Computer-Aided Design 45 (2013) 861–874

Contents lists available at SciVerse ScienceDirect

Computer-Aided Design

journal homepage: www.elsevier.com/locate/cad

Efficient feature-preserving local projection operator for geometry reconstruction

Bin Liao [a,b], Chunxia Xiao [a,*], Liqiang Jin [a], Hongbo Fu [c]

[a] School of Computer, Wuhan University, Wuhan 430072, China
[b] Faculty of Mathematics and Computer Science, Hubei University, Wuhan 430062, China
[c] School of Creative Media, City University of Hong Kong, Hong Kong, China

HIGHLIGHTS

- We present a feature-preserving locally optimal projection for static model.
- We present a spatio-temporal locally optimal projection for time-varying surfaces.
- We accelerate the projection operator using the random sampling technique.

ARTICLE INFO

Article history:
Received 30 June 2012
Accepted 16 February 2013

Keywords:
Geometry reconstruction
Feature-preserving
Time-varying data
Locally optimal projection
Random sampling

ABSTRACT

This paper proposes an efficient and Feature-preserving Locally Optimal Projection operator (FLOP) for geometry reconstruction. Our operator is bilateral weighted, taking both spatial and geometric feature information into consideration for feature-preserving approximation. We then present an accelerated FLOP operator based on the random sampling of the Kernel Density Estimate (KDE), which produces reconstruction results close to those generated using the complete point set data, to within a given accuracy. Additionally, we extend our approach to time-varying data reconstruction, called the Spatial–Temporal Locally Optimal Projection operator (STLOP), which efficiently generates temporally coherent and stable feature-preserving results. The experimental results show that the proposed algorithms are efficient and robust for feature-preserving geometry reconstruction on both static models and time-varying data sets.

1. Introduction

Reconstructing the geometry from raw scanned data has been an active research topic over the last two decades. Although various reconstruction methods have been proposed [1–8], many problems still remain to be addressed due to geometry shape complexity and noise (outliers), in addition, with high accuracy reconstruction requirements and newly arisen applications. Surface reconstruction methods (e.g., [2,4,5,9–11]) work well only for input point set data that is densely sampled and from which the orientation of the points can be accurately deduced. Point Set Surfaces (PSS) defined by local moving least squares (MLS) approximations of the point set data [10,12] have been proven to be a powerful approach. However, due to the employment of plane fit operation, PSS is highly unstable in regions of high curvature where the sampling rate usually drops significantly.

To avoid using local surface approximation and normal estimation, Lipman et al. [7] develop a parameterization-free Locally Optimal Projection operator (LOP) for geometry reconstruction. This method is robust to noise and outliers of raw scanned data. However, the LOP method encodes only the spatial relationship between input points while completely ignoring underlying surface geometry. It thus might fail to capture geometric features (Figs. 1 and 2). In addition, LOP is computationally expensive for reconstructing large point set data, while large data is commonly generated using laser and structured light scanners.

In this paper, we introduce an efficient and Feature-preserving Locally Optimal Projection operator (FLOP) for geometry reconstruction. We first develop a bilateral-weighted local optimal projection operator for preserving features, which works by taking both spatial and geometric feature information. Adaptive local-support parameter determination is exploited for robust projection. We then present an accelerated FLOP, which is based on the random sampling of the Kernel Density Estimate (KDE) [14] for the original point-set data. We show that reconstruction results by the accelerated FLOP are close to those generated using the complete point set data, to within a given accuracy, while time complexity is

* Corresponding author. Tel.: +86 13237174345.
E-mail address: cxxiao@whu.edu.cn (C. Xiao).

0010-4485/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.cad.2013.02.003

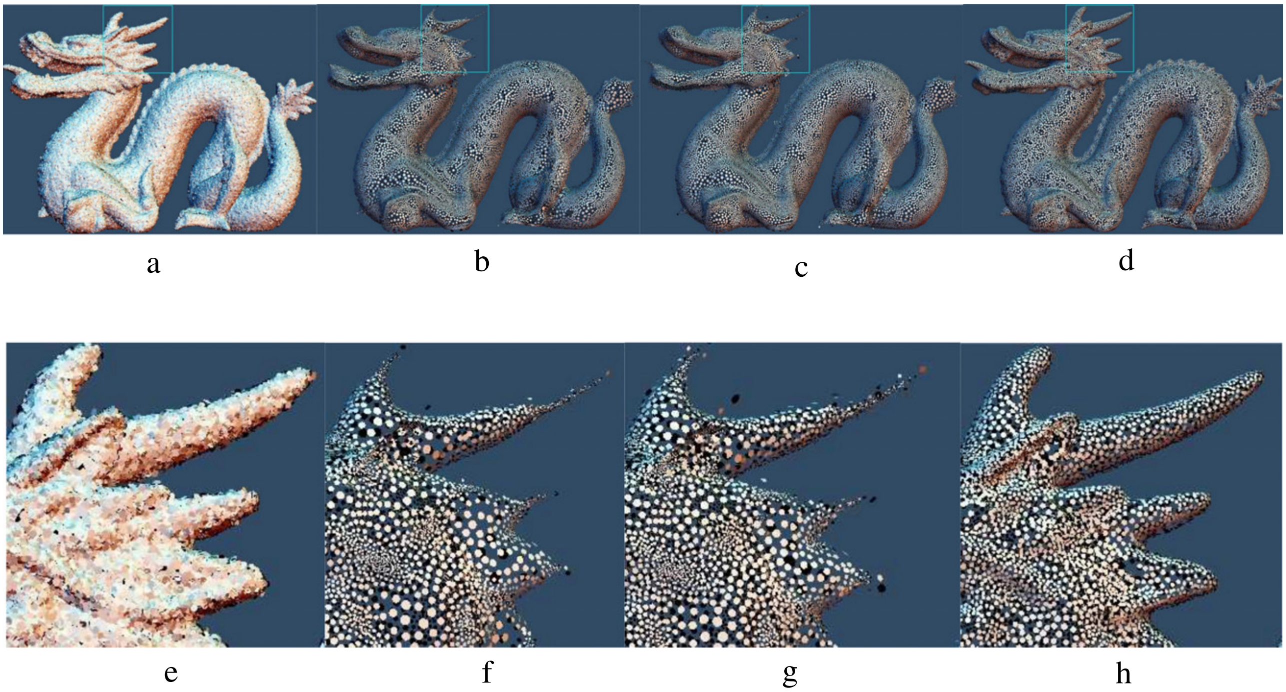

Fig. 1. Our FLOP method better preserves geometric features than LOP [7] and WLOP [13]. (a) Original dragon model. (b–d) Results by LOP, WLOP and FLOP, respectively. (e–h) Respective close-up of the highlighted regions in (a–d).

reduced significantly. Finally we show how FLOP can be extended for efficient and robust reconstruction of time-varying data.

In summary, this paper makes the following contributions:

- Developing a feature-preserving locally optimal projection operator (FLOP) for geometry reconstruction (Section 3.2).
- Proposing a Kernel Density Estimate (KDE) based random sampling technique to accelerate local optimal projection (Section 3.3).
- Introducing a fast spatial–temporal locally optimal projection operator (STLOP) for reconstructing time-varying data (Section 4).

Although the proposed FLOP algorithm is referred to as a "reconstruction" algorithm, it can also be considered as a filtering/denoising algorithm. It is very useful for the preprocessing for the following methods, such as MLS [10], APSS [8], RBF [11], MPU [4], and Poisson surface reconstruction [5], since these methods require relatively clean input. In this sense, our FLOP is complementary with these methods.

2. Related work

Many surface reconstruction methods have been proposed in recent years [1–4,10,5,7,8,15,16]. Among them the Point Set Surface (PSS) representation which is defined by the local moving least squares (MLS) projection operator [12,10] has been proven to be a powerful surface representation for point set data. The initial Levin's definition [12] and PSS definition [10] are relatively expensive to compute. Although significant progress [2,17,18] has been made to design simpler and more efficient definitions, the central limitation of the robustness of PSS is the required plane fit operation that is highly unstable in regions of high curvature where the sampling rate drops below a threshold. Recently, Guennebaud et al. [8,15] propose an algebraic point set surfaces (APSS) framework to locally approximate the data using algebraic spheres. Compared with MLS approximations, this strategy exhibits high tolerance with respect to low sampling densities while retaining a tight approximation of the surface.

Lipman et al. [7] develop a parameterization-free locally optimal projection operator (LOP) for geometry reconstruction, which originates from the multivariate L_1 median [19]. LOP works well on raw data without relying on any local parameterization of the points or their local orientation, and is thus robust to noise and outliers of raw scanned data. However, this method suffers from high computational cost for local optimal minimization and fails to preserve geometry features well. Recently, by incorporating adaptive density weighting into LOP, Huang et al. [13] modify the LOP operator to handle point sets with non-uniform sampling, which they call WLOP. They also present a robust normal estimation method based on priority-driven normal propagation and orientation-aware PCA, which is adopted for normal estimation in our current system.

Using range scanning techniques such as structured light [20] and spacetime stereo [21], it is now possible to capture detailed 3D geometry nearly at real-time rates, which though is often corrupted with heavy noise. Several methods have been proposed to reconstruct time-varying data sets. For example, to obtain smooth and temporally coherent filtering results, Schall et al. [22] extend the non-local image denoising method [23] to 3D geometry. This method is essentially a filtering method and thus cannot work as a re-sampling tool like the LOP operator. Furthermore, such a method is time-consuming since it has to compare regions of the surface. Instead, our method reconstructs clean time-varying surfaces by an efficient local optimal projection operator, which is more robust for surfaces with outliers. Furthermore, using our method, the number of reconstructed points can be deliberately different from that of the original time-varying surfaces, which is useful for producing time-varying surfaces with different resolution (sampling). Wand et al. [24] provide a system for reconstructing the topology, shape, and dense correspondences from unstructured time-varying point clouds. However, this method suffers from large computational cost, and the employed iterative assembly heuristic for inferring the discrete 4D topology does not