HOSTED BY
ELSEVIER

Available online at www.sciencedirect.com
ScienceDirect

Journal of Computational Design and Engineering 3 (2016) 102–111

www.elsevier.com/locate/jcde

Feature curve extraction from point clouds via developable strip intersection

Kai Wah Lee[a], Pengbo Bo[b,*]

[a]*Hong Kong Baptist University, China*
[b]*Harbin Institute of Technology, China*

Received 8 April 2015; accepted 20 July 2015
Available online 13 August 2015

Abstract

In this paper, we study the problem of computing smooth feature curves from CAD type point clouds models. The proposed method reconstructs feature curves from the intersections of developable strip pairs which approximate the regions along both sides of the features. The generation of developable surfaces is based on a linear approximation of the given point cloud through a variational shape approximation approach. A line segment sequencing algorithm is proposed for collecting feature line segments into different feature sequences as well as sequential groups of data points. A developable surface approximation procedure is employed to refine incident approximation planes of data points into developable strips. Some experimental results are included to demonstrate the performance of the proposed method.

Keywords: Feature extraction; Point cloud; Developable surface; Reverse engineering

---

1. Introduction

Nowadays, with the rapid development of laser scanning technology, many CAD models are stored in the form of unorganized point clouds. Extracting interesting information directly from the point cloud without first converting it to other compact representation, such as meshes, is an important and challenging problem. In this paper, we study the problem of feature extraction from point clouds and our proposed method has numerous applications in geometric processing such as model reconstruction and geometry compression.

We propose a framework for extracting feature curves from point cloud models. Refer to Fig. 1 for a point cloud model and those associated feature curves extracted using our method. Our method first computes a piecewise linear approximation of the point cloud. Based on this linear approximation, we devise a technique for fitting smooth developable surfaces to individual feature regions of the model. Finally, the smooth feature curves are computed as the intersection curves of corresponding neighboring developable surfaces.

1.1. Related works

Variational shape approximation: A variational framework was first proposed by Cohen et al. to tackle the problem of shape approximation for triangular mesh, using a normal-based error metric $\mathcal{L}^{2,1}$ [1]. Kobbelt et al. [2] enriched the variety of geometric proxy from simple plane to include sphere, cylinder and rolling-ball as additional geometric proxies. The key observation here is that technical CAD objects mostly have patches exhibiting these similar geometric forms. Following a similar vein, Yan et al. [3] generalized the proxy set with quadric surface and proposed a new algorithm for smoothing irregular boundary curves between segmented regions. Their generalization has expanded the scope of the approximation not only for technical CAD objects but also for organic models like the Stanford Bunny. We extend the variational framework for point cloud segmentation which serves as the first stage of our feature extraction pipeline from point cloud.

Feature extraction: Though feature extraction has been taken as a preprocessing step for many digital mesh processing

---

*Corresponding author.
E-mail addresses: lee.kai.wah@gmail.com (K.W. Lee), pengbo@hitwh.edu.cn (P. Bo).

http://dx.doi.org/10.1016/j.jcde.2015.07.001

algorithms such as shape matching and compression, the quest of better feature extraction algorithm for mesh and point cloud still attracts many researchers' attention.

Chica [4] has recently proposed to extract features from dense point clouds by first turning the point cloud into discrete volume representation and from which a visibility map is computed. Surface components such as vertex, edge and face are detected based on visibility information. Daniel et al. [5] leveraged the concept of Robust Moving Least Squares (RMLS) [6] and proposed a multi-step refinement method for robust smooth feature extraction from point clouds. Potential feature points are first identified with a RMLS operator which are then projected onto the intersecting surfaces near the feature locally approximated by the RMLS framework [6]. A smoothing method based on principal component analysis (PCA) is applied to remedy the jagged edges resulted from the RMLS projection. More works on extracting feature lines from point cloud data are reported in Gumhold et al. [7] and Pauly et al. [8].

Developable surface: A developable surface is a ruled surface which can be unfolded into the plane without distortion. It is the envelope of a one parameter family of planes and it has vanished Gaussian curvature everywhere [9]. These nice properties make developable surfaces widely applied in industry, like ship building [10]. The geometry properties of developable surfaces make it a good representation and a design tool for freeform shape modeling in architecture [11]. A tangent developable surface is constructed by tangent lines of a curve in 3D space with this curve as the singular curve, or regression curve [9]. Rectifying developable surface is used in paper [12] for modeling paper bending, whose shape is editable by editing the geodesic curve.

There are some papers discussing developable surfaces fitting problem. In paper [13], cones are used as proxies in variational framework to approximate a triangle 3D model. In [14], developable surfaces fitting to point cloud are studied in dual space. Paper [11] proposes developable strip model for freeform shape design. This semi-discrete representation of surface is a new way for shape design which is more powerful than plane elements and needs less effort than double curved surfaces [15,16].

2. Linear feature extraction

In this section, we propose an algorithm for finding linear features from point clouds. Our algorithm consists of two steps: (1) finding feature line segments as intersections of planes which approximate the given point cloud. The linear approximation is computed using a variational shape approximation approach; (2) a sequencing algorithm for collecting feature line segments into groups for feature curves in model.

2.1. Linear approximation of point cloud

We extend the well-known variational shape approximation approach to point clouds. Given an unstructured point cloud $\mathcal{P}=\{p_1,\ldots,p_N\}$, where $p_i\in\mathbb{R}^3$. Suppose each data point p_i has an associating normal denoted by $n(p_i)$. Our goal is to partition $\mathcal{P}$ into k disjoint point clusters $\mathcal{C}_i$ such that $\mathcal{C}_i\bigcap\mathcal{C}_j=\varnothing,\ \forall i\neq j$ and $\bigcup_{i=1}^{k}\mathcal{C}_i=\mathcal{P}$, and eventually represents each cluster with a best fitting plane subject to a defined error metric.

Denote a shape proxy to a point cluster $\mathcal{C}_i$ as a representative pair $P_i=(X_i,\mathbf{N}_i)$ where X_i is the barycenter of points in the cluster $\mathcal{C}_i$ while N_i is the direction indicated by the eigenvector associated with the smallest eigenvalue of the covariance matrix of the cluster $\mathcal{C}_i$.

The approximation error between a cluster of data points $\mathcal{C}_i$ and its corresponding proxy $\mathcal{P}_i$ is measured by

$$\begin{aligned}E(\mathcal{C}_i,\mathcal{P}_i)&=\sum_{p_j\in\mathcal{C}_i}E(p_j,\mathcal{P}_i)\\&=\sum_{p_j\in\mathcal{C}_i}\|n(p_j)-N_i\|^2\end{aligned}$$

An optimal piecewise linear geometric approximation to the point cloud is arrived when a set of proxies P_i associated to the point cluster $\mathcal{C}_i$ of a partition $\mathcal{C}=\{\mathcal{C}_1,\ldots,\mathcal{C}_k\}$ of $\mathcal{P}$ minimizes the total distortion error:

$$E(\mathcal{C},\mathcal{P})=\sum_{i=1\ldots k}E(\mathcal{C}_i,\mathcal{P}_i)$$

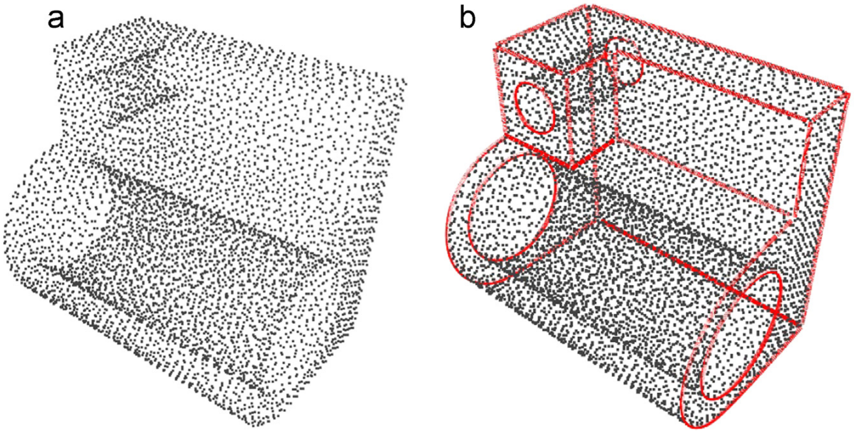

Fig. 1. (a) Original data points of a CAD model; and (b) reconstructed feature curves.