

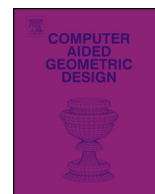


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Rolling normal filtering for point clouds

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ABSTRACT

3D geometric features represent rich details of 3D models, whose scale is much larger than noise. Traditional point cloud denoising methods cannot handle the task of processing and analyzing these features. Rolling guidance normal filtering is proved to be a useful tool in image and mesh small features removing. However, its direct extension to point cloud processing will lead to artifacts such as shape shrinkage and non-uniform distribution of points. To address these issues, we propose a new point position updating formulation and adopt a multi-normal strategy to overcome sharp edge shrinkage. Compared with other state-of-the-art denoising methods, our approach is more robust in removing small-scale geometric features while retaining large-scale structures. Even compared to its mesh counterpart, our method exhibits superiority in preventing large-scale sharp structures from severe distortion. Finally, a variety of experiments demonstrate that our approach shows its advantages in geometric feature removal against previous methods.

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1. Introduction

Point cloud processing again enters into the spot of computer graphics research due to stimulus coming from increasing of virtual/augmented reality applications and advance of shape analysis techniques. Moreover, the 3D scenes become more and more complicated and details are increasingly rich. However, overly complex geometric shapes of point clouds usually goes against subsequent processing such as reconstruction, shape structure analysis, and semantic segmentation. As a pre-processing step, suppressing small-scale features while preserving large-scale structures may be helpful for these kinds of operations. In addition, removing different scales of geometric features from 3D models can also be beneficial for geometric texture transferring, feature enhancement and feature preserving deformation.

Early multi-scale representations (Pauly and Gross, 2001; Pauly et al., 2006) are capable of achieving the goal by decomposing point clouds into a base shape in addition with different scales of geometric features. However, this kind of methods tend to over-smooth large-scale structures, and are computationally complex in general, unable to support local editing and difficult in preserving sharp features. Nader et al. (2014) employed the algebraic point set surfaces (APSS, Guennebaud and Gross, 2007) to decompose point clouds/meshes into multiple scales of geometric features. This representation can overcome the aforementioned deficiencies, but all features will become sphere-like due to use of spherical primitives.

On the other hand, a great deal of literature has been contributed to remove noise from point clouds (Guennebaud and Gross, 2007; Huang et al., 2009, 2013; Öztireli et al., 2009; Sun et al., 2015; Zheng et al., 2017). Noise is very small in scale with respect to geometric features. Applying denoising filters to feature removal may encounter different kinds of

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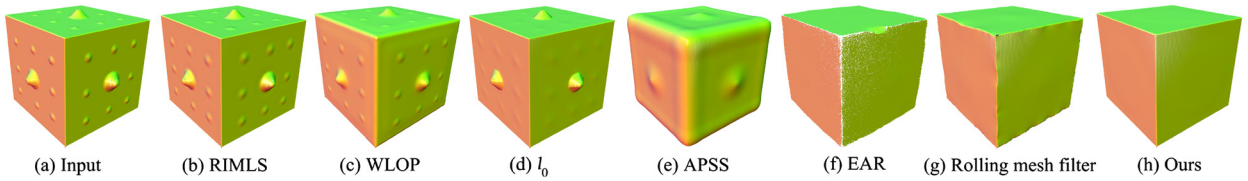


Fig. 1. Performance of applying state-of-the-art point cloud smoothing algorithms on to remove small-scale geometric features (different size cones) from Cube model (a). (b)–(g) are results by approaches from Öztireli et al. (2009), Huang et al. (2009), Sun et al. (2015), Guennebaud and Gross (2007), Huang et al. (2013) and Wang et al. (2015), respectively. Our method gives the best effectiveness (h).

issues. Some cannot suppress geometric features as shown in Fig. 1(b), (c) and (d). Guennebaud and Gross (2007) suffers from blurring structures of larger scales while removing small-scale features (see Fig. 1(e)). Resample-based methods like EAR (Huang et al., 2013) can flatten small-scale geometric features, but they are apt to result in non-uniform distribution artifacts (see Fig. 1(f)).

Texture suppression and feature removal are well studied in image processing (Karacan et al., 2013; Su et al., 2013; Zhang et al., 2014). Among these, the rolling guidance filter in Zhang et al. (2014) is a simple and efficient one. It first makes use of the Gaussian filter to smooth the image and then introduces a rolling guidance filter to recover the over-smoothed structures. Given image I and a pixel p , denote the set of the neighboring pixels of p by $N(p)$. The filter can be defined as the following iteration scheme:

$$I^{t+1}(p) = \frac{1}{K_p} \sum_{q \in N(p)} w(p, q, \sigma_s) w(I^t(p), I^t(q), \sigma_r) I(q), \quad (1)$$

where the Gaussian kernel function has the following form

$$w(x, y, \sigma) = e^{-\frac{\|x-y\|^2}{2\sigma^2}} \quad (2)$$

with σ being used to control the action range, and K_p is employed to normalize the bilateral weights.

In Wang et al. (2015), Eq. (1) was adapted to filter normal fields of 3D mesh models by Wang et al.. Suppression of small scale geometric features is achieved by using the Poisson mesh deformation to reconstruct the shape compatible with the new normal field. The authors demonstrate its great success by exploiting a couple of applications. This motivates us to extend the approach to removing small-scale geometric features from point clouds.

Our approach also consists of two stages, rolling guidance normal filtering and point updating. As establishing a gradient field from the normals on point clouds is much more difficult than doing it on meshes, our method alters point positions using a modified iteration scheme instead of the Poisson deformation method employed in Wang et al. (2015). Iterative projecting operation on point clouds will not cause triangle flips due to none connectivity. We observe by experiments that the mesh rolling guidance filter method in Wang et al. (2015) usually distorts large-scale structures seriously, as shown in Fig. 1(g) in which edges of the reconstructed cube have been seriously deformed. Furthermore, the filter fails to recover sharp features when processing noisy meshes as pointed out by the authors. Our point cloud method can greatly reduce this kind of distortion as shown in Fig. 1(h). In addition, our method can easily combine sharp feature structure analysis and the multi-normal mechanism (Zheng et al., 2017) into the framework for preserving sharp features when being applied to noisy point clouds. In summary, this paper has following three contributions:

- A rolling filter is first introduced for removing different scale of geometric features from point cloud. To our knowledge, no feature removing methods on account of point clouds have been proposed before.
- A new optimization energy is proposed for updating point positions. In the proposed formulation, a weighted point position constraint term is proposed to keep non-feature points from shrinking or dilating while posing less constraint on moving of small feature points. An iteration scheme is then derived from the energy and its convergence is analyzed numerically.
- A multi-normal strategy is employed to recover sharp features for noisy point clouds.

2. Related work

Our goal is to remove different scales of geometric features from 3D point clouds. It is most relevant to two kinds of work, point-based multi-scale geometric feature removal and mesh-based multi-scale geometric feature removal. In addition, many approaches on scale-aware texture removal for 2D images have attracted much attention, some of which have been successfully extended to 3D models. Therefore, in this section, we will review three kinds of work in details.

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