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Multi-scale geometric detail enhancement for time-varying surfaces

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ABSTRACT

This paper presents a new multi-scale geometric detail enhancement approach for time-varying surfaces. We first develop an adaptive spatio-temporal bilateral filter, which produces temporally-coherent and feature-preserving multi-scale representation for the time-varying surfaces. We then extract the geometric details from the time-varying surfaces, and enhance geometric details by exaggerating detail information at each scale across the time-varying surfaces. Our approach can process mesh sequences with consistent connections or point sequences with unconstructed point set. In addition, as applications, based on the developed multi-scale surface representation and detail enhancement operators, we present geometric detail transfer, space–time morphing, and local regions detail enhancement for the time-varying surface.

1. Introduction

Time-varying surfaces have been widely used in computer games, 3D animated films and medical data visualization. Many approaches have been proposed to reconstruct and edit the time-varying surfaces [1–6]. Although most of the existing methods successfully capture or manipulate the motion of the time-varying surfaces, in practice, many of them ignore the existence of the true surface detail. In this paper, by building a multi-scale representation and extracting the geometry details for the time-varying surfaces, we develop a novel geometry detail enhancement approach for editing the time-varying surfaces.

The manipulation of detail enhancement for time-varying surfaces requires three main building blocks:

– a smoothing operator to generate successively smoother and feature preserving approximation levels of the input time-varying surfaces, and
– a decomposition operator to extract the detail level between the successive approximation levels of the time-varying surfaces, and
– an enhancement operator to adaptively exaggerate the extracted detail coefficient for generating the final detail enhancement results.

Comparing with multi-scale geometric detail enhancement for static models [7], time-varying surfaces have an additional temporal dimension, which leads to a much larger data set and some new technical challenges. Firstly, it is difficult to build an effective filter for computing a feature-preserving and temporally coherent multi-scale representation for the time-varying surfaces, especially for the point-sampled surfaces that usually do not hold the point-to-point correspondence between adjacent surfaces. Secondly, it needs to produce spatio-temporally detail enhancement results without exaggerating the basic geometry shape as much as possible. Finally, for time-varying surfaces, the amount of data is usually much larger compared with the single static object, the efficiency is one of the major performance bottlenecks needing to be addressed.

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In this paper, we develop a novel adaptive spatio-temporal bilateral filter to generate successive smooth scale levels of the input time-varying surfaces. The spatio-temporal bilateral filter is a function that adaptively integrates both the spatial and temporal neighbors at each point, and can produce feature-preserving and temporally coherent multi-scale representation for time-varying surfaces. Furthermore, the filter does not depend on the topology connections of the points of the time-varying surfaces, thus, it can be applied for both regular mesh sequences and point-sampled surface sequences. To reconstruct the final exaggerated shape, we build an adaptive detail enhancement operator, which results in a spatio-temporal smooth enhancement results. With the multi-scale presentation and detail exaggeration operators, our method can easily be extended to develop geometric detail transfer, space–time morphing, and local regions detail enhancement for the time-varying surfaces.

The main contributions are as follows:

- Develop an adaptive spatio-temporal bilateral filter to produce multi-scale representation for time-varying surfaces.
- Develop a temporally coherent geometric detail enhancement operator for time-varying surfaces.
- Present geometry detail transfer, space–time morphing, and local-region detail enhancement operators for time-varying surfaces.

2. Related work

Movie and digital effects production involve heavy use of time-varying surfaces. In recent years, significant advances have been made in developing methods to acquire and model the time-varying surfaces. Using range scanning techniques such as structured light [8,9] and space–time stereo [10,11], it is now possible to perform high-quality capture of detailed 3D geometry at close to video frame rates. Many approaches have been proposed to reconstruct deforming geometry for the acquired time-varying point clouds [12,13,3,4]. Once the time-varying surfaces have been generated, these data can be altered to adapt to other uses, for example, taking cloth captured from a flapping flag and attaching it to a character to make a cape. Several methods [1,2,5] have been developed to edit or reuse the existing time-varying surfaces, more methods refer to [3,5]. In this paper, however, we focus on the multi-scale representation and detail enhancement for time-varying surfaces.

Multi-scale surface representation provides a set of surface approximations for extracting the geometry details at different levels of smoothness [7]. Based on the implicit surface definition, Pauly et al. [7] proposed a weighted least squares approximation for the static point-sampled geometry, and produced a multi-scale representation by computing a series of approximation at successively higher levels of smoothness. By using mean-curvature flow filtering Digne et al. [14] decomposed each scan data into a smooth base and a height function as well for multi-scan mergence. However, smoothing operators based on diffusion or the least squares projection operation [7] are approximate low-pass filters which are not effective for extracting the geometry detail. Xiao et al. [15] used the B-spline surface to build multi-scale surfaces for the static point-sampled geometry, while this method has to perform parameterization to constructing the approximation surfaces.

Once the multi-scale representation and geometry details have been generated, higher-level editing semantics allows surface modifications at different detail scales. After obtaining the multi-scale representation for point-sampled geometry, Pauly et al. [7] implemented multi-scale free-form surface deformation, filtering, enhancement, and morphing operation on the point-sampled geometry. Xiao et al. [15] used the B-spline surface approximations to extract geometry details for detail transfer, however, B-spline surface cannot effectively extract the details because of the approximation accuracy. Based on the surface Laplacian representation, as an application of the presented framework, Sorkine et al. [16] developed a geometry detail transfer algorithm. Using the transfer functions defined in the frequency domain for the static point set surface, Miao et al. [17] extracted high frequency geometric detail from the point set for detail-preserving editing.

Recently, a related work on facial performance enhancement [18] also decomposed facial models into both low- and high-frequency components by mean-curvature flow filtering. However, their method utilized details from analyzing an existing high-resolution expression database to enhance the input low-resolution facial animation.

To work on the multi-scale geometric detail enhancement for time-varying surfaces, we need to design an efficient and effective filter for time-varying surfaces. Schall et al. [19] presented a non-local denoising method for time-varying range data. This method computed the resemblance of two points on the surface not only utilizing their local properties (position or normal) but also comparing the region of the surface surrounding the vertices. Although this method can produce feature-preserving filtering results for time-varying range data, non-local neighborhood filtering is a time-consuming process.

The bilateral filter [20] is a non-linear filter that replaces each pixel value with a weighted average of the neighboring pixel values, with weights respecting distances in both position and color. With small spatial extent it is an effective way to denoise, and with large spatial extent it is used for decomposing the image into base and detail layers. Bilateral filter have been widely used in image and video processing [21], including multi-scale image detail enhancement [22], video enhancement [23]. Bilateral filter also have been extend to 3D geometry for triangular mesh filtering [24,25]. Inspired by the bilateral filter, in this paper, we present a spatio-temporal bilateral filter to produce spatio-temporally coherent multi-scale presentation for the time-varying surfaces.

3. Detail enhancement for static model

For static models, our geometric detail enhancement system is composed of two stages: multi-scale representation

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