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Local surface sampling step estimation for extracting boundaries of planar point clouds

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ABSTRACT

This paper presents a new approach to estimate the surface sampling step of planar point clouds acquired by Terrestrial Laser Scanner (TLS) which is varying with the distance to the surface and the angular positions. The local surface sampling step is obtained by doing a first order Taylor expansion of planar point coordinates. Then, it is shown how to use it in Delaunay-based boundary point extraction. The resulting approach, which is implemented in the ModiBuilding software, is applied to two facade point clouds of a building. The first is acquired with a single station and the second with two stations. In both cases, the proposed approach performs very accurately and appears to be robust to the variations of the point cloud density.

1. Introduction

This study originates from the problem of reconstructing 3D-CAD model of buildings from point clouds provided by Terrestrial Laser Scanner (TLS) for renovation purpose. Such a 3D-CAD model is intended at being used by external wall insulation companies to automatize the design of the insulation modules. More generally, accurate 3D-CAD of building is required in the development for building information modeling (BIM) for existing buildings (Mill et al., 2013; Volk et al., 2014). In this paper we restrict our attention to Terrestrial Laser Scanner (TLS) which, due to its high level of accuracy and detail, is generally used in applications such as building modeling, cultural heritage recording and deformation analysis (Brenner, 2005; Becker and Haala, 2007; Rabbani et al., 2007; Pu and Vosselman, 2009; Mill et al., 2013) where highly resolved point clouds of large dimension objects are required. Because of recent advances in hardware and software, coupling data capturing and building surveying techniques with terrestrial or mobile or airborne Laser Scanner is increasingly being used (Wang et al., 2015; Yang et al., 2016).

The accuracy of laser scanning has been studied in Lichti and Jamtsho (2006). Its ability to distinguish fine details is depending on the resolution of its components. Firstly, the range resolution corresponds to the ability of the measurement system to distinguish objects on the same line of sight; it basically depends on the laser pulse duration. Secondly, the angular resolution depends on both the laser beam width and distance to the object since the beam footprint increases with the distance. In practice, TLS manufacturers are providing the angular resolution for a given distance (generally 50 or 100 m) which corresponds to a minimum angular sampling step. In fact, the angular sampling step implicitly supposes that the object surface is orthogonal to the laser beam at a distance lower than the nominal distance for which the angular resolution is defined (Schulz, 2007). A detailed analysis of the influence of the beam width on the scanner resolution (Lichti and Jamtsho, 2006) reveals that the angular sampling step does not reflect the actual resolution of the TLS and that decreasing it does not necessarily result in an increased resolution. The authors, then, introduce the so-called Effective Instantaneous Field Of View (EIFOV) which better reflects the actual TLS resolution. Based on the EIFOV, Pesci et al. (2011) proposes a method to determine the optimal angular sampling steps considering the distance and the size of the detail. However, this approach does not take into account the surface orientation with respect to the TLS: only planar surface orthogonal to the TLS is considered.

In this work, we are primarily concerned with the modeling of the surface sampling step which is defined as the spatial sampling step at the surface of the object to be scanned. Having a constant surface sampling step imposes that the object is always orthogonal to the laser beam which is, most of the time, impossible. In general, the angular sampling step is kept constant for the whole scanning

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which results in a surface scanning sampling steps varying with the distance and the orientation of the object. To handle this problem, an option is proposed on some TLS allowing the user to define highly resolved regions, that is regions where the angular sampling step is low. Here, it is proposed to derive approximate expressions for the surface sampling step of planar point clouds and to adapt the point cloud processing accordingly.

The performances of algorithms for point cloud processing depend highly on the point cloud density. This was already mentioned by Stamos and Allen (2002) for point cloud segmentation using a region growing approach; their method consists in computing the normal vector for each point and then to merge the points whose normal vectors are similar and whose distance to seed surfaces is lower than a threshold. It is mentioned that using a unique global threshold may lead either to over segmentation in regions with low point cloud density or under segmentation in regions with a high point cloud density.

Another example of the influence of the point cloud density can be found in feature and boundary point extraction methods. A number of approaches are trying to determine if a point is belonging to a boundary or surface features by examining the evolution of geometrical features calculated over a neighborhood surrounding the considered point. For example, Pauly et al. (2003) uses the evolution of the variance evaluated on successive neighborhoods whose sizes are varying, while (Belton and Lichti, 2006) considers the distance of the point to the center of the ellipsoid corresponding to a given neighborhood. In Tong et al. (2004) a tensor voting approach is proposed; it basically consists in evaluating the normal directions of points in the neighborhood of a given point. In Cao et al. (2012), the approach of Tong et al. (2004) is extended by considering the evolution of the normal directions over successive neighborhoods. In Pu and Vosselman (2009) and Boulaassal (2010), Delaunay-based boundary point extraction methods are proposed: the boundary point extraction of planar point cloud is performed by comparing the length of triangle edges, as provided by Delaunay triangulation, to a threshold: the vertices of the longest edges correspond to boundary points. Another approach relies on the notion of α-shape (Edelsbrunner et al., 1983): it consists in comparing the triangle circumcircle radius to a threshold. In all these Delaunay-based approaches, assuming a uniform point cloud density results in a global threshold. However, this may lead to wrong boundary point extraction as the surface sampling step is varying with the distance to the surface and the angular positions.

In fact, most of the point cloud processing algorithms rely on the notion of neighborhood defined as the number of points surrounding a given point. It appears to be dependent on the point cloud density which is directly connected to the surface sampling step: the spatial extent of the neighborhood increases as the point cloud density decreases. As a consequence, determining features and boundary points is strongly depending on the point density. In high density regions, it is possible to detect fine boundaries while in low density regions only coarse boundaries can be detected. In this work, we derive the local surface sampling step of a planar point cloud as a function of the distance to the TLS and orientation of the plane and boundary point extraction methods are adapted accordingly.

The paper is organized as follows: in Section 2, Delaunay-based boundary point extraction methods are presented. Then, in Section 3, the local surface sampling step corresponding to a planar point cloud is derived. We discuss how it can be used to approximate the point cloud density and how to modify Delaunay-based boundary point extraction methods of Section 2. In Section 4, the proposed approach is then evaluated on real data corresponding to a building point cloud. The proposed solution is part of the ModiBuilding software allowing the reconstruction of 3D-CAD models of buildings from TLS point clouds.

2. Delaunay-based boundary point extraction

Boundary point extraction is a problem arising in a number of applications. A specific example which has motivated this work is the reconstruction of 3D-CAD building model from a TLS point cloud. This is generally achieved in two main phases. Firstly, the point cloud is segmented into co-planar point sets representing the building facades. The features of the facade (facade contours, windows, doors, facade irregularities) are then obtained by first extracting the boundary points of each facade point set and the modeling accuracy of these features is clearly depending on the boundary point algorithm accuracy. In this work, we restrict our attention to Delaunay-based boundary point extraction method which proved to be effective and which does not require to match the point cloud to predefined geometrical features. It is widely used in 3D-surface meshing and for 2D and 3D boundary point extraction. In this section, two Delaunay-based algorithms for boundary point extraction are presented: Delaunay triangle edge length (Section 2.1) and α-shape (Section 2.2). We also discuss in Section 2.3 how the point cloud density is influencing the results provided by these methods.

2.1. Delaunay triangle edge lengths

The principle of this method is based on a property of the Delaunay triangle edges: boundary points correspond to the vertices of edges having the largest lengths. As illustrated in Fig. 1, in the regular rectangular surface sampling case, the maximum length of non-boundary points corresponds to the hypotenuses of the triangles. Each edge whose length is greater than this distance has vertices (black dots) belonging to a boundary.

2.2. α-shapes

The α-shape is a generalization of the convex hull of a point set (Edelsbrunner et al., 1983). It is composed of a set of α-exposed segments. According to Edelsbrunner and Mücke (1994), a segment is said to be α-exposed if there exists an empty circle of radius α that circumcircles it. The notion of α-shape can be extended to higher dimensional problems by considering k-simplexes instead of segments and α-balls instead of circles. Let α_{th} be a user defined threshold. The α-shape algorithm for boundary point extraction consists in removing the Delaunay triangles which have a circumcircle radius larger than α_{th}. This results in a 2-D simplicial complex which, by definition, is composed of vertices, edges and triangles (free and attached). Fig. 2 shows the set of Delaunay triangles, the simplicial complex of the point set where two different subsets can be distinguished if α is properly

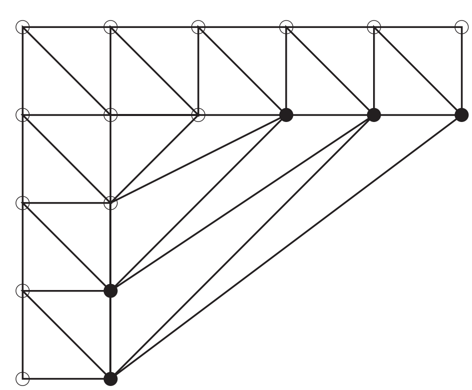

Fig. 1. Illustration of a Delaunay triangulation for boundary point extraction in the regular rectangular surface sampling case (boundary points: •, non-boundary points: ∘).