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Optimal pitch map generation for scanning pitch design in selective sampling

E. Vezzetti *

Dipartimento di Sistemi di Produzione Ed Economia dell'Azienda, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Torino, Italy

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ABSTRACT

The reverse engineering process represents one of the best known methodologies for creating three-dimensional (3D) virtual models starting from physical ones. Even if in the last few years its usage has significantly increased, the remarkable involvement of the operator has until now represented a significant constraint for its growth. Having regard to the fact that this process, and in particular its first step (that is the acquisition phase), strongly depends on the operator's ability and expertise, this paper aims at proposing a strategy for automatically supporting an "optimal" acquisition phase. Moreover, the acquisition phase represents the only moment in which there is a direct contact between the virtual model and the physical model. For this reason, designing an "optimal" acquisition phase will provide as output an efficient set of morphological data, which will turn out to be extremely useful for the following reverse engineering passages (pre-processing, segmentation, fitting, ...). This scenario drives the researcher to use a selective sampling plan, whose grid dimensions are correlated with the complexity of the local surface region analyzed, instead of a constant one. As a consequence, this work proposes a complete operative strategy which, starting from a first raw preliminary acquisition, will provide a new selective sampling plan during the acquisition phase, in order to allow a deeper and more efficient new scansion. The proposed solution does not require the creation of any intermediate model and relies exclusively on the analysis of the metrological performances of the 3D scanner device and of the morphological behaviour of the surface acquired.

1. Introduction

The reverse engineering process starts from the usage of a scanning device which usually provides a "point cloud", that is, a particular set of points describing a discrete sample of a physical model surface. The following steps are usually carried out by using the Delaunay approach, which is simply a triangulation technique used to generate a polyhedral model of a physical one starting from a point cloud.

These are only two of the steps which form the reverse engineering process. This process starts from the point cloud acquisition to arrive at the virtual model reconstruction. It can be characterized by many possible settings and choices, which are sometimes quite difficult to define and which may possibly cause significant inconsistencies between the scanned sample region and the real surface.

One of the most common sources of errors is undoubtedly the 3D scanning device. Being a real measuring tool, the 3D scanner is likely to be affected by measurement uncertainty; that is why its outputs, which are usually represented by point clouds, often introduce anomalies which do not belong to the original shape and that are usually defined as "noise".

This "noise" is normally removed during the phase which follows the acquisition one and which consists of two different steps: the "pre-processing" step and the "segmentation" step, in which the points cloud is divided into several different subdomains and patch surfaces [1].

The efficiency of the "pre-processing" step and of the "segmentation" stage strongly depends on the initial characteristics of the point cloud, and in particular on the number of points and on their placement in Cartesian space. For this reason, it is necessary to provide a point data set (known as a "selective sample") already during the acquisition phase. Besides, this "selective sample" must be strictly correlated with the morphological characteristics of the original scanned surface.

In order to provide an efficient "selective sample", it is important to remember that most 3D scanners acquire the object surface by using a constant grid, whose dimensions depend on the technology (contact or non-contact) employed [2]. When working on a wide range of possible surface morphologies, the use of the above-mentioned constant grid is likely to give rise to one of the two following scenarios: the generation of a too scattered points cloud, which would not be suitable for working on complex zones, or the formation of a plane, cylinder or cone-like scanning area, whose high resolution performances would be redundant.

* Tel.: +39 011 5647294; fax: +39 011 5647299.
E-mail address: enrico.vezzetti@polito.it.

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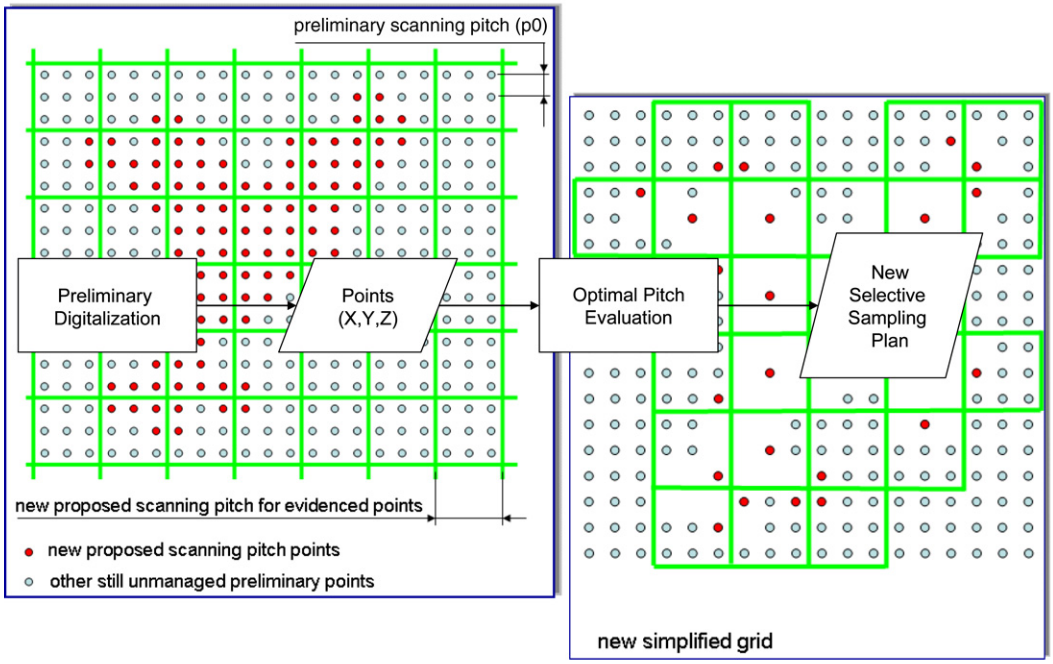

Fig. 1. General description of the selective sampling concept.

Having regard to the falseness of the common assumption that "the database quality improving goes always together with the sampled points density", it is possible to state that a sample grid crowded with too many points and obtained from a relatively simple surface increases the uncertainty propagation, whose presence is normally due to the measuring tools. It is therefore possible to make a new assumption that "the database quality improving is directly proportional to the property of the points of the cloud".

Hence, considering that the acquired point density depends on the scanning resolution (whose value varies locally depending on the surface morphological complexity), the selective sampling approach may be obtained by involving an "expert" operator for deciding which is the best pitch to be locally employed. However, in this case, the whole process would be expected to be extremely time-consuming because of the possible iterations, and its final result would probably be highly subjective.

On the other hand, the whole process could be automated by employing a morphological descriptor parameter associated with the optimal point density (or scanning pitch). It would be theoretically possible to start from a preliminary acquired point set, characterized by a constant resolution, and then to perform and manage an automatic point cloud optimization in order to provide a new, more efficient plan (defined in terms of new point number and locations) for the new scanning session (Fig. 1).

2. Technical literature

Even though, at present, the standard approach used during the 3D scanner acquisition is still principally handmade and driven by the operator expertise, some efforts have been made in the direction of an automatic methodology. However, most of the works already developed on the study of a selective acquisition pitch [3–8] have been developed not for reverse engineering purposes, but rather for computer inspection operations, which are often implemented with the availability of CAD models.

One of the most original solutions [9,10] developed for inspection purposes suggests an interesting strategy for selecting the distribution of discrete data points on sculptured surfaces. This strategy is based on the surface curvature and consists of a two-step surface subdivision stage. During the first step, the surface is uniformly divided into several smaller regions, which, during the second step, are in turn divided into even smaller subregions. The surface mean curvature is then calculated thanks to a uniform grid of points displaced on each of the subregions, which are subsequently ranked according to their average curvature values.

While these previously developed inspection strategies work on differentiable geometries, the new methodology described in this paper is based only on a preliminary raw point cloud, and on no other mathematical model. The main goal of this new methodology is to design a selective sampling plan able to provide a well organized point cloud in order to efficiently support the surface fitting step.

3. Optimal pitch map design strategy description

Gaussian curvature has proved to be a good parameter for describing the local morphological surface complexity, because of its "intrinsic" behaviour (that is, it does not depend on the particular direction of the surface analysis) [11].

The Gaussian curvature approach for differentiable surfaces can be easily extended to point cloud analysis by using a triangulated model. Thanks to the Gauss–Bonnet theorem, the discrete Gaussian curvature can be easily calculated, since it is given by the angular excess of each one of the triangulated neighbourhoods, which have been previously generated through the Delaunay approach.

The Gaussian discrete parameter provides an intrinsic curvature value which enables the operator to assess the discrepancy between the actual local geometry and the planar one by employing the following formula:

$$K = 2\pi - \sum_i \vartheta_i, \quad i = 1, \ldots n, \tag{1}$$

where K represents the Gaussian curvature value. This curvature value is calculated for each discrete neighbourhood, that is for each triangle, individuated through the index i, and sharing the central node with the other triangles. It is important to notice that there are as many triangulated neighbourhoods as there are points in the