SEGMENTATION AND FILTERING OF LASER SCANNER DATA FOR CULTURAL HERITAGE

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ABSTRACT

The use of terrestrial laser scanners is increasing in the field of cultural heritage recording due to their high data acquisition rate, relatively high accuracy and high spatial data density. The main problem related to this new technique is the treatment of the collected data.
This paper describes an automatic approach in laser scanning point clouds for architectural modelling. The aim of the algorithm is to obtain real surfaces of the scanned object and reduce the data volume. For that purpose, our algorithm extracts automatically all the planar surfaces of the monument, including the vertical ones, and filters out non-relevant points. The surfaces consist of groups of points. Obtaining its bounds we can eliminate all the original points that form the surfaces leading to a better representation of the object and the reduction of the data volume. The algorithm bounds the surfaces regardless the planar orientation and shapes. This is performed by three different techniques according to the shape of the surface: intersection of planar surfaces, the Hough transform and a new method based on the projection of the surfaces into accumulator tables.
The algorithm has been tested in a Baroque monument placed in the city centre of Valencia. For that purpose, the measurement included the four outer façades and was carried out from three stations, lasting three hours. The results of the test are presented in this paper.

1. INTRODUCTION

The use of terrestrial laser scanners is increasing in the field of cultural heritage. Because of their high data acquisition rate, relatively high accuracy and high spatial data density, laser scanners are being used for several applications like documentation of historic monuments or virtual visualizations.
Nevertheless, the laser scanner data has some problems. The first problem is the huge amount of data. The point cloud of a monument easily contains more than one million of measured points. Such an amount of data causes problems on CAD software. In addition, some of the measured points are erroneous. Errors origin is multiple: systematic instrumental errors; and partial reflection of the laser spot at edges. Additionally, the collection of massive point clouds requires further filtering for non-relevant features, e.g. moving objects such as people or birds. Besides, the absence of semantic information within the laser scanning point clouds makes difficult the object interpretation.
Some authors have combined laser scanner data and photogrammetry in cultural heritage recording (Heinz, 2002; Briese et al., 2003; Boehler et al., 2003; Ioannidis, et al., 2003; Drap et al, 2003). Others have used different techniques to treat laser data only. Some of the techniques are focus on the object segmentation of architectural facades (Bornaz et al, 2003; Biosca, 2005).
In order to solve the above mentioned problems, we present an approach to obtain real surfaces from a scanned object, on the one hand, and a reduction of the data volume, on the other. The algorithm is based on clustering techniques and manages to extract planar surfaces, including vertical ones, and filters out non-relevant points. Once we have the planar surfaces of the monument, several methods are proposed to extract feature bounds.
This algorithm has been tested in a Baroque monument placed in the city centre of Valencia, the *Marques de Dos Aguas* palace.
The paper will be organized as follows. Section 2 gives a description of the study site. Section 3 presents the acquisition of laser scanner data in the study site. Section 4 covers the algorithm developed. Section 5 provides the results of the study and a discussion. Finally, section 6 summarizes the main achievements reached in this work.

2. STUDY SITE

The *Marques de Dos Aguas* palace is a Baroque building placed in the Valencia city centre. The initial house was built in the 15^{th} century by one of the most prestigious families of that period. The palace is the result of a radical restyle performed in the 1740s.
The current building is composed by two levels more than the ground floor and is 20 metres high. It has three towers in the corners that arise 28 metres high.
The main door was adorned with a scene made of alabaster where two big human figures stand out at the sides representing the two main rivers of the region.
The façade was decorated with frescoes but in 1867 were replaced by grey and pink stuccos imitating marble stones. At the same time balconies of French style were added.
Nowadays, the palace is property of the Spanish authority and the National Ceramic Museum is located therein.

3. LASER SCANNING SURVEY

Laser scanning survey was made with a MENSI GS100 laser scanner. It is a hybrid time-of-flight laser scanner with a maximum range of 100 metres. The survey was carried out from three different stations and took up three hours. Figure 1 shows the position and field of view of each station.

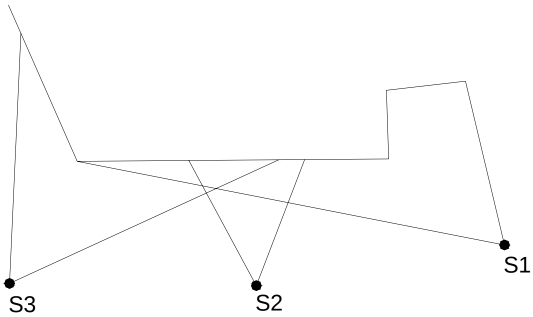


Fig. 1. Position and field of view of the three stations.

Fig. 2. 3D Point cloud after registration.

More than 1.7 million points were measured on the outer facades at different resolutions. The irregular point distribution is due to the difference in distance of each measured point to the station in a single scan. Moreover, the scan of the central station (S2) was performed with higher resolution. Point density in the scan 2 is 50 points per dm^2 approximately, while the mean density in the scans 1 and 3 is 15 per dm^2. Figure 3 shows the points measured on the same zone from stations 1 and 3 and station 2.

4. METHODOLOGY

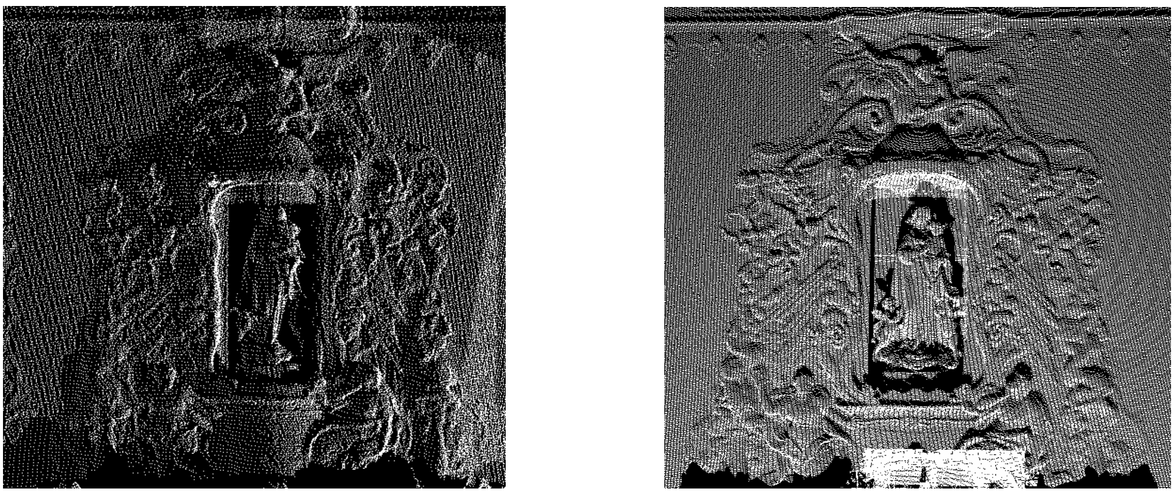
The methodology is performed in two main steps: firstly, segmentation of the data set; secondly, extraction of the surfaces bounds. The aim of the segmentation is to group the points so that each group corresponds to a planar surface of the scanned object. Additionally, we will obtain a representation of the surfaces with the extraction of the bounds.
In order to manage a successful point cloud segmentation, we need more information than just the three point coordinates. Considering the neighbourhood of each point, we can obtain more features of them and create a new space with higher dimensions. Thus, each point is characterized by both its three positional coordinates and its neighbourhood attributes.

4.1 Feature attributes

In order to obtain unique surfaces we need to group points with similar features. For each measured point more than three attributes are added as suggested by Filin (2004). The position of each point in this feature space is determined by a unique feature vector. Each vector has 6 parameters $\{x_i, y_i, z_i, h_i, \theta_i, \phi_i\}$. The angles of the tangent plane let us separate the points of the planar category in several planes of different orientation, meanwhile h_i parameter is used in the segmentation of the original data set in different categories. Each category consists on the group of points that belong to the same kind of surface.

4.2 Segmentation

The segmentation process of the data set is performed in three steps. In the first and second steps, we use two clustering algorithm methods. In the last step, we implement a region growing algorithm.
In a first step we divide the original data set in several categories according to the nature of the surfaces. We can define a maximum of four different categories: planar surfaces, smooth surfaces, undulated surfaces and very undulated surfaces. In the second step, we focus our study in the points belonging to planar surfaces. The goal is to separate the points on planar surfaces in different classes. Each class is the group of planes with the same slopes. In other words, each class represents a group of parallel planes that only differ in the distance to the origin. In the third step, the points of a class are separated in several parallel planes.



(a) (b)

Fig. 3. (a) Detail of merged point clouds from stations 1 and 3. (b) Detail of the point cloud acquired from station 2.

As it is mentioned above, the parameter that we use to perform the first step is h_i. The clustering method is the fuzzy C-means algorithm (FCM). It is based in the fuzzy theory and is able to divide the original data set in the specified number of classes so that each point belongs to a unique class. Each of the resulting classes has a centre and satisfies that the sum of each point to the centre of his class is minimum and that each centre is maximally separated of the rest.

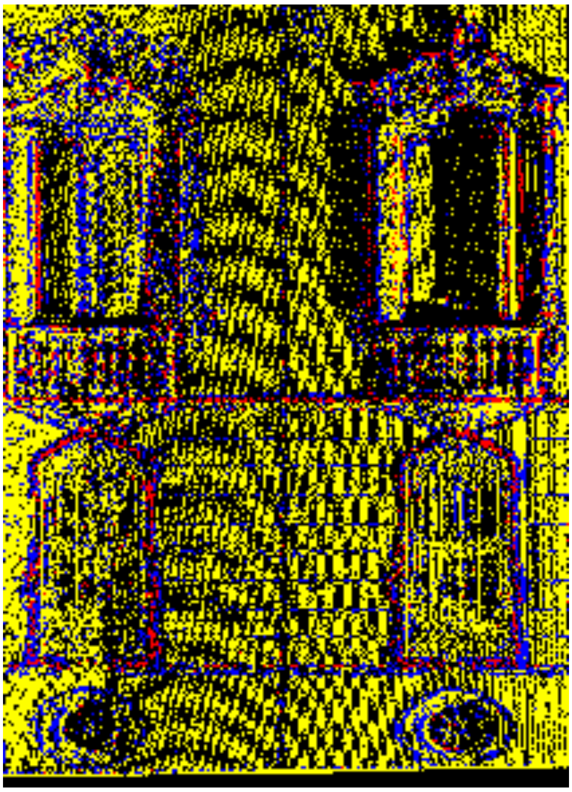


Fig. 4. Example of surface categories: in yellow, points belonging to planar surfaces; in blue, points of smooth surfaces; in red, points of undulated surfaces.

Once we have the group of points belonging to a planar surface, we want to obtain the different planes existing in our data. With the angles of the plane we can separate non parallel planes. In this case we make use of an unsupervised classification method, a mode-seeking method like the possibilistic C-Means (PCM). This algorithm is a modification of the FCM based in the possibilistic theory and is able to find the data structure. It means that it is not necessary to specify the number of classes existing in the data. It is essential because we are not able to know the number of different planes orientations in a data set. As a result of this algorithm we obtain the points separated in groups that represent planes with a determined orientation, but two points in parallel planes are still in the same group. It has not been used the position of the point to make the segmentation of groups that do not have spatial connectivity. To separate points of different parallel planes and obtain groups of points that represent real regions of the object we follow a region growing algorithm.

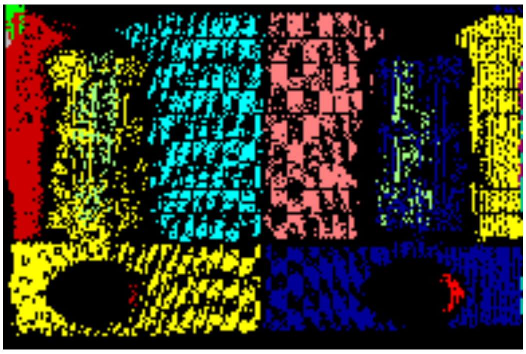


Fig. 5. Example of final planes. Each plane is represented in a different colour.

4.3 Surface fitting

Once we have the points separated in different planes, we fit each group of points to the equation of a plane. With planar fitting we obtain the equation that defines the plane and the accuracy of the adjustment. Points with a large distance to the plane are eliminated. If the accuracy of the adjustment is bigger than an established threshold the whole group is eliminated.
At this point of the process we have several groups of points as a result of the segmentation process. Each group corresponds to a region of the object, although it is possible to have over segmentation. It means that a plane of the object does not correspond to a unique group of points, but also to several groups representing a unique planar feature. Thus, we need to join those groups that correspond to different parts of the same surface to obtain unique surfaces. Furthermore, the accuracy of a plane resulting from the union of another two has to be smaller than a threshold.

4.4 Bound extraction

The software we developed can follow three different methods for bound extraction. The first two methods require that the surfaces were quadrilateral. Thus extracting the vertex of the surfaces we will be able to define the bounds. The first method consists in obtaining the points as a result of the intersections of three planes. With this method we can obtain some vertex of the planes. In order to obtain other vertexes where planes do not intersect with more planes we use the Hough transform. Thus we obtain the straight lines of the bounds and we get the vertex intersecting pairs of lines.

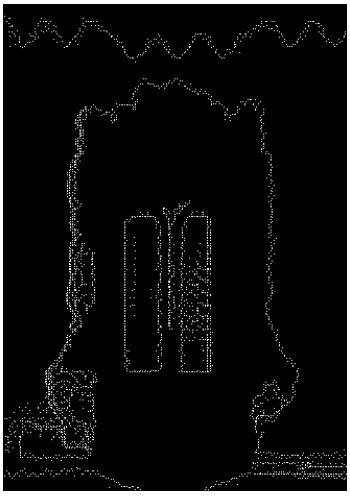


Fig. 6. Detail of extracted bounds.

If the surfaces are not quadrilateral, these methods are not able to extract the bounds. Last method can extract bounds regardless of the shape of the surfaces even if the surfaces have internal holes. The algorithm defines the bounds with a polyline. This method is based on the projection of the surfaces into accumulator tables.

5. RESULTS AND DISCUSSION

At first, scan 2 was treated separately from scans 1 and 3 because of their different point density. Once the segmentation was done for each set of scans the resulting planes were joined into a single set of planes. At the end, we obtained a number o 556 planes represented by 645.046 points. We can see in figure 7 a frontal view of the palace with each plane represented in a different colour.

Because of the shape of the planes their bounds were extracted by the third described method. Two different resolutions were used, 25 and 50 mm. Figures 8 and 9 show the results of this method.

Fig. 7. View of the result of the segmentation process. Each plane is represented in a different colour.

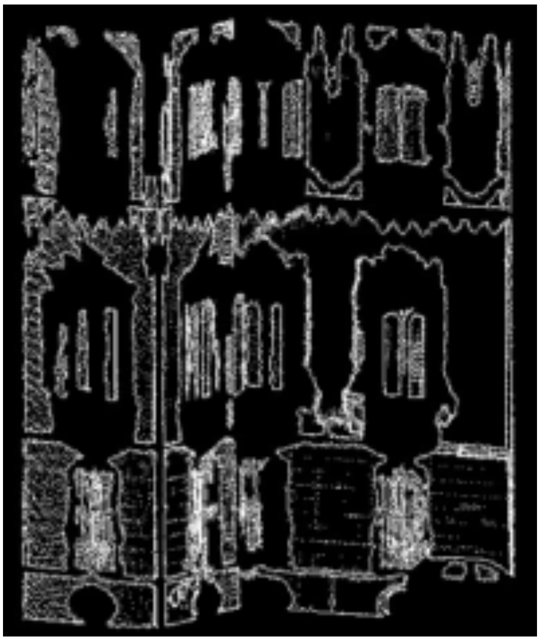


Fig. 8. View of bounds extracted with a resolution of 25 mm.

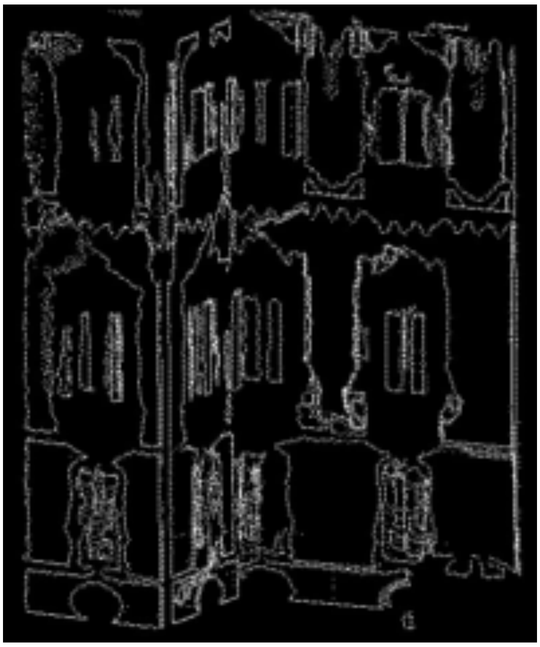


Fig. 9. View of bounds extracted with a resolution of 50 mm.

With the aim of testing the methods based on intersection of planes and Hough transform for bound extraction, we have applied the algorithm to the right scan with a threshold of 50 mm in planar fitting. Thus, we obtain only four planes with quadrangular shape, except the ground plane. These planes are not real planes due the high threshold in planar fitting. They correspond to several real planes and other smooth surfaces. The bound lines generated with their correspondent virtual planes can be seen in figure 10.

In figure 7 it can be seen that not all the parts of the planar surfaces are obtained completely. It mostly occurs at the top, where there is abundant decoration and poor point density.

Analyzing figure 8 we see two different phenomena. On one hand we have zones with good bounds. These zones correspond to the surfaces nearest to the station. On the other hand there are zones with excessive amount of vertex. It occurs because the resolution of scan data is smaller than the resolution of the accumulator table.

This problem disappears in figure 9. This is due to the chosen resolution of the accumulator table. In this case the resolution is 50 mm and is not common that the distance between two near points was greater than 50 mm. A disadvantage of this case is the loosing in spatial accuracy of the bounds.

Analyzing the bounds extracted by planar intersection and Hough transform we can see that the methods can obtain the surface bounds although they were partially occulted. This is the right down corner of the yellow plane. At the moment of the survey there was a car parked between the station and the façade and this part of the building was not surveyed. Other thin objects like street lamps and plants are removed.

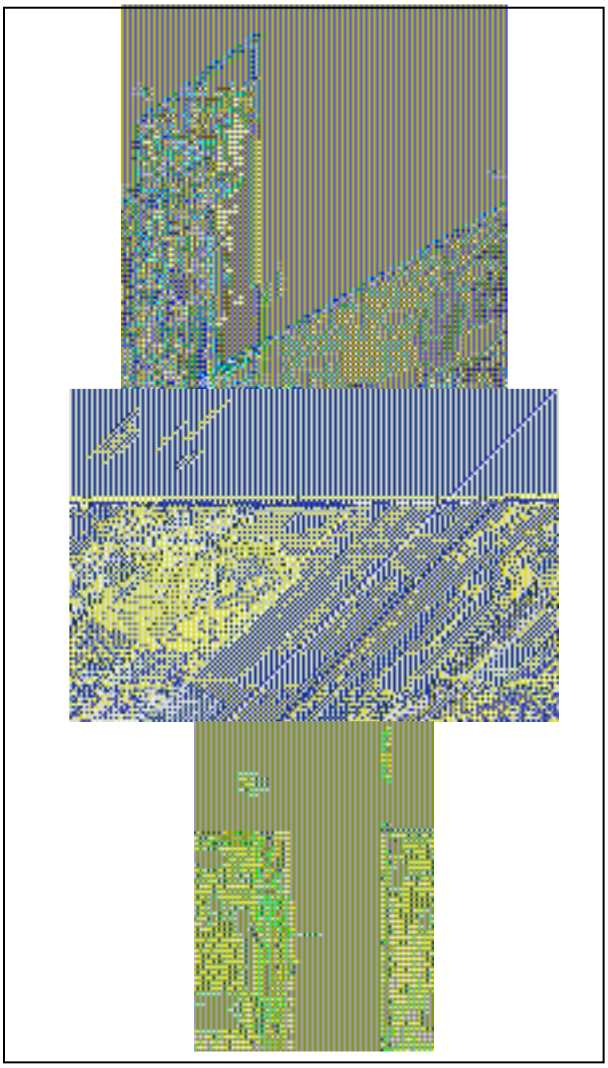


Fig. 10. Three views of the bounds extracted by planar intersection and Hough transform.

6. CONCLUSIONS

This approach for planar segmentation is valid for monuments with planar surfaces. It drastically reduces the huge amount of laser data and adds information about the nature of the data. Thus, this data can be treated easily with most of the existing CAD software in order to make 3D modelling or other applications.
Some precautions in data acquisition should be taken for future works. First of all, the location of the stations should ensure both the complete covering of the object and the most possible homogeneity along each single scan. Another precaution is to perform the scan with appropriate resolution thinking in the resolution of the bound extracted at the end.

REFERENCES

Biosca Taronger, J.M., 2005. Filtrado y segmentación de datos obtenidos mediante láser escáner 3D. *Universidad Politécnica de Valencia*, Valencia.

Boehler, W., Bordas Vicent, M., Kanke, K., Marbs, A., 2003. Documentation of german emperor Maximilian I's tomb. *The ISPRS International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. XXXIV-5/C15, pp. 474-479.*

Bornaz, L., Rinaudo, F., Roggero, M., 2003. Object segmentation in cultural heritage. *The ISPRS International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. XXXIV-5/C15, pp. 490-495.*

Briese, Ch., Pfeifer, N., Haring, A., 2003. Laserscanning and photogrammetry for the modelling of the statue Marc Anton. *The ISPRS International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. XXXIV-5/C15, pp. 528-533.*

Conselleria de Cultura, Educació i Ciencia de la Generalitat Valenciana, 1983. Catàleg de monuments o conjunts de la Comunitat Valenciana (II). Valencia, pp 711-721

Drap, P., Sgrenzaroli, M., Canciani, M., Cannata, G., Seienturier, J., 2003. Laser scanning and close range photogrammetry: towards a single measuring tool dedicated to architecture and archaeology. *The ISPRS International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. XXXIV-5/C15, pp. 629-634.*

Filin, S., 2004. Surface classification from airborne laser scanning data. *Computer and Geosciences*, 30, pp. 1033-1041.

Heinz, G., 2002. Pharaoh Pepi I.: documentation of the oldest known life-size metal sculpture using laser scanning and photogrammetry. *Proc. of the CIPA WG6 Int. Workshop on scanning for cultural heritage recording.*

Kaymak, U., Setnes, M., 2002. Fuzzy clustering with volume prototypes and adaptive cluster merging. *IEEE Transaction on Fuzzy Systems*, 10(6), pp. 705–712.

Krishnapuram, R., Keller, J.M., 1993. A Possibilistic Approach to Clustering. *IEEE Transactions on Fuzzy Systems*, 1(2), pp. 98-110.

Krishnapuram, R., Keller, J.M., 1996. The Possibilistic C-Means algorithm: insights and recommendations. *IEEE Transactions on Fuzzy Systems*, 4(3), pp. 385-393.

Mensi, 2005. GS100 3D laser scanner. www.mensi.com/Website2002/index2.html (accessed 25th May 2005.

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