

AN EFFICIENT CODING FOR 3-D GEOMETRY DATA BASED ON SURFACE SIMPLIFICATION AND WAVELET TRANSFORM

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ABSTRACT

This paper presents a new coding method for 3-D geometry data using surface simplification and the wavelet transform. A polygonal mesh model is constructed from the connectivity information and the geometric data. We have previously presented a coding method for the structured geometry data structured on a 2-D lattice plane. In this paper we present a coding method for the structured geometry data including the vertices which were contracted by the surface simplification as extended nodes on the 2-D plane. We apply the shape-adaptive wavelet transform to the structured geometry data containing the extended nodes to obtain the wavelet coefficients. Defining the parent-children dependency of the wavelet coefficients among the different frequency bands in consideration of the extended nodes, we obtain the coded data by using SFQ. Some experiments for a statue showed that the proposed method gives good coding performance compared to TAGC scheme.

1. INTRODUCTION

Efficient representation of a 3-D object is required for such applications as Internet games, interactive design for industrial products, and “Digital Museum” [1]. The polygonal mesh representation is well known as a general purpose shape model for representing 3-D objects [2]. The polygonal mesh is represented from the connectivity data of the vertices which make up the polygons and geometry data of the vertices. Schemes to reduce the amount of data required for the polygonal mesh representation have been proposed. Such schemes include the simplification method [3], which simplifies a 3-D shape model by contracting some vertices to a vertex, and the method of predictive coding for the geometry data [2] [4]. In addition, the authors have been proposed a coding method for geometry data based on the data structuring on a 2-D lattice plane and wavelet transform of the structured geometry data [5]. In this paper we propose a new coding

method for a 3-D shape model using surface simplification and the vertex structuring scheme on the 2-D lattice plane. The nodes on the 2-D lattice plane are composed of representative nodes which are assigned a vertex, extended nodes which are assigned the same vertex as the representative node, and outside nodes which are not assigned any vertex. We applied the shape-adaptive wavelet transform to the structured geometry data, which were obtained as the coordinate values of the vertices arranged on the 2-D lattice plane. Then, we define the parent-children dependency in the wavelet coefficients with consideration of the extended nodes and obtain the coded data by using the SFQ. We present experimental results applying the proposed method to 3-D shape data which were obtained by using a laser range finder, and compare the coding performance with that of the Topologically-assisted Geometry Compression (TAGC) scheme.

2. 2. 3-D GEOMETRY MODEL AND SURFACE SIMPLIFICATION

A rendering image of statue measured by a laser range finder is shown in Fig.1. The geometry data of the 3-D shape model were structured on a 2-D triangular lattice plane shown in Fig.2(a) [5]. The structured geometry data are shown in Fig.2(b). Although the geometry data are constructed from the coordinate values of many vertices for representing the details of the 3-D model, there are vertices which hardly affect the rendering image of the 3-D shape model when they are removed from the geometry data. So the simplified 3-D shape model can be obtained by contracting some vertices to a vertex, while maintaining the rendering image quality of the 3-D object. The vertex contraction reduces the number of the vertices required to represent the object shape, and reduces the coordinate values for the reduced vertices. In the vertex contraction process, we derive the distortion of the 3-D model that results when each vertex is contracted, and select the vertex which yields the smallest distortion. An example of the vertex contraction process is shown in Fig.3. In this figure, the deformed triangles are shown

with shadow when the vertex contraction shown with an arrow occurred. We define the distortion when a vertex is

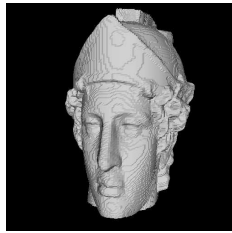


Fig.1 Original model "statue"
(vertices: 48643, polygons: 96350).

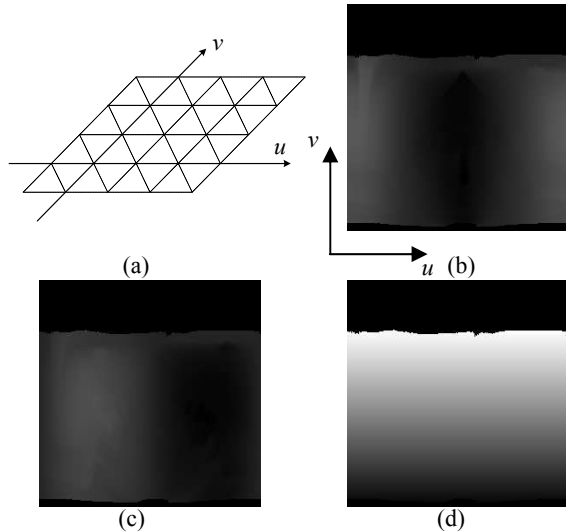


Fig.2 Structured geometry data: (a) triangular lattice plane used in structuring process (b), (c) and (d) show each component of the structured data for the x, y and z, respectively.

contracted as the sum of the distances between the destination vertex, which the target vertex is contracted to, and the deformed triangles. When some vertices are contracted to the target vertex, the distortions for the triangles including those vertices are taken into account. This procedure is repeated as follows.

1. The vertices forming the polygon edge with each target vertex are selected.
2. The distortion of the shape model is calculated for the case in which the target vertex is contracted to each selected vertex. The contraction distortion for the target vertex is determined as the minimum value.
3. Of vertices not contracted, the vertex with the minimum contraction distortion is contracted.
4. The contraction distortion for the vertices which are connected to the vertex contracted in Step 3 is renewed.
5. Step 3 and 4 are repeated until the number of vertices which were not contracted reaches the desired number.

The contraction process assigns a vertex to several nodes on the triangular lattice plane. A node is selected from the

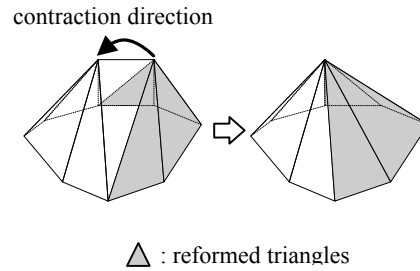


Fig.3 Transformed polygon mesh

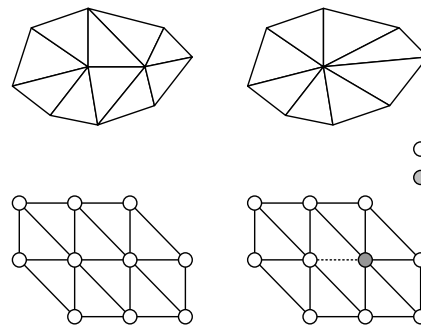


Fig.4 Example of vertex reduction: (a) original polygon mesh, (b) polygon mesh with reduced number of vertices, (c) (d) shape maps of (a) (b).

nodes which were assigned the same vertex, which is called a representative node, while the other is called an extended node. A shape map which includes the representative nodes, the extended nodes, and outside nodes which were not assigned a vertex, are defined on a triangular lattice plane. An example of the shape map is shown in Fig.4. The number of triangles which includes a representative node on the triangle lattice plane can be changed by using the extended nodes appropriately. By substituting the coordinate values of the vertex to its representative node position on the triangular lattice plane, the structured geometry data of the 3-D model is obtained. As the structured geometry data have an arbitrary-shaped support, a coding method is required suitable to the arbitrary-shaped data defined on the triangular lattice plane including regions of extended nodes and outside nodes.

3. CODING OF STRUCTURED GEOMETRY DATA WITH WAVELET TRANSFORM

It is well known that wavelet representations are very effective in reducing the correlation for image coding application. In this paper, we encode the geometry data structured on a 2-D triangular lattice plane, applying the

Shape-Adaptive Wavelet Transform (SAWT) and SFQ considering extended nodes [5]. The Shape-Adaptive Wavelet Transform decomposes a set of input data into two components using low-pass and high-pass wavelet filters, judging whether each pixel contains data or not. By repeating the two band decomposition of the structured geometry data in the horizontal and vertical directions for the lowest frequency band, the wavelet coefficients which describe the location of the coefficients in the decomposed frequency bands are obtained as shown in Fig.5. In Space Frequency Quantization, a tree structure is defined on wavelet coefficients in the difference band decomposed by SAWT. A subset of the wavelet coefficients of each vertex coordinate component is pruned, i.e., quantized to zero. The remaining coefficients of the subtree are quantized by a scalar quantizer. This process determines an optimal set of a spatial zerotree quantization and a scalar frequency quantization based on a rate-distortion property.

In a conventional wavelet coding, a spatial wavelet coefficients tree is constructed based on the parent-children dependency between the set of coefficients at similar positions in different bands. If the extended nodes and outside nodes which were not assigned a vertex exist in the triangular lattice plane, these nodes are usually allocated unnecessary codes by encoder. We propose a method, which constitutes a tree-structure by defining the parent-children dependencies only among the representative nodes. Each node which is not representative is assumed to depend on the nearest representative node in the same subband, so each representative node holds a subordinate relation in the subband. The parent-children dependencies are defined as relations only among the representative nodes; a representative node is accompanied by some representative nodes in the similar area in a level higher frequency band as shown in Fig.6. The procedure is described below.

1. In each frequency band, all extended and outside nodes are related to the nearest representative node.
2. The parent-children dependency is defined between the representative nodes in different frequency bands. Each representative node is related to several representative nodes, which are in a similar area in a higher frequency band.

The nearest representative node for each node is determined based on a Peano scan as shown in Fig.7. The geometry data are encoded by using the spatial frequency quantization with the parent-children dependency mentioned above.

4. EXPERIMENTAL RESULTS

We performed some experiments to evaluate the coding

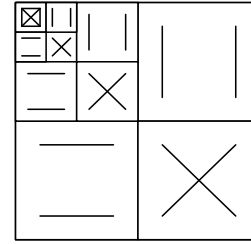


Fig.5 Multi-decomposition by Wavelet Transform.

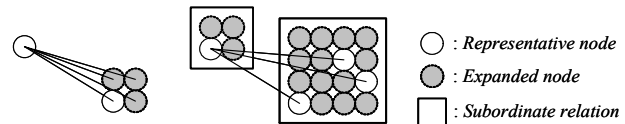


Fig.6 Example of tree-structure: (a) conventional method, (b) proposed method considering the subordinate relation.

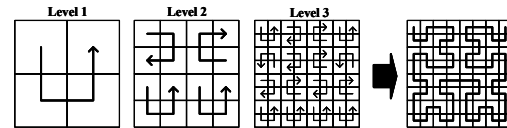


Fig.7 Scan pattern used for sorting the nearest representative node.

performance of the proposed method by using the 3-D polygonal model “statue” shown in Fig.1. Fig.8 (a) and (b) show the rendering images for the simplified 3-D model obtained by the vertex contraction and Fig.8 (c) and (d) show the shape maps for them. In the shape map, a white pixel indicates a representative node which is assigned to the vertex constructing the model surface, a gray pixel indicates an extended node, and a black pixel indicates an outside node. The number of vertices of the simplified model shown in Fig.8 (a) and Fig.8 (b) are about nine-tenth and one-fourth of the original model, respectively. The figures suggest the shape model can be simplified substantially maintaining the quality of the rendering image.

In order to evaluate the distortion of the reconstructed model, we introduce a metric for the shape distortion $D_{surface}$, defined as the mean squared distance between the reconstructed model and original.

$$D_{surface} = \frac{1}{N_{original} + N_{reconstructed}} \left\{ \sum_{i \in B} d^2(\mathbf{r}_i, M_{reconstructed}) + \sum_{i \in B} d^2(\hat{\mathbf{r}}_i, M_{original}) \right\}$$

where $N_{reconstructed}$ and $N_{original}$ are the number of vertices in the reconstructed and original 3-D models, respectively. $M_{reconstructed}$ and $M_{original}$ represent the reconstructed model

and original, respectively. $d(\mathbf{r}, M)$ is the minimum distance between a vertex \mathbf{r} and the 3-D model M .

Fig.9 and Fig.10 show the coding performance for the geometry data of the simplified model shown in Fig.8 (a) and (b). In these figures the coding performance of the

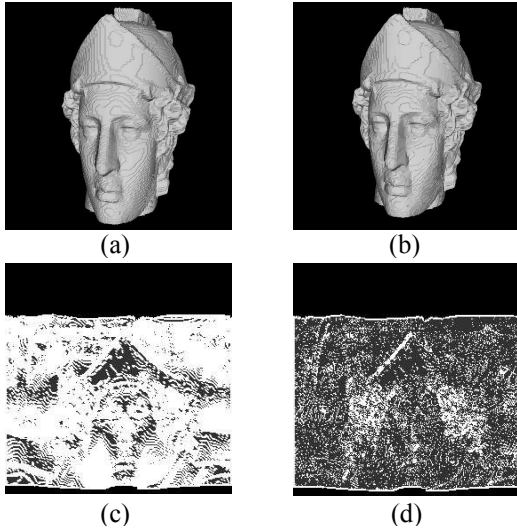


Fig.8 Simplified models of "statue":
 (a) model having 39069 vertices and 77202 polygons,
 (b) model having 13797 vertices and 26658 polygons,
 and (c)(d) shape maps of (a)(b).

proposed wavelet coding is compared with the Topologically Assisted Geometry Compression (TAGC) method. Fig.9 shows that the proposed method achieves the equivalent quality of reconstruction for the simplified model of Fig.8 (a) using one-third the amount of data of TAGC method. While Fig.10 shows that the coding performance of the proposed method becomes closer to that of TAGC method as the level of the simplification becomes higher. Fig.11 shows the rendering images of the reconstructed models for Fig.8 (a) obtained from the proposed method and TAGC method using almost the same amount of data coding. It can be seen in the figure that the proposed method can reconstruct the model with the smaller distortion than the TAGC method.

5. CONCLUSION

In this paper we have presented a wavelet coding method wherein a polygonal mesh model is structured on a triangular lattice plane and a simplification method for the 2-D structured data is applied. The method adapts a tree-structure considering extended nodes on the triangular lattice plane. This study has shown that an efficient tree-structure can be made, by introducing the subordinate relations on the wavelet coefficients in the same frequency band. The experiments demonstrated that the surface simplification taking the distortion of the 3-D model into consideration is effective, and that the wavelet

coding with the surface simplification gives a good coding performance compared to the TAGC method.

6. REFERENCES

[1] F. Mintzer, "Images on the path to the digital

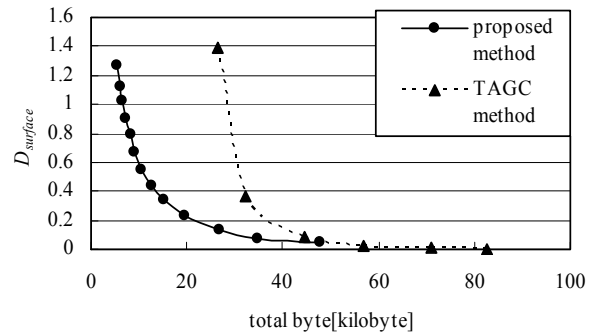


Fig.9 Coding performance for the simplified model shown in Fig.8(a).

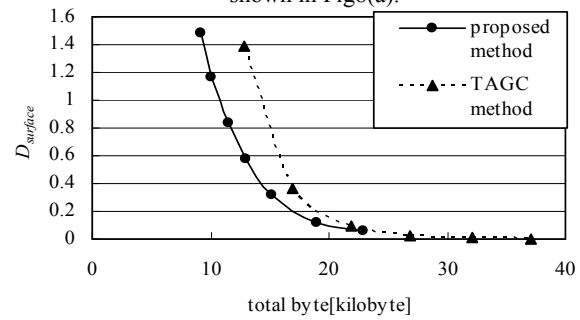


Fig.10 Coding performance for the simplified model shown in Fig.8(b).

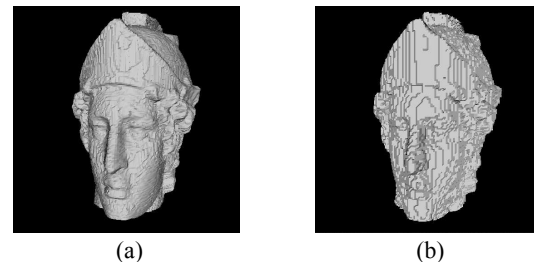


Fig.11 Reconstructed models for "statue": (a) by proposed method (26754 bytes), and (b) by TAGC method (26628 bytes).

museum," *Proc. Int. Conf. Image Processing*, Thessaloniki, Greek, pp.555-559, 2001.

[2]G. Toubin, W. P. Horn, F. Lazarus, and J. Rossignac, "Geometry coding and VRML," *Proc. IEEE*, vol.86, no.6, pp.1228-1243, Jun. 1998

[3] H.Hoppe, "Progressive Mesh," *Computers Graphics (SIGGRAPH '96 Proceedings)*,pp.99-108,1996

[4] J. W. Park, K. W. Song, H. Y. Lee, J. Y. Nam, and Y-H. Ha, "Topological surgery encoding improvements based on adaptive bit allocation and DFSVQ," *IEEE*

Trans. Circuits Syst. Video Technol. Vol.9, No.2, pp.370-377, Mar. 1999.

[5] S. Hirata, M. Tsunoda, K. Fukuda and A. Kawanaka, "Polygonal mesh data compression based on triangular lattice structuring and Wavelet Transform" *Proc. Int. Conf. Image Processing*, Rochester, USA, pp.241-244, 2002.