LIFTING WAVELET CODING WITH PERMUTATION AND COEFFICIENTS MODIFICATION FOR STRUCTURED 3-D GEOMETRY WITH EXPANDED NODES

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ABSTRACT

One promising method for coding 3-D geometry is based on the structure processing of a 3-D model on triangle lattice planes, while maintaining connectivity. In the structuring process, each vertex may be assigned to several nodes on the triangular lattice planes. One of the nodes to which a vertex is assigned is selected as a representative node and the others are called expanded nodes. Only geometry data of the vertices at the representative nodes are required for reconstructing the 3-D model. In this paper we apply a lifting wavelet transform with the permuting and modifying process for an expanded node at even locations and the neighboring representative node to reduce the correlations among the separated coordinate values in the lower frequency band. Experimental results show the proposed scheme gives better coding performance compared to the usual schemes.

Index Terms— Wavelets, polygonal mesh, geometry data, 2-D structuring, triangular lattice plane

1. INTRODUCTION

3-D models are used in a wide range of applications, from computer graphics to online shopping. Polygonal mesh representation is a well known general purpose shape model for representing 3-D models. The polygonal mesh is represented by three components: (a) geometry data – the coordinate values of vertices of the mesh constructing the 3-D model, (b) connectivity data – the set of vertex indices which represents each polygon of the mesh, and (c) property data – such as color and normal vector of the vertices or polygon faces. To make optimum use of data storage and communication resources, an efficient scheme to represent the 3-D model polygonal mesh data is required.

Data compression schemes for the polygonal mesh can be roughly classified into two categories, i.e., those that maintain the connectivity of the polygonal mesh, and those that change the connectivity. A typical example of the former represents the connectivity of the model by the vertex and triangular spanning trees, and encodes the geometry data by using a predictive coding method according to the vertex spanning tree [1]. This scheme is able to perfectly reconstruct the model from the encoded data. An example of the latter data compression scheme is that of using the semi-regular mesh wavelet transform[2]. The semi-regular mesh which is obtained by using the MAPS algorithm[3] generally has more vertices than the original model, and the coordinate values of the vertices and property data are determined so as to minimize the approximation error from the original model. Although the semi-regular WT scheme is not able to reconstruct the original model perfectly, its coding performance is significantly better than the former scheme in lower coding rate. We have been proposed a coding scheme which is capable of perfect reconstruction and is based on the structuring of the connectivity of polygonal mesh on triangle lattice planes[4],[5]. In this scheme a vertex constructing the polygonal mesh may be assigned to several nodes on the triangular lattice planes, and the polygonal mesh is structured on several triangular lattice planes in order to structure the polygonal mesh with complex connectivity. Among the nodes to which a vertex was assigned, one node is selected as the representative, and the structured geometry data are obtained by defining the position of the representative node as that of the vertex assigned to the representative node. All other nodes (except the representative node) are called expanded nodes. For the reconstruction of the polygonal mesh only the geometry data at the representative nodes are required. We can obtain wavelet coefficients for the structured geometry data by applying the shape-adaptive discrete wavelet transform (SA-DWT) to each connected region of the representative nodes. However, the coordinate values at the representative nodes separated from continuous expanded nodes have a relatively high correlation between them, because the vertices of the representative nodes are adjacent in 3-D space. In order to restrain the many expanded nodes to be

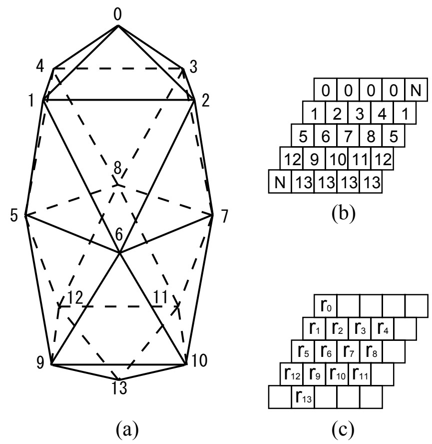

Fig.1 A polygonal mesh model and structured data: (a) A polygonal mesh model, (b) Vertex index table of the model, (c) Structured geometry data.

placed in the lower frequency band, permuting and lifting wavelet transform (P-LWT) [4] [5] was proposed. The lifting wavelet transform separates the input sequence to two sequences at even and odd positions. The high frequency component is derived from the odd sequence by prediction and the low frequency component is then obtained from the even sequence by an update process.

In this paper, we propose a new wavelet coding scheme for structured geometry data with expanded nodes. We introduce to modify the coordinate values of the permutated representative node with that of the adjacent representative node. This coefficient modification process restrains the growth of the prediction error with the large absolute value in the decomposition stage that follows. We call this scheme the Permuting and Modifying Lifting Wavelet Transform(PM-LWT). The performance of the proposed scheme is compared to the SA-DWT scheme as well as the topologically- assisted geometry compression (TAGC) scheme using a predictive coding.

2. STRUCTURING OF POLYGONAL MESH

A coding scheme based on the structuring of the connectivity of polygonal mesh on triangular lattice planes has been proposed in order to apply 2-D wavelet coding to the geometry and property data. This scheme assigned the vertices of the polygonal mesh to the nodes on the triangular lattice plane to structure the connectivity. In this process, a vertex may be assigned to several nodes for structuring the polygonal mesh with complex connectivity. Then, from all the nodes to which a vertex has been assigned, one node is selected as the representative node, and all the others are designated expanded nodes. Expanded nodes allow to change the number of vertices connecting a node on a triangular lattice plane and we structure the geometry data maintaining the connectivity of the polygonal mesh. The structured geometry data are obtained as the sets of the vertex coordinate values, of a vertex which are located at the position of the representative node to which the vertex is assigned. Fig.1(a) shows an example of a polygonal mesh which has 14 vertices. Fig.1(b) shows a vertex index table of the model shown in Fig.1(a). The numbers from 0 to 13 denote vertex index. N denotes outside nodes, which are not assigned to a vertex. Fig.1(c) shows structured geometry data which are substituted for the coordinate value at representative nodes.

3. PERMUTING WITH MODIFYING AND LIFTING WAVELET TRANSFORM

The detail of P-LWT is described in [4] and Fig.2 shows that of flow diagram. The permutation process restrains many expanded nodes to be decomposed into the low frequency band. When the coefficients in the low frequency band are decomposed in the following process, the coefficients obtained by the prediction process are often of large magnitude. In order to restrain the increase in coefficient magnitude, we introduce the coefficient modification process, in which the coefficient of the permuted representative node is changed to the interpolated value with the coefficients of adjacent representative nodes.

Let $f^{(l)}(n)$ denote the input sequence in one analysis step of the lifting wavelet decomposition. We use an index l to indicate a lifting decomposition step. $f^{(l+1)}(n)$ and $p^{(l+1)}(n)$ are the decomposed components of the updated and predicted processes of $f^{(l)}(n)$, respectively. In addition, $a^{(l+1)}(n)$ and $b^{(l+1)}(n)$ denote the node attributes for the updated and predicted components, respectively. The node attribute is defined as R when the node is a representative node, E when an expanded node, and **O** when an outside node. When a node is an outside node, its coefficient $f^{(l)}(n)$ or $p^{(l)}(n)$ is treated to be zero. The process of coefficient modification is taken place as follows,

Procedure 3.1

if $a^{(l)}(2k) = \cdots = a^{(l)}(2k+m-1) = E$ **and**

$a^{(l)}(2k-1) = R$ **and** $a^{(l)}(2k+m) = R$ **then**

$$f^{(l)}(2k) \leftarrow \frac{m}{m+1} f^{(l)}(2k-1) + \frac{1}{m+1} f^{(l)}(2k+m);$$

$$a^{(l)}(2k) \leftarrow P; \quad a^{(l)}(2k-1) \leftarrow E;$$

else if $a^{(l)}(2k) = \cdots = a^{(l)}(2k-m+1) = E$ **and**

$a^{(l)}(2k-m) = R$ **and** $a^{(l)}(2k+1) = R$ **then**

$$f^{(l)}(2k) \leftarrow \frac{m}{m+1} f^{(l)}(2k+1) + \frac{1}{m+1} f^{(l)}(2k-m);$$

$$a^{(l)}(2k) \leftarrow P; \quad a^{(l)}(2k+1) \leftarrow E;$$

$k = 0, 1, \cdots, N/2$

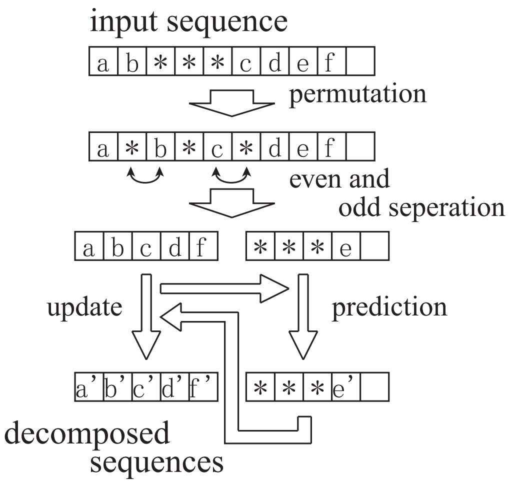

Fig.2 Permutation processing for structured geometry data with expanded nodes.

where the symbol P indicates that the corresponding node has permuted the neighboring node, N denotes the length of the input sequence and $m \geq 1$ denotes the number of the connected expanded nodes which separates the representative nodes at the both sides.

The structured geometry data can be reconstructed perfectly from the decomposed wavelet coefficients by PM-LWT, as follows,

Procedure 3.2

if $a^{(l)}(2k) = P$ **and** $a^{(l)}(2k-1) = E$ **then**

  if $a^{(l)}(2k+1) = \cdots = a^{(l)}(2k+m-1) = E$ **and**

    $a^{(l)}(2k+m) = R$ **then**

$$f^{(l)}(2k-1) \leftarrow f^{(l)}(2k) - \frac{1}{m}\left\{f^{(l)}(2k+m) - f^{(l)}(2k)\right\};$$

  else

$$f^{(l)}(2k-1) \leftarrow f^{(l)}(2k);$$

$$a^{(l)}(2k) \leftarrow E; \quad a^{(l)}(2k-1) \leftarrow R;$$

else if $a^{(l)}(2k) = P$ **and** $a^{(l)}(2k+1) = E$ **then**

  if $a^{(l)}(2k-1) = \cdots = a^{(l)}(2k-m+1) = E$ **and**

    $a^{(l)}(2k-m) = R$ **then**

$$f^{(l)}(2k+1) \leftarrow f^{(l)}(2k) - \frac{1}{m}\left\{f^{(l)}(2k-m) - f^{(l)}(2k)\right\};$$

  else

$$f^{(l)}(2k+1) \leftarrow f^{(l)}(2k);$$

$$a^{(l)}(2k) \leftarrow E; \quad a^{(l)}(2k+1) \leftarrow R;$$

$k = N/2, N/2-1, \cdots, 0$

This procedure is performed based on the node attribute on the decomposed process when a permuted expanded node is at an even position.

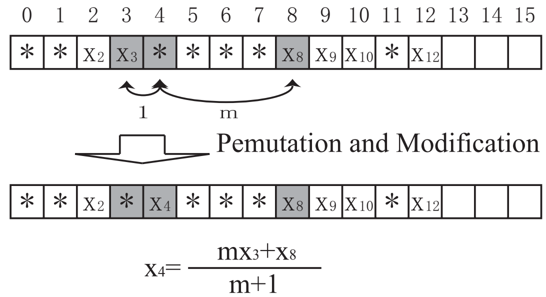

Fig.3 Coefficient modification processing with the coefficients at adjacent representative nodes.

4. EXPERIMENTAL RESULTS

In order to evaluate the coding performance of the proposed coding scheme, we carried out some experiments using the 3-D polygonal mesh “statue”, which is shown in Fig.4. Fig.5 shows a node attribute map and structured geometry data of which is shown in Fig.4. In the node attribute map, a white pixel indicates a representative node, a gray pixel indicates an extended node, and a black pixel indicates an outside node. These structured geometry data were applied to a wavelet decomposition using the permuting with modifying and lifting wavelet transform. We obtained the wavelet coefficients in octave decompositions of five levels by using the5/3 tap spline filters. the obtained wavelet coefficients were quantized by SFQ (Space-Frequency Quantization)[6], which was combined with pruning of descendant coefficients and linear quantization of each coefficient, and the encoded data were derived by applying the zero-tree coding.

We used a metric D_{rms} for the shape distortion of the reconstructed model, which was calculated as the root mean square error between the reconstructed model and original with an open software Metro[7]. Fig.6 shows the rate-distortion curves of the geometry data obtained by the proposed scheme, the P-LWT scheme, the SA-DWT scheme, and the TAGC scheme which is adopted in the MPEG4 standard. The proposed scheme improved the shape distortion of the reconstructed model for all coding rates examined. The PM-LWT scheme also improves the coding performance about 20% at relatively higher coding rates compared to P-LWT. These show that the PM-LWT scheme is effective as a polygonal mesh coding method compared to the usual schemes. Fig.7 shows the rendered images of the reconstructed models obtained from the proposed scheme and the TAGC schemes at approximately the same coding rate. In the rendered image of the TAGC scheme shown in Fig.7(a), some step-like discontinuities, which are a characteristic of quantization error on the predictive coding, appeared. The proposed scheme is able to reconstruct the 3-D model faithful to the original by introducing the lifting wavelet transform

Fig.4 Original model “statue” (vertices: 36482, polygons: 72411).

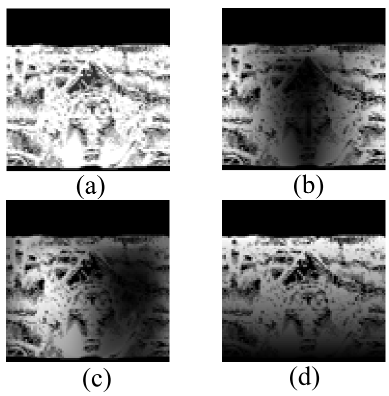

Fig.5 Structured geometry data of “statue”: (a) node attribute map, (b) x component, (c) y component, (d) z component.

including the permutation and coefficient modification, as shown in Fig.7(b).

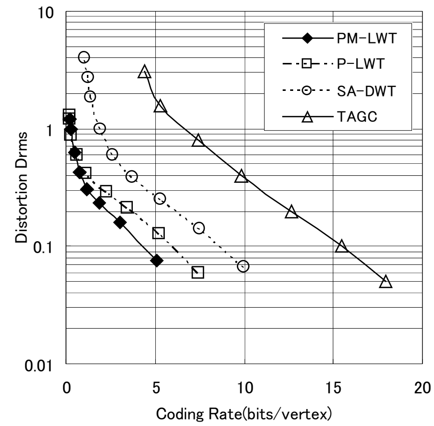

Fig.6 Coding performance for model “statue”.

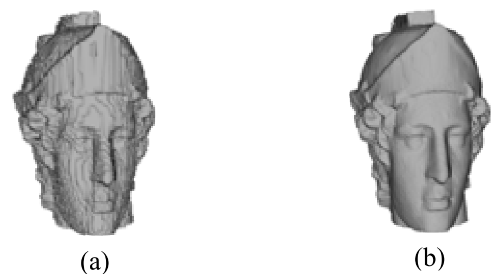

Fig.7 Rendering images of reconstructed models for “statue”. (a) TAGC scheme, coding rate: 5.31bpv, D_{rms}: 1.56, (b) PM-LWT scheme, coding rate: 5.05bpv, D_{rms}: 0.076.

5. CONCLUSION

In this paper we proposed a new coding scheme for polygonal mesh based on a permuting with modifying and lifting wavelet transform considering expanded nodes. The coefficients modification procedure following the permutation procedure restrained the increases in the magnitude of wavelet coefficients, and improved the coding performance further. Experimental results showed that the proposed scheme gave better coding performance at all coding rates comparing to the P-LWT, SA-DWT and TAGC schemes.

6. REFERENCES

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