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Optimal modelling of buildings through simultaneous automatic simplifications of point clouds obtained with a laser scanner

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ABSTRACT

In recent years, the laser scanner has become the most used tool for modelling buildings in pure documentation and structural studies. Laser scanning provides large numbers of points in a minimum amount of time with great precision. The point clouds generated and the subsequent mosaics (data fusion of different clouds) contain millions of points with a heterogeneous density that define the 3D geometry of the buildings. Often, the number of points results in excessive information without offering a better definition. As a result, it is necessary to analyse which points can be eliminated and which ones cannot, based on precision criteria, to obtain a precise geometry with the smallest possible number of points for each part of the building. The algorithm developed in this work reduces the point clouds (in mosaics made up of clouds with over 10 million points) with precision criteria by as much as 99% while still accurately resolving the geometry of the object. The developed process is automatic such that different models with different resolutions can be obtained simultaneously. As a result, we obtain single clouds with homogenous distributions and densities throughout the model of the building (based on multiple overlapping clouds), with a computational cost of only a few seconds per cloud. The final result is a complete model of the entire building with the optimal resolution for each element of the structure.

1. Introduction

The evolution of laser scanners has made it possible to obtain point clouds with a spherical distribution of the entire measurement environment in under 2 min, achieving point clouds with over 10,000,000 points. The density of the points obtained is excellent, with densities exceeding 1 point/cm^2. Although the recording time is sometimes high (recording a complex object requires multiple scans from different positions), it is preferable to conduct as dense a measurement as possible and then reduce it, if necessary.

The scope of application of laser scanning extends across in a variety of fields of engineering and architecture [5–9]. The suitability of laser scanners for the purposes of precise measurement has been studied in depth [1–4]. For example, one study focused on the of structural deformity measurements using this equipment [10–13]. The complementary use of photogrammetric techniques [14,15] is also useful in many situations.

There are a number of recording procedures, depending on the type of object, which can be achieved in a single scan or in multiple scans. The latter case is more frequently used in order to avoid leaving hidden zones. This procedure generates different separate point clouds that overlap to generate a complete model; however, duplicate recordings for many zones of the object are formed. Regardless of the number of scans, the degree of accuracy necessary to obtain the subsequent sections is determinant, so the density of the data is a critical factor [16].

The recommended mesh size for measurements of this type is 0.5–2 cm. The continuing advancement of laser scanners makes it possible to record this density of points without any problem. However, for modelling, triangulation and texture generation, the number of points affects the number of triangles that will be generated, so while the scanner is capable of resolving very small features, the resultant mesh is often too fine for use in processing, e.g., building modelling. If the cloud has areas with densities greater than 1 point/cm^2, it will need to be simplified.

This need for simplifying the scanned mesh is one of the largest challenges in the overall process of scanning, processing and modelling. There are interesting cloud simplification methods that require an initial triangulation of the clouds, thus eliminating points located in the flat zones of the triangles [17], analysing the curvature of the environment at those points [18], studying

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the effect of eliminating a point in the overall mesh through the distance between the point eliminated and the resulting mesh [19] or conducting a resampling of the surface based on the distance to the nearest points [20]. There are also frequent studies that divide the cloud into clusters [21,22], analysing the distance between the points as a density classification [23] or adding edge detection constraints [24]. Although most of the published works follow these approaches, there are alternatives based on studying the normal in each point to analyse its importance and determine its elimination [25] or studies based on quadratic matrices with analysis of auto-values and auto-vectors [26]. However, they are not valid when the dimensions of the cloud result in immense volumes (3D clouds made up of millions of points and several gigabytes of information) or when there are several clouds simultaneously. Along this line, there are procedures that make it possible to process the information derived from the clouds but do not allow either the analysis or reduction of the clouds or subsequent modelling (except in cases in which the geometries are defined by known geometries, such as spheres and cylinders) [27,28].

In our work, we do not begin with an initial surface or with single clouds made up of manageable quantities of points. Additionally, it is not generally possible to record a building in a single scan, so the need for different scans will cause some zones to overlap, which, aside from an excess of points in the overlap zone, also necessitates identifying which overlapping scan provided higher quality feature resolution. Our work distinguishes the point density and evaluates the precision of the points eliminated, which will be determined based on the distance from the scanner and on the inclination of the surface with respect to the scanner—the greater the inclination or distance is, the lower the precision that is obtained. Thus, in the zone in which different scans overlap, it is necessary to eliminate certain points based on these precision factors.

This work shows a procedure that makes it possible to process and simplify millions of points in a matter of seconds. First, the point clouds from the different stations are simplified, generating new homogenous clouds, and then the data fusion of these clouds is created, taking into consideration the precision of the points in the overlapping zones. The final result is a simplified cloud of points that are homogenous in density and distribution, which define the geometry of the building.

2. Point cloud simplification algorithm

The laser scanner provides enormous quantities of points based on a uniform measurement strategy that, by contrast, provides clouds with an irregular density and distribution. The measurement strategy of these instruments responds to a spherical methodology based on constant increases of horizontal and vertical angles. While the increases are constant, it is not implied that the distribution of the points and their density are constant, as that depends on the position of the instrument with respect to the object (Fig. 1).

The density obtained is influenced by the distance and the inclination of the surface with respect to the measurement direction. As shown in Fig. 1, a constant increase in angle α provides a greater density of points in the areas nearest the instrument ("object 1" will be defined by a quantity of points much greater than "object 2"), as well as in the direction closest to normal to the object ("object 3" shows an increase between points due to inclination). The position in which there is a greater density of points is always in the direction of the rotation axis of the laser scanner with a null vertical angle (which is not the rotation axis of the mirror), which is where all of the scan profiles converge. In addition, due to the spherical measurement distribution, the zenith direction creates groups of all of the profiles made, which results in an unnecessarily high density.

Given that a measurement job is normally made up of multiple stations, the point density will be much greater in the zones in which the different scans overlap. In addition to affecting the point density in different zones of the object, different scanning positions impact the quality of the points measured, as the points belonging to two different scans will have different degrees of precision. This means that the final point cloud used to obtain the 3D model of the object is generated with data of varying precision that stem from both within the scan of a single zone and the combination of data from scans of different zones.

Following a measurement job, we obtain an enormous number of points with distribution, density and precision that are not uniform. Accordingly, it becomes necessary to design a procedure that makes it possible to obtain uniform point clouds, i.e., they must be simplified. To do so, the best option would be to leave the points based on a matrix distribution with a separation as similar as possible between them (uniform density) and with the maximum precision possible (choosing the points that have been measured with the greatest precision within overlapping zones).

The procedure is carried out in three stages: sorting the point cloud, simplifying the cloud and creating a mosaic of different clouds (with simplification in the overlaps).

2.1. Sorting the point cloud

Each point cloud is located within a rectangular prism whose maximum and minimum coordinates correspond to real extreme coordinate points in the cloud generated by the scan. This prism is divided into cubic cells with a side length of d defining a 3D matrix whose indexes are (1)

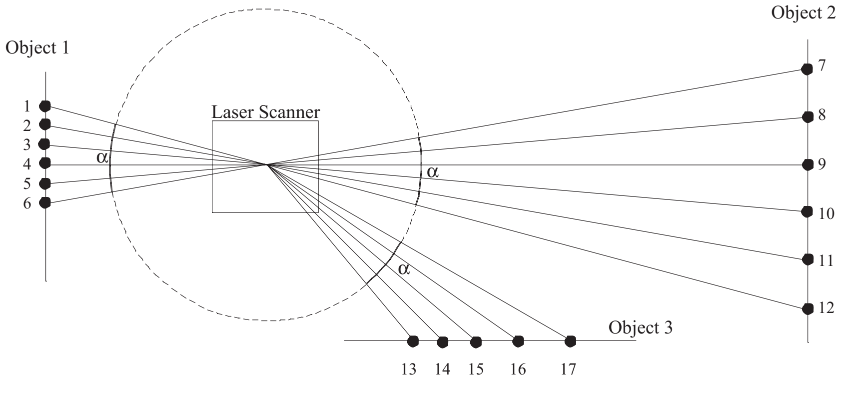

Fig. 1. Scanning three objects at different distances/inclinations from the common laser scanner station.