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Towards an expeditious as-is surface reconstruction

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ABSTRACT

Conservation and rehabilitation of structures such as urban buildings and heritage requires a growing effort on the establishment of sufficiently comprehensive documentation concerning the time evolution of these structures' characteristics and health condition. These documentation archives and databases should be much more than just a collection of structure's design plans, and desirably they should contain information about the as-built and as-is states of a certain structure. Due to the technological evolution of data acquisition systems, 3D laser scanning points' clouds became an important data source that enables the subsequent representation of 3D surface's geometries, and thus the constitution of data repositories. However, it is known that the volume of data obtained, can be enormous and the computation time to process it, a heavy task. The present work proposes an expeditious, continuous processing methodology that aims in a first step the generation of a points' structured grid and its associated triangle structured mesh by defining an injective function from a virtual surface onto the surface's cloud points. The additional possibility of selecting the virtual grid dimension to be used, enable representations with different levels of detail. In a second step, the resulting structured grids are used to reconstruct the corresponding surfaces by considering compactly-supported radial basis functions. The main contribution of this work is thus related to the proposal of an expeditious integrated processing methodology of points' clouds. A set of case studies are presented to illustrate the performance of the present integrated methodology.

1. Introduction

Among other types of health monitoring strategies, the use of image-based or 3D laser scanning techniques may be effective alternatives or complementary techniques, namely because of their non-invasive character and due to the ability of providing a global information record necessary to feed an information system. Laser scanners are therefore being increasingly used to acquire as-built/as-is conditions, which are translated into very high dimension files of point clouds data. Point clouds are generally dense although non-homogeneous, unorganized and noisy. These characteristics are a source of difficulties that have to be taken into account in subsequent processing to reconstruct three dimensional models of the desired objects or structures. This subject still continues to draw the attention of many researchers in various scientific areas and may be illustrated by the published works found in the literature. Among other studies we can refer Koo et al. [1] where an iterative methodology is used to construct an approximating mesh to the original surface, departing from a set of unorganized points. Another simplification approach for point clouds was proposed by Moenning and Dodgson [2], where they used fast marching farthest point sampling for implicit surfaces and point clouds to devise a coarse to fine uniform or feature-sensitive simplification algorithm. Huang et al. [3] have developed a methodology to consolidate the point cloud before proceeding to the surface reconstruction. To that consolidation the propagation direction information is set as a priority setting, by using principal component analysis. Also in the context of simplification strategies, one can refer the work proposed by Ma et al. [4]. They used a flatness-based segmentation algorithm for plane detection in point clouds, in articulation to a quadtree-based algorithm for decimating the point cloud involved with the segmented plane. According to the authors this approach improved the efficiency of triangulation, although the efficiency of this depends on a great extent on the amount of planes in the scene. Simplifying the information stored in the clouds data files, is therefore an important issue from the computational cost perspective, but it can also be seen as a tool that one may/should consider when one intends to obtain different

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levels of detail representations. This last aspect is worth of mention as we can control the quality of the reconstructed surfaces depending on the work final purpose. Concerning to the reconstruction approaches using radial basis functions (RBF), which are considered in the present work, one can to refer the works developed by Carr et al. [5–7] based on the implicit representation of object surfaces. Carr et al. used these functions to reconstruct cranial bone surfaces from 3D CT scans and thin-plate spline RBF for the interpolation of surrounding large irregular holes in the skull. In another work, these authors concluded that the RBFs can be evaluated anywhere to produce a mesh at the desired resolution without an augmentation of the computation time and the memory requirements, because of these functions ability to approximate the input data using significantly fewer centers comparing to the global number of grid points. They have also concluded that RBFs can describe exactly the range data and interpolate across holes and gaps, and the smoothing can vary as needed without having to fit a new RBF to the data. Other relevant work in this context is due to Wu et al. [8], where a scheme for 3D reconstruction of implicit surfaces from large scattered point sets based on the radial basis functions is proposed. They used the partition of unity method and a binary tree to organize the point sets into some overlapping local subdomains and reconstructing a local surface for each of the subdomains from non-disjunct subsets of the points. The global solution was obtained by combining the local solutions. With respect to the development of new approaches in the interpolation of RBFs, Morse et al. [9] proposed an algebraic method for creating implicit surfaces using linear combinations of radial basis interpolants to form complex models from scattered surface points. Concerning to other works in the context of the piecewise interpolation to approximate scattered data, it is also relevant to refer the works developed by Cuomo et al. [10,11]. In the first work, the authors departed from a short survey on the main methods for the scattered data problem, to the presentation of a new triangle-based interpolation method, which in the context of the second paper is enhanced via the proposal of a class of piecewise interpolating functions which expressions are related to the barycentric coordinates.

The present work one proposes an integrated methodology that goes from a user-defined simplification of a given point cloud until the reconstruction of the corresponding 3D open surface. This methodology doesn't require a previous analysis of the surface as other methods do, and preserve the original point cloud, thus allowing for considering different levels of details whenever wanted. This simplification step plays also an important role associated to the potential elimination of noisy information, that often appear in the 3D laser scanning points' clouds. Following the simplification of the original data set or point cloud, and subsequent constitution of the structured grid and triangle mesh, one proceeds to the reconstruction phase wherein compactly-supported radial basis functions are used to achieve the final surfaces. An additional relevant characteristic is that this approach does not require the use of different commercial applications, as the whole process possesses a continuous, parametrized character. Illustrative case studies are presented and discussed to analyze the influence of different parameters associated to each of the phases of the process.

2. Methodology

Concerning to the whole methodology, we can consider two main phases. The first deals with the information collected by the acquisition system, which in the present study is generically the 3D laser scanner. Due to its highly unorganized and heterogeneous character, this phase consists in the constitution of a virtual structured grid with a chosen dimension. If necessary, this grid may lead immediately to a triangle structured mesh, which can be an input for other applications such as a computer aided design or a finite element analysis application, for example. The second phase of the methodology is devoted to the surface reconstruction, which in the present work is carried out by using compactly-supported radial basis functions. The quality level of the 3D open surface, as in the previous step can be selected to yield a more or less detailed surface. In the next sections one describes in more detail, the whole methodology.

2.1. Surfaces mapping

The main idea behind this simplification methodology is related to the possibility of defining a continuous map from a reference surface to another surface (cf. Fig. 1). This mapping and its parameterization can be defined as:

$$\begin{aligned} \vec{\varphi}: \quad & \Omega \rightarrow \tilde{\Omega} \\ & (u, v) \mapsto (x, y, z) \end{aligned} \tag{1}$$

and it is a one to one continuous mapping between two regions with two degrees of freedom.

This parameterization principle will be applied between a giving unorganized set points $\tilde{\mathrm{P}}$ and a structured and organized set of points P, referred here as a virtual cloud P. The map is defined by choosing the best point of $\tilde{\mathrm{P}}$, for each point of P. To choose this best point we take into account the proximity to the point of P and if this point is close to the boundary of the cloud. As it will be explained, this proximity can be other than the Euclidean distance. It is important to note that this follows a non-surjective map, being why one can control the elimination of points on $\tilde{\mathrm{P}}$ and transmit, through the map, the organization of P to $\tilde{\mathrm{P}}$. We introduce a formalization of this scheme:

Definition 2.1. A point $\mathrm{p} \in \Re^3$ have a projection $\Pi(\mathrm{p})$ onto a plane $(x-a, y-b, z-c) \cdot \vec{n} = 0$ defined by $\Pi(\mathrm{p}) = \mathrm{p} - \lambda \vec{n}$, with $\lambda = (\mathrm{p} - (a,b,c)) \cdot \vec{n}$. The quantity $|\lambda|$ is the Euclidean distance from the point p to the plan.

Lemma 2.1. *For all the points* P *in* $\Re^3$ *there exists a point* $(a,b,c) \in \Re^3$ *and* $\alpha, \beta, \gamma \in \Re$ *such that*

$$\mathrm{P} \subset \mathrm{T} = \{(x,y,z) \in \Re^3 : |x-a| < \alpha, |y-b| < \beta, |z-c| < \gamma\} \tag{2}$$

and the volume of T *is minimum.*

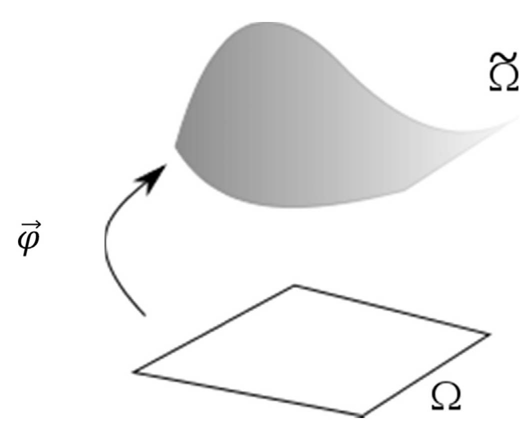

Fig. 1. Schematic representation of the surface transformation vectorial field.