Shape Deblurring with Unsharp Masking Applied to Mesh Normals

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Abstract

Unsharp masking is a well-known image sharpening technique. Given an image and its smoothed version, amplifying high frequencies of the image via unsharp masking is achieved by linear extrapolation of the input images. In this paper, we adapt the unsharp masking technique for 3D shape deblurring purposes. Consider a blurred shape represented by a triangle mesh. Usually such a shape results from a 3D data corrupted by noise and then oversmoothed. First we apply unsharp masking to the mesh normals. To smooth the filed of mesh normals we use several local averaging iterations applied to the mesh normals (iterative mean filtering). Then we apply linear extrapolation of the original and smoothed fields of normals. Finally we reconstruct the deblurred mesh by integrating the field of extrapolated normals. We also give a quantitative evaluation of the proposed unsharp masking technique. To perform the evaluation, we use L^2 error metrics on mesh vertices and normals. Experimental results show that the unsharp masking technique is effective for shape deblurring.

Keywords: triangle meshes, shape deblurring, unsharp masking, processing mesh normals.

Technical Areas: Computer Graphics, Geometric Modeling, Mesh Processing.

1 Introduction

Triangle meshes reconstructed from real-world data frequently contain undesirable noise. Noise can be suppressed by mesh smoothing. Developing robust and effective mesh smoothing techniques continues to be an active area of research, see, for example, [10, 5, 2, 7, 11]. Mesh smoothing often leads to blurring salient shape features.

In this paper, we propose a method for restoring oversmoothed shape features (deblurring). The core of our method consists of adapting and applying an unsharp masking technique to the mesh normals.

Unsharp masking is a well-known image sharpening technique (see, for example, [3]). Given an image and its smoothed version, unsharp masking enhances image features by linear extrapolation of the original and smoothed images. Given a blurred (oversmoothed) shape approximated by a triangle mesh, first we apply mean filtering [12] to smooth the mesh normals. Then we use unsharp masking and obtain a new field of normals with amplify high frequencies. Finally we modify the mesh by fitting it to the new field of normals.

We also give a quantitative evaluation of the proposed shape deblurring technique. Vertex-based and normal-based L^2 error metrics [8] are used at the evaluation.

Previously, Guskov et al. [4] used unsharp masking for mesh exaggeration and caricature. They applied an unsharp masking technique directly to mesh vertices. In order to avoid triangle flipping and mesh self intersections they used a multiresolution framework and applied unsharp masking at different scales. Thus their approach is not easy to implement.

Recently Tolga et al. [9] studied shape smooth-

ing and enhancing operations for shapes represented by level sets (isosurfaces) and applied unsharp masking to the level set normals. Their approach turned out to be computationally expensive.

Our unsharp masking technique is similar to that proposed in [9]. However in contrast with [9] we work with triangle meshes and combine unsharp masking with a mean filtering scheme applied to mesh normals [12] and a method for mesh reconstruction from a field of modified normals [8]. The result is a new powerful shape deblurring method which is free from drawbacks of approaches developed in [4] and [9]

The rest of the paper is organized as follows. In Section 2, we introduce an algorithm of deblurring shape features with unsharp masking applied to mesh normals. Vertex-based and normal-based L^2 error metrics are described in Section 3. Experimental results are presented and discussed in Section 4. Section 5 concludes the paper.

2 Shape Deblurring Method

A process of deblurring an oversmoothed triangle mesh consists of three phases. We first smooth the mesh normals by an iterative mean filtering scheme [12] and produce a field of smoothed normals. Second, we carry out a linear extrapolation with the smoothed normals and the original ones. Unsharp masked, or enhanced, mesh normals are obtained through the linear extrapolation. Finally, we reconstruct a deblurred mesh by integrating the field of extrapolated normals, i.e., updating mesh vertex positions to fit them to the processed normals [8].

Let T be a mesh triangle, $\mathbf{n}(T)$ be the unit normal of T, and $A(T)$ be the area of T. Denote by $\mathcal{N}(T)$ the set of mesh triangles sharing either an edge or vertex with the T. Let U be a triangle from $\mathcal{N}(T)$. One pass of mean filtering is a combination of the following two steps.

Step 1. We compute the mesh normal $\mathbf{n}(T)$ at each triangle T and carry out an area-weighted averaging:

$$\mathbf{n}^{(k)}(T) = \frac{1}{\sum A(U)} \sum_{U \in \mathcal{N}(T)} A(U)\mathbf{n}(U) \qquad (1)$$

where $\mathbf{n}^{(k)}(T)$ is a mesh normal smoothed by k iterations.

Step 2. After the **Step 1**, the smoothed normal $\mathbf{n}^{(k)}$ is normalized as follows:

$$\mathbf{n}^{(k)}(T) \longleftarrow \frac{\mathbf{n}^{(k)}(T)}{\|\mathbf{n}^{(k)}(T)\|}.$$

The field of smoothed mesh normal $\{\mathbf{n}^{(k)}(T)\}$ is used for extrapolating and producing enhanced normals.

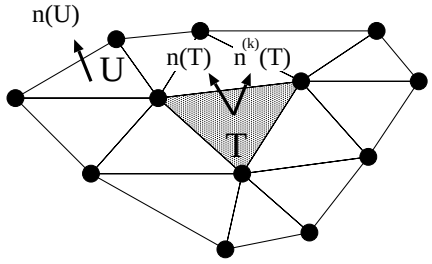


Figure 1: A mesh triangle T and its neighborhood $\mathcal{N}(T)$.

Second, a linear extrapolation process is considered. A new mesh normal $\mathbf{m}(T)$ is computed by

$$\mathbf{m}(T) = \frac{\mathbf{n}(T) + c\,\{\mathbf{n}(T) - \mathbf{n}^{(k)}(T)\}}{\|\mathbf{n}(T) + c\,\{\mathbf{n}(T) - \mathbf{n}^{(k)}(T)\}\|} \qquad (2)$$

where c is a positive threshold. This operation defines a new unit vector field $\{\mathbf{m}\}$.

The integrability of the field of mesh normals is lost after the linear extrapolation. We optimize the mesh vertex positions via minimizing errors between the original normals $\mathbf{n}(T)$ and the extrapolated ones $\mathbf{m}(T)$ [8]. Let P be a vertex to be updated at this phase and R be a mesh triangle adjacent to P. The normal-based error at P is defined by

$$E_n = \sum A(R)(\mathbf{n}(R) - \mathbf{m}(R))^2. \qquad (3)$$

The summation is taken over all triangles adjacent to P. The derivative of the error metric E_n with respect to P is given as follows:

$$\begin{aligned} \frac{\partial E_n}{\partial P} &= \sum 2\frac{\partial}{\partial P} A(R)(1 - \mathbf{n}(R)\cdot\mathbf{m}(R)) \\ &= \sum 2\left(\frac{\partial A(R)}{\partial P} - \frac{\partial A(S)}{\partial P}\right) \end{aligned} \qquad (4)$$

where S is a triangle obtained by projecting R onto a plane defined by $\mathbf{m}(R)$. The summation

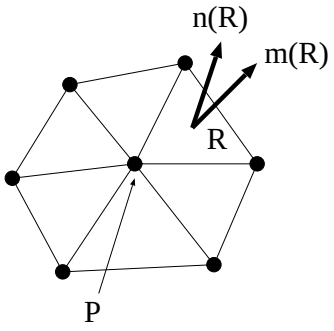


Figure 2: 1-ring neighborhood of mesh vertex P.

is taken over all the triangles adjacent to P. The gradient of a triangle area is computed by the following equation:

$$\frac{\partial A}{\partial P} = -\frac{1}{2}\{(P_1 - P)\cot\alpha + (P_2 - P)\cot\beta\} \quad (5)$$

where A is an area of triangle $P\,P_1P_2$, as seen in Figure 3. Derivations of Equation (5) are described in [2, 6]. Let $P_{\text{old}} = P$, and P_{new} be an

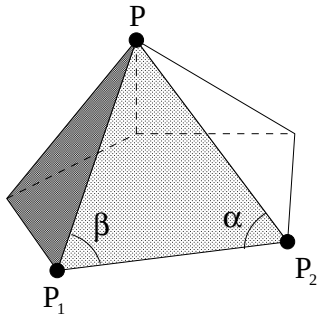


Figure 3: Triangle $P\,P_1P_2$ has angles α and β at the base P_1P_2.

optimized vertex position obtained by the following rule:

$$P_{\text{new}} \longleftarrow P_{\text{old}} - \lambda \sum \left(\frac{\partial A(R)}{\partial P} - \frac{\partial A(S)}{\partial P} \right). \quad (6)$$

This rule is a standard gradient descent method for minimizing E_n. According to our experiments, the gradient descent (6) works robustly with $\lambda = 0.1$. When mesh normals smoothed by k iterations are used at the linear extrapolation, we apply the updating operation (6) $10 \times k$ times.

3 Evaluation Method

This section presents two vertex-based and normal-based L^2 error metrics used for a quantitative evaluation of the proposed shape deblurring method. Given two close meshes with the same connectivity, the metrics measure errors at mesh vertex positions and mesh normal directions between the meshes.

Consider a reference mesh M and a mesh M' obtained from M by oversmoothing and deblurring. Consider a vertex P' of the deblurred mesh M'. Let us set $\text{dist}(P', M)$ equal to the distance between P' and a triangle of M closest to P'. Our vertex-based L^2 error metric is given by

$$\varepsilon_v = \frac{1}{3A(M')} \sum_{P' \in M'} A(P')\,\text{dist}(P', M)^2 \quad (7)$$

where $A(P')$ is the sum of areas of all triangles of M' incident with P', and $A(M')$ is the total area of M'. Our normal-based L^2 error metric is defined in a similar way. Consider a triangle T' of the mesh M', and let us find a triangle T of M closest to T'. Let $\mathbf{n}(T)$ and $\mathbf{n}(T')$ be mesh normal orientations of T and T' respectively. The normal-based error metric is given by

$$\varepsilon_f = \frac{1}{A(M')} \sum_{T' \in M'} A(T')|\mathbf{n}(T) - \mathbf{n}(T')|^2 \quad (8)$$

where $A(T')$ is the area of T'.

4 Experimental Results

We evaluate the developed deblurring method from two points of view: a quantitative evaluation according to L^2 error metrics and a effectiveness for real-world data (obtained by a laser scanning technique).

Figure 4 demonstrates the results of applying the shape deblurring method to a blurred mesh obtained from the original Stanford bunny mesh (Fig. 4 a) to which noise was added (Fig. 4 b) and then a mesh smoothing technique was excessively applied (Fig. 4 c). The deblurring process was achieved (Fig. 4 d) by linear extrapolation using mesh normals of the blurred mesh and those smoothed by $k = 20$ mean filtering iterations. Threshold c in (2) is equal to 1.5 in this case. Graphs on the vertex- and normal-based L^2 errors are demonstrated in the bottom of Figure 4.

Values on the x-axes of two graphs are corresponding to the k. The graphs in Figure 4 indicate that the vertex- and normal-based L^2 errors take the minimum value around $k = 20$.

Figure 5 presents the results of applying the deblurring technique to a triangle mesh reconstructed from real-world data [1]. The top image shows the original noisy model. The middle image demonstrates the model oversmoothed by the Laplacian smoothing flow. The bottom image exposes the model restored by our shape debulrring technique. The eyebrows, feather patterns on wings are well restored.

5 Conclusion and Future Work

We have developed a new shape deblurring technique for 3D shapes represented by triangle meshes. The technique seems to be very useful for improving shapes damaged by excessive smoothing.

We have adapted an unsharp masking technique from image processing and applied it to the field of mesh normals. We have used an iterative mean filtering applied to the mesh normals as a smoothing method required for unsharp masking. Using more sophisticated smoothing methods constitutes a promising direction for future research.

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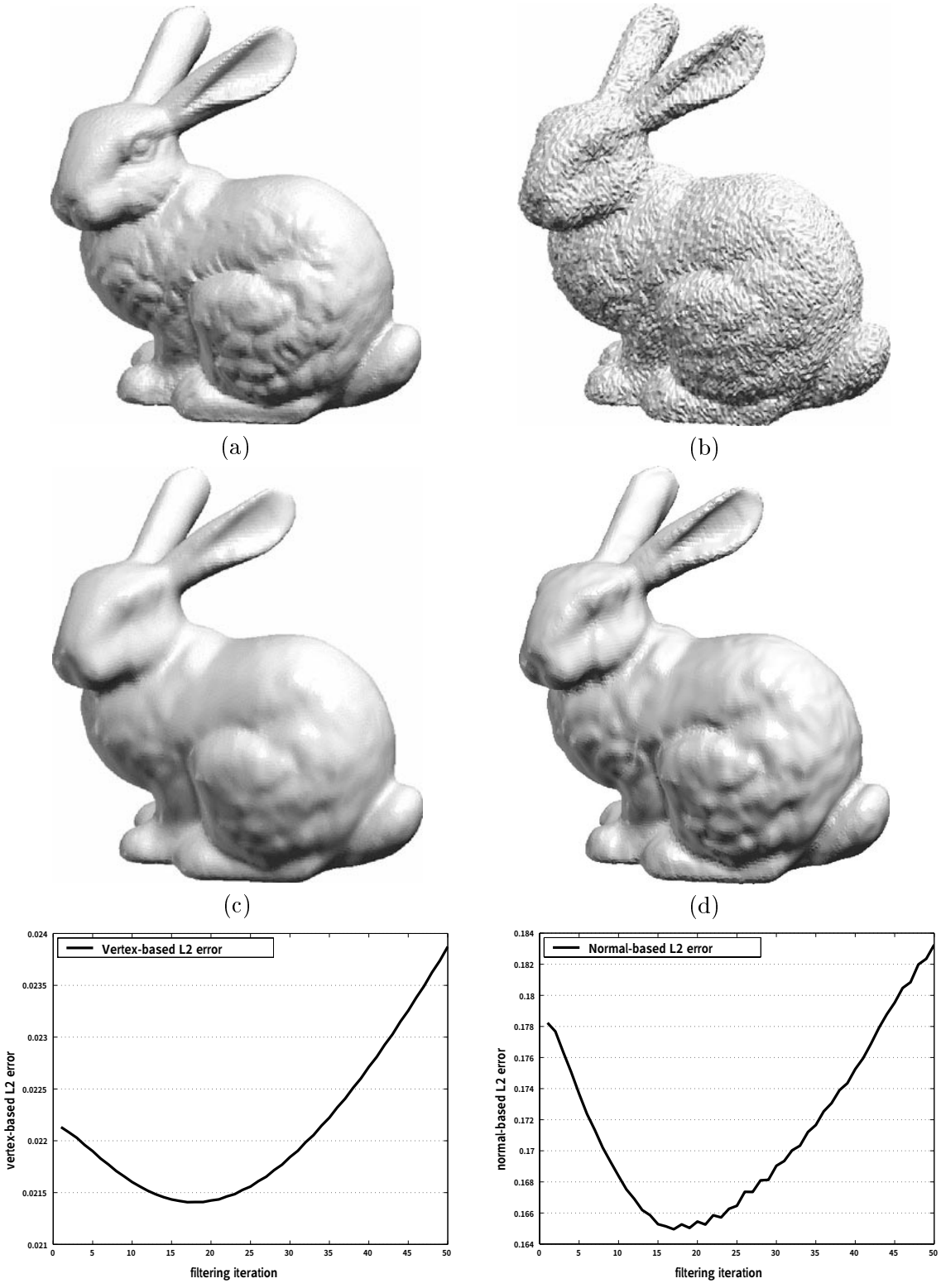


Figure 4: Shape deblurring. (a) Original model. (b) Noise is added. (c) Smoothed by a conventional smoothing method. (d) Deblurred by an unsharp masking method presented in this paper. Bottom-left: a graph of vertex-based L^2 error. Bottom-right: a graph of normal-based L^2 error.

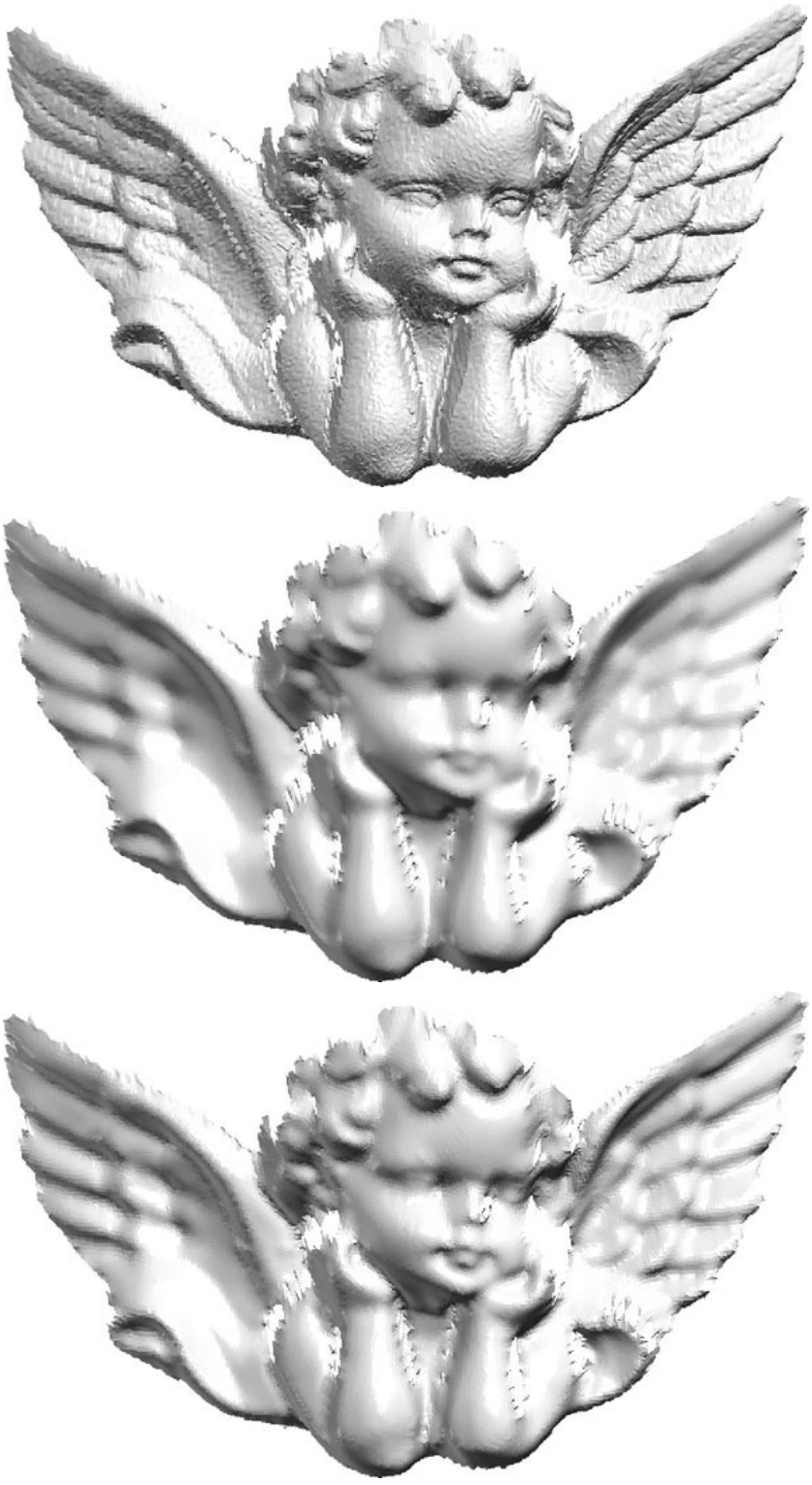


Figure 5: A angel model. Top: original model. Middle: excessively smoothed (oversmoothed) by the Laplacian smoothing. Bottom: deblurred by the unsharp masking technique presented in this paper.