3-D DYNAMIC MESH COMPRESSION USING WAVELET-BASED MULTiresOLUTION ANALYSIS

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ABSTRACT

In this paper, we present a wavelet-based progressive compression method for 3-D dynamic meshes. Our method exploits the spatial and temporal redundancy. We encode the geometry of base mesh, the wavelet coefficients and the connectivity of each resolution level in order to reduce the spatial redundancy of intra meshes. For inter mesh coding, we encode the differences of geometry of base meshes and of their wavelet coefficients between adjacent frames to reduce the temporal redundancy. Our proposal is based on the wavelet-based multiresolution analysis which uses a perfect reconstruction filter bank and therefore it enables not only progressive representation but also lossless compression. The simulation results demonstrate that the proposed method is applicable to lossy and lossless compression of 3-D dynamic meshes.

Index Terms— Data compression, image compression, wavelet transform

1. INTRODUCTION

With the rapid progress of network technology, the demand of 3-D data such as animation, virtual reality and medical image has increased. A 3-D data is generally represented as polygonal mesh which can be classified into static mesh and dynamic one. A static mesh is generally defined by geometry of vertices and their connectivity. A dynamic mesh consists of successive static meshes. Because it requires enormous bandwidth or capacity in order to transmit or store, it is important to develop efficient compression techniques for dynamic meshes.

Since dynamic 3-D mesh compression technique was introduced by Lengyel [1], there have been several attempts to improve the rate-distortion performance. He proposed a geometry compression method. It segments the original mesh into small rigid body meshes. Each sub-mesh is redefined by affine transform, and then the transform coefficients and the residuals are quantized and encoded. This algorithm uses temporal coherence of rigid body meshes. However, it is difficult to cluster the vertices into same sub-mesh. Karni and Gotsman [2] proposed a PCA (Principal Component Analysis) based method. They also reduced temporal redundancy by using LPC (Linear Prediction Coding), but it is hard to efficiently work on finer meshes as reported in [3]. In addition, it requires high computational complexity to calculate the eigen vectors. Payan and Antonini [4] use a temporal wavelet transform to reduce a temporal redundancy. They achieved an efficient coding performance by using their optimal quantization scheme, but spatial redundancy was not considered. Guskov and Khodakovsky [3] introduced a progressive compression algorithm. They encoded the difference of wavelet coefficients between the previous frame and current one. Here, the wavelet coefficients are obtained by using the Burt-Adelson style pyramid scheme. Their method can transmit the original from a coarse mesh to the finest one. All of these algorithms fall into lossy compression. A lossless compression method was presented in [5]. It can simultaneously reduce the temporal redundancy and spatial one by using a space-time replica predictor which can effectively predict the geometry.

In this paper, we propose a wavelet-based compression method for 3-D dynamic meshes. We assume that the number of vertices and their connectivity are not changed. Our proposal is based on the wavelet-based multiresolution scheme for 3-D surface meshes which uses perfect reconstruction filter bank, the lifted Lazy wavelets [6]. Our scheme encodes the intra frame by using static mesh coder [6], and then both the differences of wavelet coefficients and the differences of base mesh geometry between adjacent frames are encoded in order to reduce the temporal redundancy. The scheme follows a similar approach with [3], however, it enables not only lossy progressive transmission but also lossless compression.

The rest of this paper is organized as follows. In Section 2, we review the wavelet-based multiresolution scheme which is adapted in this paper. Section 3 describes the proposed compression scheme. Here, intra and inter frame coding are separately introduced. Section 4 shows the simulation results in terms of lossless and progressive compressions. Finally, we conclude in Section 5.
2. OVERVIEW OF WAVELET-BASED MULTIRESOLUTION SCHEME

Wavelet-based multiresolution scheme was firstly introduced by Lounsbery [7]. The multiresolution analysis is performed by two analysis filters, $A_j$ and $B_j$ as follows,

$$C^{j-1} = A_j C^j$$  \hspace{1cm} (1)

$$D^{j-1} = B_j C^j$$  \hspace{1cm} (2)

where, $j$ is the resolution level, and $C^j$ is the $v_j \times 3$ matrix representing the coordinates of the mesh $M^j$ having $v_j$ vertices. A fine mesh $M^j$ is simplified by analysis filters to a coarse mesh $M^{j-1}$ and wavelet coefficients $D^{j-1}$ that represent lost details. We obtain a hierarchy of meshes from the simplest one $M^0$, called base mesh, to the original mesh $M^J$. The reconstruction is done by two synthesis filters, $P_j$ and $Q_j$. It is formulated as,

$$C^j = P_j C^{j-1} + Q_j D^{j-1}$$  \hspace{1cm} (3)

The fine mesh is reconstructed from the coarse mesh and the corresponding wavelet coefficients. If the filter bank satisfies the following constraint, we can achieve the perfect reconstruction.

$$\begin{bmatrix} A_j^\dagger \\ B_j^\dagger \end{bmatrix} = \begin{bmatrix} P_j & Q_j \end{bmatrix}^{-1}$$  \hspace{1cm} (4)

Both scale and wavelets are ‘hat’ functions, called Lazy wavelets. For a given resolution level, the wavelet-support is a half that one of the scaling function. However, wavelets are not orthogonal to scaling functions. Then a primal 2-ring lifting is used to construct new wavelets more orthogonal to the scaling functions in order to obtain the coarse meshes with good quality. Valette and Prost [6] introduced an exact integer analysis and synthesis with the lifting scheme based on Lazy filter bank and Rounding transform. Now, the analysis is sequentially performed by the lifted Lazy filter bank.

$$D^{j-1} = B_j^\text{laz} C^j$$  \hspace{1cm} (5)

$$C^{j-1} = A_j^\text{laz} C^j + [\alpha_j D^{j-1}]$$  \hspace{1cm} (6)

where, $A_j^\text{laz}$ and $B_j^\text{laz}$ are Lazy analysis filters, and $\alpha_j$ is a $v_j^3 \times (v_j^3 - v_j^{3-1})$ matrix chosen to ensure that $C^{j-1}$ is the best approximation of $C^j$. The synthesis is done by

$$C^j = \left[ P_j^\text{laz} \left( C^{j-1} - [\alpha_j D^{j-1}] \right) + Q_j^\text{laz} D^{j-1} \right]$$  \hspace{1cm} (7)

where, $P_j^\text{laz}$ and $Q_j^\text{laz}$ are Lazy synthesis filters. Consequently, this wavelet-based multiresolution scheme enables us to accomplish a lossless compression. Note that the proposed method uses this modified filter bank for lossy progressive to lossless compression. In addition, it solved the major problem of the previous scheme [7] which cannot work on irregular surface mesh.

3. PROPOSED COMPRESSION METHOD

To compress 3-D mesh sequences, we exploit the spatial and temporal redundancy by using wavelet-based multiresolution analysis [6] which allows lossless compression. It means that our scheme can decode the mesh sequence with the bit stream from lossy progressive to lossless. As used in H.26x and MPEG (Motion Pictures Experts Group), we use optionally the repeating pattern of frame types, IPP (i.e., IPP … P), IBP (i.e., IBPBP … BP) and IBBP (i.e., IBBPPBP … BBP), where:

- I (Intra) frame is intra coded mesh which is compressed without reference to other meshes.
Fig. 2. Histogram of wavelet coefficients (x-axis in the first frame of Cow)

- P (Predicted) frame is a predicted mesh from I-frame (or previous P-frame)
- B (Bi-directional) frame is a bi-directional predicted mesh from I and P frames (or past P and future P frames).

Fig. 1 shows the proposed encoder for I/B/P frames. The decoding is done by reverse process of encoding. In the next sub-sections, I, B, and P-frame codings are respectively described in detail.

3.1. Intra frame coding

To reduce the spatial redundancy, we encode the geometry of base mesh, the wavelet coefficients and the connectivity of each resolution level for the first frame mesh. The connectivity is only encoded once in I-frame since we assume that all input meshes are isomorphic to I-frame, that is, the connectivity is maintained all over frames. The I-frame coding method is same as the proposed in [6]. Since the probability distribution of wavelet coefficients follows laplacian with sharp peak as shown in Fig. 2, we can achieve an efficient entropy coding. In this paper, we employ an arithmetic coder.

3.2. Inter frame coding

For reducing the temporal residuals, we employ P and B-frame codings. P-frame coding is performed by encoding two kinds of geometry information. One is the difference of base mesh geometry between adjacent two frames (between I and P-frame or between P-frames).

\[ \Delta C^0_n = C^0_n - C^0_{n-1} \]  

where, \( n (0 \leq n \leq N - 1) \) indicates frame index. And the other is the difference of wavelet coefficients between adjacent two frames such as follows.

\[ \Delta D^j_n = D^j_n - D^j_{n-1} \]  

B-frame coding is also performed by encoding two kinds of geometry information. One is the difference between the base mesh geometry of B-frame and the average of past and future ones (Eq. 10). The other is the difference between the wavelet coefficients of B-frame and the average of past and future ones (Eq. 11).

\[ \Delta C^0_n = C^0_n - \frac{(C^0_{n-1} + C^0_{n+1})}{2} \]  
\[ \Delta D^j_n = D^j_n - \frac{(D^j_{n-1} + D^j_{n+1})}{2} \]

4. SIMULATION RESULTS

Simulations are carried out on two 3-D dynamic irregular triangle mesh models with fixed connectivity, Cow (with 204 frames and 2,904 vertices/frame) and Face (with 10,002 frames and 539 vertices/frame) which are respectively represented by 12 bits/coordinate. The number of vertices and their connectivity are not changed. As mentioned in Section 2, we employ the lifted Lazy wavelet analysis and synthesis filter bank. The coding results are classified into lossless compression and progressive compression.

4.1. Lossless compression

Table 1 presents the results of lossless compression in terms of bit-rate (bits/vertex/frame) and compression ratio according to IPPP, IBP, and IBBP codings. To evaluate the performance of the proposed method, we compare the results with Dynapack [5]. The proposed IBP coding has better compression ratio than two others, IPPP and IBBP, for both mesh sequences. The results show that our method can achieve a compression ratio over 1:33 in the case of large size mesh sequence such as Cow model. However, our approach has slightly less compression ratio than Dynapack in small size Face model. Note that the proposed allows progressive transmission.

4.2. Progressive compression

To measure the quality of the reconstructed progressive mesh model, we used Metro [8], which provides the forward and backward surface-to-surface RMS (Root Mean Square) errors, \( e^f (V, V') \) and \( e^b (V', V) \), respectively. We used the maximum value between the two RMS values for each frame, called MRMS (Maximum RMS). And then, we finally used the average of MRMS for all over the frames, called AMRMS (Average MRMS), as the quality measure.

The proposed method can perform lossy progressive compression by using wavelet-based multiresolution scheme. Fig.
Fig. 3. Rate-distortion curve of Cow

3 and Fig. 4 depict the rate-distortion curve of Cow and Face which have 17 and 10 resolution levels, respectively. Here, five highest resolution levels are presented. As shown in these figures, a 3-D dynamic mesh can be reconstructed as the simplified meshes of each level.

5. CONCLUSIONS

In this paper, we have proposed a wavelet-based progressive compression method for 3-D dynamic irregular triangle meshes with fixed connectivity. We reduced the spatial redundancy of a mesh sequence by using lifted Lazy filter bank. And the temporal redundancy is reduced by encoding the differences of geometry of base meshes and of their wavelet coefficients between adjacent frames. Through simulations, we demonstrated that our scheme is applicable for lossy progressive to lossless compression.

6. REFERENCES


Table 1. The results of lossless compression

<table>
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