introduction, Section 2 explains in detail the segmentation approach of point clouds. Section 3 develops the basic primitives fitting process. Section 4 describes the novel laserscanning processing software developed. Section 5 shows the experimental results tested with our own software. A final section is devoted to give some conclusions and future works.

2. SCAN SEGMENTATION

In the process of 3D modeling structures from randomly distributed laser points, a number of steps are involved. One of the critical steps is segmentation, which contributes to segment the structures from the background of the original laserscanning point cloud. The reliability and accuracy of the segmentation method affect the result of the final structures extraction to a large extent. Therefore, image segmentation plays an important role in laserscanning modeling. Recently, several segmentation techniques for laser scanner have been reported (Min et. al., 2004) and (Bellon and Silva, 2002). In the first approach, the authors develop an automated framework for evaluating the performance of range image segmentation algorithms. This framework should make it possible to objectively and reliably compare the performance of range image segmentation algorithms; allow informed experimental feedback for the design of improved segmentation algorithms. The framework is demonstrated using range images, but in principle it could be used to evaluate region segmentation algorithms for any type of image. In the second approach, the authors present new improvements for range image segmentation based on edge detection techniques. The developed approach better preserves the object's topology and shape even in noisy images. The algorithm also does not depend on rigid threshold values, thus being useful in unsupervised systems. Experiments are performed in a popular range image database and the results are compared to four other traditional range image segmentation algorithms, demonstrating the efficiency of the proposed algorithm.

In our case, laser points have been processed with various well-known segmentation algorithms following a triple process.

In a first step, orthogonal sections to the vertical are obtained (Figure 5). This segmentation requires a previous definition of the Z axis which coincides with the vertical, due to the vertical is the mainly character of the shapes of the buildings. Afterwards, sections and profiles are simplified automatically based on Douglas-Peucker algorithm (Douglas&Peucker, 1973) which keeps the basic geometric features of every section (Figure 2). This step also includes a process to localize circumferences, and in this way, the final results of all these sections are polygonal lines and circles.

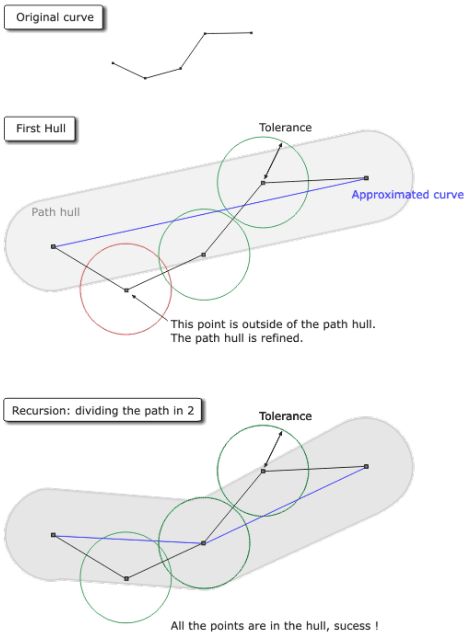


Figure 2. Simplification of laser sections based on Douglas-Peucker.

In a second step, a clustering of different sections allows us to extract partial primitives such as planes, cylinders and cones, working recursively with groups of three sections to verify the results.

The algorithm is completely automatic. Two adaptative thresholds are selected:

- The threshold α is used to decide whether two sections have a similar orientation.
- The threshold d is used to decide whether two sections have a logical position in space, in order to discriminate between sections which are in different parts of the scene, like regular patterns.

For each straight segment belonging to the first section, similar features such as position, orientation and size are searched in segments belonging to the second and third sections. This processing is based on the regularity of the facade, and for every three segments which verify the previous condition, a new partial extraction of planes is obtained. The process with cylinders and cones is similar, but this time, values such as the position and radius are the main goal. Discrimination between cylinders and cones is established based on the radius variation.

To improve the efficiency and reliability of the process, RANSAC robust estimator is implemented with a twofold purpose in order to check for possible outliers. Firstly, through Douglas-Peucker simplification, allowing that possible outliers do not take part during the process. Secondly, in the clustering of sections, determining the best three combinations of sections and profiles for extracting basic primitives.

The final step is a growing clustering of each partial primitive in order to obtain a global primitive. To do this, geometric characteristics of each primitive such as the diedric angle between planes, the angle between the axes of the cylinders, or the relationship between the radius of cylinders, as well as its neighbouring relations are checked. Moreover, each threshold of geometric characteristics can be modified by the user interactively.

3. PRIMITIVES FITTING

At a final level, the segmented range dataset is fitted to basic surfaces. Particularly, the results from segmentation give potential architectural elements, but it is required to fit these features to the real object accurately.

Particularly:

3D planes are extracted by an automatic fitting of planar primitives with points of the object.

3D lines are extracted as a result of planar surface intersections. The extraction of 3D lines involves two steps:

i) Intersection of neighbouring 3D planes to produce 3D lines of infinite extent.

ii) Verification of the infinite 3D lines. This step involves the computation of the distance between the bounded primitives and the produced 3D line.

Cylinders and cones are processed in the same way that planes, using the segmentation results to limit the workspace that is used in the fitting.

At last, an analytical and simplified parameterization of the basic extracted geometries is performed.

On the other hand, the visualization of a 3D model is often the only product of interest for the external world and remains the only possible contact with the model. Moreover, an interactive visualization of the object enables us to obtain impossible views and perspectives to support further analysis tasks. Therefore, a realistic and accurate visualization is often required. However, working with laser scanner dataset complexity increases considerably, especially if we consider the volume of information, so the modeling pipeline described before remains crucial to transform our laser polygonal models to VRML automatically.

The VRML (Virtual Reality Modeling Language) format was the standard chosen to provide an interactive visualization of the results guaranteeing flexibility and scalability in the visualization at the same time, so different 3D models can be incorporated and managed easily. In this way, an automatic transformation of the reconstructed 3D model into a topological structure (points, lines and surfaces) sorted hierarchically in a nodes network was performed, allowing three different levels of visualization: wireframe, shaded and textured. Materials defined by their colours and radiometric properties (opaqueness, transparency, diffusion, reflection and emission) and photographic textures, are mapped through a uniform and continuous renderization supported internally by VRML.

4. THE LSM3D SOFTWARE

Nowadays, laser scanner technology continues relying on a strong hardware and software dependence. In fact, some companies have invested heavily on digital implementations of laserscanning principles, and lead the market in order to obtain massive range data production. Consequently, prices remain high and the access to laser scanner equipment continues being limited only to those who can afford it.

Our aim tries to improve this ‘bottleneck’ through the development of free laser scanner software and tools. The basic idea is to develop laserscanning tools that can be used as didactical elements for Computer-assisted teaching and training on Internet, regular Classes, Summer Courses and Seminars, in order to ease the students’ assimilation of main laserscanning concepts.

In principle, the laserscanning tool LSM3D consists of two parts: Knowledge and Tasks. In the 'Knowledge' part, LSM3D describes the synergies between disciplines such as close-range photogrammetry, computer vision and computer graphics, as well as the methodology developed for laser scanner modeling. These contents are interlaced with hyperlinks to a glossary of technical terms and definitions, as well as supported with graphic illustrations. In the ‘Tasks’ part, LSM3D allows to carry out exercises and simulations (Figure 3). This interface allows to work in different levels, from students who use the program only with learning purposes to PhD students who develop new tools and even professionals who are interested in applying the software to an specific context.

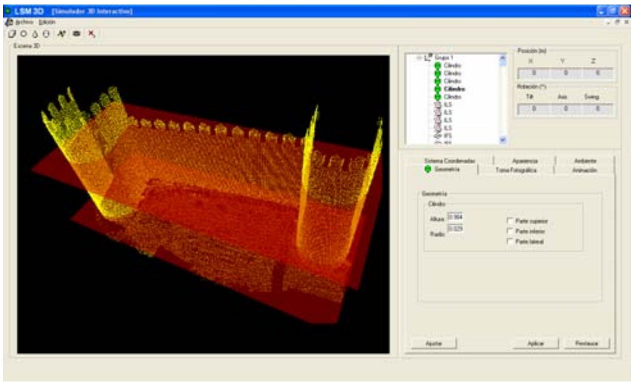
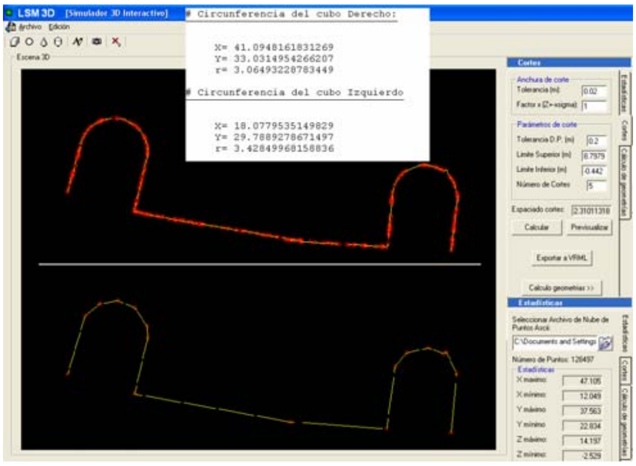


Figure 3. LSM3D: 'Tasks' interface.

Particularly, LSM3D allows:

- Importing and exporting point clouds and high resolution digital images;
- Projecting the texture of high resolution image onto the point cloud.
- Obtaining sections over the point cloud (Figure 4).
- Modeling simple structures through the extraction of basic primitives.
- Modeling complex structures through mesh triangulation algorithms and using the previous structures as geometric constraints.
- Gaining feedback between image re-projection and primitive extraction to improve the results.
- Exporting results to VRML language.



```
# Circunferencia del cubo Derecho:

   X= 41.0948161831269
   Y= 33.0314954266207
   r= 3.06493228783449

# Circunferencia del cubo Izquierdo

   X= 18.0779535149829
   Y= 29.7889278671497
   r= 3.42849968158836
```

Anchura de corte
Tolerancia (m): 0.02
Factor x (Z+-sigma): 1

Parámetros de corte
Tolerancia D.P. (m): 0.2
Límite Superior (m): 8.7979
Límite Inferior (m): -0.442
Número de Cortes: 5

Espaciado cortes: 2.31011318

Seleccionar Archivo de Nube de Puntos Ascii: C:\Documents and Settings

Número de Puntos: 128497

Estadísticas
X máximo: 47.105
X mínimo: 12.049
Y máximo: 37.563
Y mínimo: 22.834
Z máximo: 14.197
Z mínimo: -2.529

Figure 4. LSM3D: laserscanning segmentation.

As a result, LSM3D represents a clear contribution in the laserscanning context, destined to the synergic integration of different methodologies and tools. Therefore, teaching and research work can be presented as an interactive learning program. The 'knowledge' is presented by dynamic figures and hypertexts, while 'tasks or experiments' can be carried out with different free tools such as LSM3D.

5. EXPERIMENTAL RESULTS

In order to determine the accuracy, limitations and advantages of the 3D modeling approach proposed, a series of experiments are tested using our own developed tool.

5.1 The medieval wall of Avila

Problem and goal

The aim of this study is the automatic 3D modeling of the basic structures of the medieval wall of Avila. A time of flight laser scanner, Trimble GX200, is used to obtain laser scanner dataset. The main problems are focused on the own complexity and irregularity of an emblematic object like that.

Methodology and results

A first segmentation approach based on orthogonal sections with an equidistance of 1 meter and a tolerance of 200 millimeters for Douglas-Peucker is applied (Figure 5).

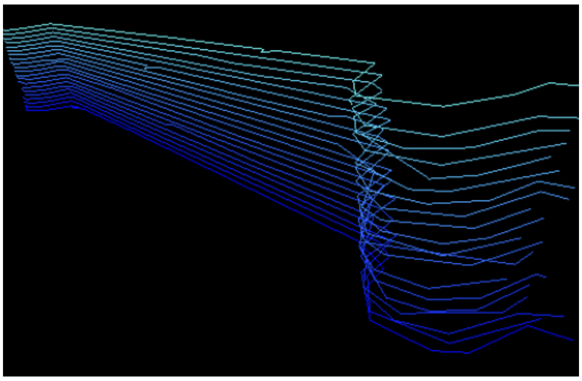


Figure 5. Laserscanning segmentation with orthogonal sections and Douglas-Peucker simplification before circle extraction

A second segmentation approach based on the clustering of sections allows us to extract partial primitives (Figure 6), which are transformed into global primitives following a growing surface strategy.

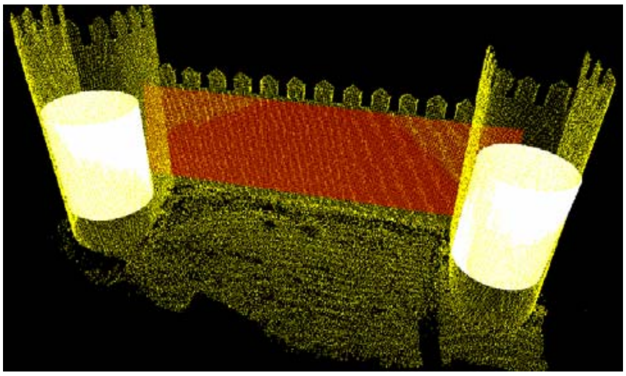


Figure 6. Partial extraction of primitives.

A maximum threshold of 3º corresponding to the diedric angle between planes has been used to clustering adjacent planes, preserving the basic geometric characteristic of each primitive. Regarding cylinders, a maximum threshold of 2º and 1 meter between cylinders axis have been considered to validate them.

Finally, a fitting of basic primitives is performed using object coordinates as reference. Particularly, 3D planes corresponding to the main wall and cylinders corresponding to towers are extracted by an automatic fitting of basic primitives with points of the object (Figure 7).

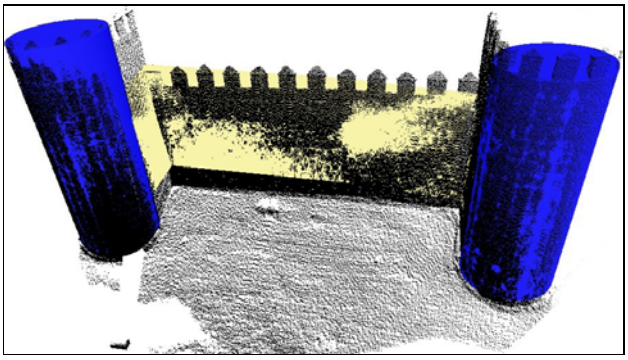


Figure 7. Automatic medieval wall 3D modeling.

The final fitting error for 3D planes and cylinders is around 50 millimetres. However, some problems remain in the battlements, due to their irregular shape and discontinuity in the transition with towers.

5.2 The romanesque church of San Pedro

Problem and goal. The workspace is focused on the two main façades of the church. The aim of this study is the automatic modeling of the basic structures of the romanesque church of San Pedro. A time of flight laser scanner, Trimble GX200, is used to obtain laser scanner dataset.

Methodology and results

A first segmentation approach based on orthogonal sections with an equidistance of 1 meter and a tolerance of 100 millimetres for Douglas-Peucker is applied (Figure 8).

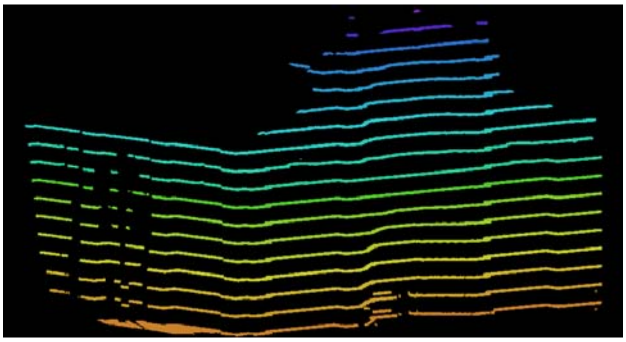


Figure 8. Laserscanning segmentation with orthogonal sections and Douglas-Peucker simplification.

A maximum threshold of 2º corresponding to the diedric angle between planes has been used to clustering adjacent planes, preserving the basic geometric characteristic of each primitive.

Finally, a fitting of basic primitives is performed using object coordinates as reference. Particularly, 3D planes corresponding to the main facades are extracted by an automatic fitting of basic primitives with points of the object (Figure 9).

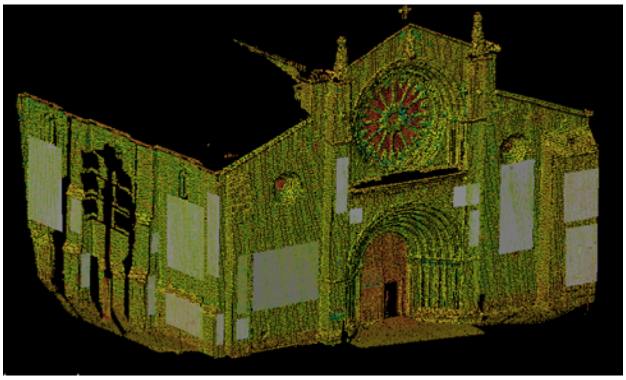


Figure 9. Automatic romanesque church 3D modeling.

The final fitting error for 3D planes is around 30 millimetres.

6. CONCLUSIONS AND FUTURE PERSPECTIVES

The presented paper has investigated and developed a range segmentation and 3D feature modeling from laser scanner dataset. We proved the applicability of these algorithms in architectural scenes. A consistent and reliable full process pipeline has been developed and presented. It was demonstrated with different practical examples tested through our own software, LSM3D.

We feel that we have attacked one of the most difficult problems in laserscanning. Regarding the most relevant aspects of the proposed approach, we could remark on:

- Automation in the modeling of basic primitives.
- Creation of geometrically correct solid models.
- Simplification of laser scanner models through VRML transformation.
- More reliability in segmentation step through the incorporation of RANSAC robust estimator.
- Original approach which provide a new point of view to solve the problem of laserscanning 3D modeling.

Due to the scope of the system, there are still a number of open technical issues that need to be addressed:

- A number of thresholds have to be tested by the user before obtaining good results.
- The object must be linear in order to apply orthogonal sections.

As for the future perspectives, we believe that this novel laser scanner tool could be improved towards the automatic, accurate and reliable construction of CAD models of urban structures from laser scanner dataset.

Acknowledgements

First of all, we would like to thank to the students Luis García, Fernando Castro and Esteban Ruiz for their support during this project. Furthermore, we are especially grateful with several local institutions, especially ‘Ayuntamiento de Ávila’ and ‘Institución Gran Duque de Alba’ for providing all technical and human assistance as well as for the partial economical support of the research work.

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