Analysis of digitized 3D mesh curvature histograms for reverse engineering

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\textbf{A B S T R A C T}

Today, it has become more frequent and reasonably easy to digitize the surface of 3D objects. However, the obtained results are often inaccurate and noisy. In this paper, we present an efficient method to analyze a curvature histogram from a digitized 3D surface using a real object. Moreover, we propose to use the curvature histogram analysis for many steps of a reverse engineering process, which can be used to retrieve a CAD model from a digitized one for example. Our objective is to design a fast and fully automated method, which is seldom seen in reverse engineering. Experimental results applied on digitized 3D meshes show the efficiency and the robustness of our proposed method.

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\section{1. Introduction}

The availability of 3D scanners has increased the fast development of applications in Computer-Aided Design (CAD), reverse engineering, medicine and inspection. Many 3D processes use the objects shape, like segmentation, recognition or classification for example. In the production line of manufactured objects, steps can be distributed to many partners, and during the process, some data can be lost. An industrial reverse engineering application aims to reconstruct an object as a combination of geometric primitives, from a digitized 3D mesh or 3D point cloud \cite{1,2}. For mechanical objects, we search for planes, spheres, cylinders and cones, but also torus and more specifically developable or ruled surfaces. This can lead to quality control or object modification issues for example. To reconstruct the initial geometry, we must take into account the shape of the objects and their relationship with each other. But an object shape can be very complex, and the measured data can often be noisy. So, we need robust 3D descriptors to accurately define the objects shape.

In previous work, geometry descriptors like the curvatures \cite{3,4} allow us to deal with the 3D mesh shape. But the curvature is computed locally, while it is often necessary to characterize the shape globally. To do this, we can construct curvature distributions \cite{5,6} and analyze them.

In this paper, we propose a method based on the analysis of a digitized 3D mesh curvature histogram. We use the curvature approximation from Bénière et al. \cite{7} who incorporates two other methods \cite{8,9}. Then, a distribution is constructed continuously by a kernel estimation from all of the curvature values. Finally, an accurate curvature distribution analysis is realized. In the distribution, we propose to search for peaks and valleys, and compute some statistics depending on the chosen application. Indeed, curvature distribution approximately describes the objects shape, so these distributions can be useful to many applications. In this paper, we propose to use a curvature histogram to segment 3D meshes, detect primitive type and measure the quality of the mesh.

This paper is organized as follows. Previous work in this topic is presented in Section 2. In Section 3, we present in detail our distribution construction and analysis. Section 4 is dedicated to three uses of curvature distribution, which are mesh segmentation, primitive type detection with tolerances adaptation and mesh quality evaluation. In Section 5, we apply our proposed analysis on digitized 3D surfaces of real objects and we show that our analysis hugely improves the obtained results. Finally, we conclude and propose directions for future research in Section 6.

\section{2. Previous work}

We present in Section 2.1 previous work on curvatures and distributions. Then, we show three fields in 3D mesh processing:
mesh segmentation in Section 2.1.1, geometric primitive type
detection in Section 2.1.2 and mesh quality evaluation in
Section 2.1.3.

2.1. Curvature distribution

Intuitively, curvature quantifies the deviation between a curve
and a straight line, or between a surface and a plane in 3D. The
curvature of a 2D curve at a point $P$ equals the inverse of the
osculating circle radius $r$ at $P$. The osculating circle is the circular arc
which best approximates the curve around $P$ (Fig. 1a).

On a 3D surface, an infinity of curvature directions exists around
the normal vector of $P$ (Fig. 1b). So, we need to distinguish
particular curvatures. Principal curvatures are the minimum and
maximum curvatures. Mean curvature and Gaussian curvature
equal respectively the mean and the product of principal

![Fig. 1. Curvature representation on: (a) 2D curves and (b) 3D surfaces.](image1)

![Fig. 2. (a) Discrete and (b) continuous distribution samples.](image2)

![Fig. 3. Examples of mesh segmentation from [19]: (a) A section-type segmentation, (b) a surface-type segmentation.](image3)
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