3D MULTIRESOLUTION CONTEXT-BASED CODING FOR GEOMETRY COMPRESSION

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ABSTRACT

In this paper, we propose a 3D geometry compression technique for densely sampled surface meshes. Based on a 3D multiresolution analysis (performed by a 3D Discrete Wavelet Transform for semi-regular meshes), this scheme includes a model-based bit allocation process across the wavelet subbands and an efficient surface adapted weighted criterion for 3D wavelet coefficient coordinates. This permits to highly improve the visual quality of quantized meshes obtained by classical bit allocation based on MSE distortion. Moreover, the coefficients are encoded with an original 3D context-based bitplane arithmetic coder. The main contribution of this paper is the introduction of 3D multiresolution contexts adapted to 3D semi-regular mesh geometry information.

1. INTRODUCTION

Surface meshes are a powerfool tool for modeling complex 3D objects because of their simple representation (vertices and edges). In the triangular mesh setting, there are two distinct approaches: monoresolution representations, and multiresolution ones. A lot of methods belonging to the first framework can be found in [1, 2, 3, 4]. Generally these non progressive methods are only based on a specific reduced topology representation associated to scalar quantizations of geometric information. An overview of these kind of methods can be found in [5]. Despite the fact that wavelet representation and multiscale approach is very performant in image coding [6], multiresolution approach is relatively new for mesh coding. Few years ago, Lounsbery [7] introduced a progressive compression scheme using 3D multiresolution analysis and wavelet transform on meshes. Based on the rate-distortion theory, these kind of methods provides very good results. Then, Schröder, Sweldens and Kovacevic developed several 3D wavelet tranform techniques for geometry compression schemes like [8] or [9]. Other recent works showed that the multiresolution approach provides very efficient compression methods [10, 11].

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In order to optimize the trade-off rate-distortion, it is necessary to perform bit allocation across the different subbands. In our framework we proposed to dispatch the bits according a model-based allocation [12]. The models of rate and distortion are adjusted to fit the distribution of wavelet coefficients of each vertex coordinate subband [13, 14, 15]. Moreover, in this paper we propose to improve the encoding of the quantized coefficients by exploiting the spatial and multiscale correlations of the progressive meshes. For this purpose, we introduce three-dimensional multiresolution contexts in a context-based arithmetic coder.
This paper is organized as follows. Section 2 introduces backgrounds. Section 3 proposes our surface-adapted bit allocation. Section 4 deals with an original 3D multiresolution context-based coder. Finally, we compare our algorithm to state-of-the-art methods and conclude in Section 5.

2. OVERALL SETTING

Our geometry compression scheme is presented in figure 1. This method deals with surface semi-regular meshes obtained by remeshing methods [16, 17]. This permits to apply the Lifted Butterfly Wavelet Transform [9]. The resulting representation is a set of $(N-1)$ *high frequency* wavelet coefficients, a *low frequency* subband corresponding to a coarse version of the original mesh and the *topology* information of this coarse mesh. Wavelet coefficients are three-dimensional vectors $X_i = (X_{i,1}, X_{i,2}, X_{i,3})$, where i stands for the resolution index. The coordinate sets are processed separately and can be modeled by a *Generalized Gaussian Distribution* [13]: this permits to fasten the bit allocation. Note that the highly correlated low frequency subband requires a predictive preprocessing before encoding. Topology information is not treated here but can be encoded using any connectivity coder like [2, 14].

3. DISTORTION MEASURE AND ALLOCATION

3.1. Weighted distortion

The proposed distortion measure arises from the following statement: applying a noise on vertices according to their

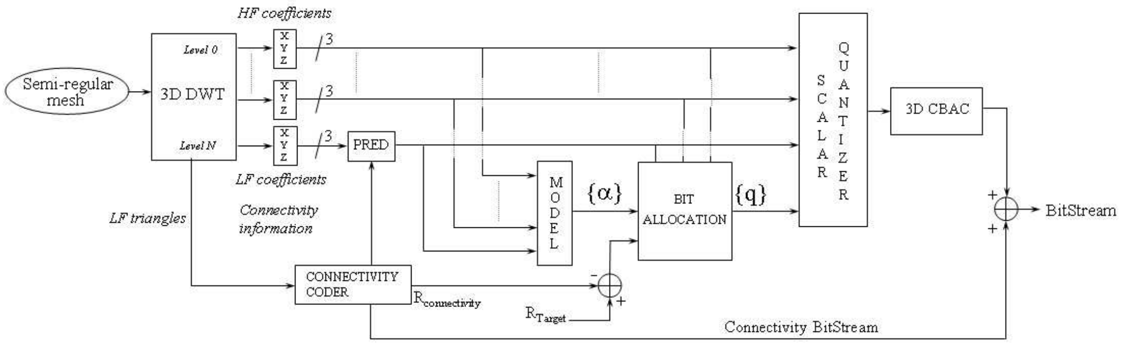

Fig. 1. Global Scheme.

tangent plane does not affect the overall shape. But applying the same noise on vertices according to their normal direction considerably changes the surface geometry. Since wavelet coefficients are computed in a local coordinate frame induced by the surface tangent plane (corresponding to x and y components, the z axis being the normal direction), the metric error is much less sensitive to quantization error of tangential (x and y axis) than normal coordinates (z axis). Thus, from a rate-distortion point of view, bits should be allocated preferentially to the local normal direction. To take into account this statement, direction selection weights $\delta_{i,j}$ are introduced in the criterion [15].

3.2. Bit allocation

The general purpose of our bit allocation process is to *determine the best set of quantization steps $\{q_{i,j}\}$ for each subband (in our case, set of coordinates $\{x_{i,j}\}$ for i and j fixed) that minimizes the total distortion D_T at a given rate R_{Target} (bits/vertex)*. By introducing Lagrangian operators, this constrained allocation problem can be written as:

$$J_\lambda(\{q_{i,j}\}) = D_T + \lambda(R_T - R_{Target}),$$

or equivalently,

$$\begin{aligned} J_\lambda(\{q_{i,j}\}) &= \sum_{i=0}^{N}\sum_{j=1}^{3} W_i \delta_{i,j} \sigma_{i,j}^2 D_{i,j}\left(\frac{q_{i,j}}{\sigma_{i,j}}\right) \\ &+ \lambda\left(\sum_{i=0}^{N}\sum_{j=1}^{3} a_{i,j} R_{i,j}\left(\frac{q_{i,j}}{\sigma_{i,j}}\right) - R_{Target}\right), \quad (1) \end{aligned}$$

where $\sigma_{i,j}^2$ is the variance of the subband i, j. The coefficients $a_{i,j}$ depend on the subsampling and correspond to $a_{i,j} = size(\{x_{i,j}\})/(3 \times \#$ semi-regular vertices$)$. $D_{i,j}$ and $R_{i,j}$ are respectively the distortion and the bitrate of each subband which depend on the quotient $\frac{q_{i,j}}{\sigma_{i,j}}$.

The weights W_i depend on the non-orthogonality of the wavelet filter bank. Indeed, using biorthogonal filters weights the MSE distortion of the reconstructed quantized mesh. Their values can be found in [15].

The direction selection weights $\delta_{i,j}$ are introduced to allocate more bits to the normal information. They are related to the resolution level: from coarser to finer levels, geometric information ratio between normal coordinates and tangential coordinates are more and more important. In [15], we propose to choose these weights related to the resolution level. They are given by:

$$\begin{cases} \delta_{i,j} = 2^{N-i} & \text{for } j = 3 \text{ (z axis);} \\ \delta_{i,j} = 1 & otherwise. \end{cases}$$

Minimization of (1) according to $\{q_{i,j}\}$ and λ gives the optimal sets of quantization steps $\{q_{i,j}^*\}$. Bit allocation solutions use theoretical models for $D_{i,j}$ and $R_{i,j}$ [12]. They are given in [13, 14] for the non-weighted criterion and in [15] for the weighted one.

4. PROPOSED 3D CONTEXT-BASED CODER

4.1. Problem statement

Once quantized using the optimal quantization steps found in section 3, the subbands are coded through a Context-based Bitplane Arithmetic Coder (CBAC). Dealing subbands with a coder using contexts computed from the neighborhood and parent-children relations of wavelet coefficients is a good way to exploit all correlations of semi-regular meshes. In this way, we introduce here *3D spatial contexts adapted to geometric data*.

Recall that input meshes are semi-regular and multiscale: each triangle of one resolution level is subdivided to form the finer mesh at next resolution. Topologically, subdivision is done by inserting midpoints on the edges and quadrisecting the triangle. Figure 2 describes the topology representation for a vertex X_i of a semi-regular mesh.

As it was explained in section 3, wavelet coefficients are computed in a local coordinate frame induced by the surface tangent plane corresponding to x and y component, z axis being the normal direction. It arises from this a close relation between subbands of x and y components. Then, we can define two kinds of geometric contexts:

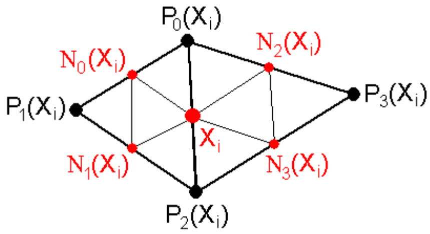

Fig. 2. 1-Neighborhood topology for a vertex: the set $\{N_k(X_i)\}$ is the 1-neighborhood of X_i at the same resolution level and $\{P_k(X_i)\}$ the "parent" vertices at the lower resolution level.

- a context for "tangential information" (x and y axis);
- a context for "normal" information (z axis).

Neighbors states used to form the context are presented in the following tables 1, 2 and 3. Then, context values are computed using [6] and an arithmetic coding is performed for each context.

4.2. Tangential context

The quantized x and y components obtained by our bit allocation process are relatively close (same variance, same order of magnitude): this arises from the fact that they depends on the "tangential" information at each vertex. Moreover, two spatially close coefficients are highly correlated. To exploit this correlation, we choose to predict a x-component (respectively y-component) from the x and y-components of its 1-neighborhood $\{N_k(X_i)\}$. In other words, the contexts used to encode subbands of "tangential" components (the sets $\{x_{i,1}\}$ and $\{x_{i,2}\}$ for each resolution level i) depends on the values $\{x_{i,1}\}$ and $\{x_{i,2}\}$ of their "tangential" 1-neighborhood $\{N_k(X_i)\}$. Tables 1 and 2 show how the components are organized in the new contexts for tangential coordinates.

$N_1(x_{i,2})$	$N_0(x_{i,1})$	$N_0(x_{i,2})$
$N_1(x_{i,1})$	$x_{i,1}$	$N_2(x_{i,1})$
$N_3(x_{i,2})$	$N_3(x_{i,1})$	$N_2(x_{i,2})$

Table 1. Tangential context used to encode a coordinate $x_{i,1}$ (x axis).

$N_1(x_{i,1})$	$N_0(x_{i,2})$	$N_0(x_{i,1})$
$N_1(x_{i,2})$	$x_{i,2}$	$N_2(x_{i,2})$
$N_3(x_{i,1})$	$N_3(x_{i,2})$	$N_2(x_{i,1})$

Table 2. Tangential context used to encode a coordinate $x_{i,2}$ (y axis).

$P_1(x_{i,3})$	$N_0(x_{i,3})$	$P_0(x_{i,3})$
$N_1(x_{i,3})$	$x_{i,3}$	$N_2(x_{i,3})$
$P_3(x_{i,3})$	$N_3(x_{i,3})$	$P_2(x_{i,3})$

Table 3. Normal context used to encode a coordinate $x_{i,3}$ (z axis).

4.3. Normal context

To obtain the "normal" context, we first exploit the high correlation existing between spatially close coefficients. Hence, as for the tangential information, the main information for a z-component in the "normal" context is the z-component of its 1-neighborhood at the same resolution $\{N_k(X_i)\}$. Moreover, introducing the 1-neigborhood corresponding to the "parent" vertices to predict a z-component permits to exploit the relation between a coefficient and its "parents" $\{P_k(X_i)\}$ at the lower resolution level. Table 3 shows the corresponding multiresolution context for a "normal" coordinate set $\{x_{i,3}\}$.

5. RESULTS AND CONCLUSIONS

Tables 4, 5 and 6 show bitrate gains provided by the arithmetic coding using the proposed 3D multiresolution contexts compared to the arithmetic coder from JPEG200 [6] for three models. Using the proposed 3D multiresolution contexts with CBAC coder decreases the bitstream size up to 6.95% at some rates compared to the coder from [6]. Then, we compare the performances of the proposed coder with two well-known compression methods: Touma-Gotsman [2] and PGC [10]. The quality criterion is the PSNR computed with the surface-to-surface distortion measure obtained by MESH [18] (see figure 3). Our connectivity information is encoded with the Touma-Gotsman method [2]. The proposed algorithm provides very good performances: it reaches the accuracy of the PGC method. Furthermore, the proposed algorithm has low computational cost since it includes a model-based bit allocation.

R_{Target} (bits/vertex)	Bitstream size (bits)		
	3DCBAC	[6]	Gain %
0.18	19823	20900	**5.1**
0.3	31067	33300	**6.7**
0.6	57002	61264	**6.95**
1.2	110467	117684	**6.13**
1.8	171731	181300	**5.28**
3.0	310615	322053	**3.55**

Table 4. Horse model: CBAC with proposed multiresolution contexts versus monoresolution coder from [6].

R_{Target} (bits/vertex)	Bitstream size (bits)		
	3DCBAC	[6]	Gain %
0.18	21761	22546	**3.48**
0.3	35450	36947	**4.05**
0.6	67905	71438	**4.95**
1.2	135555	142433	**4.83**
1.8	211517	221154	**4.36**
3.0	389622	402779	**3.27**

Table 5. Bunny model: CBAC with proposed multiresolution contexts versus monoresolution coder from [6].

R_{Target} (bits/vertex)	Bitstream size (bits)		
	3DCBAC	[6]	Gain %
0.18	44875	46754	**4.02**
0.3	71981	75075	**4.12**
0.6	140537	147598	**4.78**
1.2	296240	310233	**4.51**
1.8	405035	425739	**4.86**
3.0	561063	590844	**5.04**

Table 6. Feline model: CBAC with proposed multiresolution contexts versus monoresolution coder from [6].

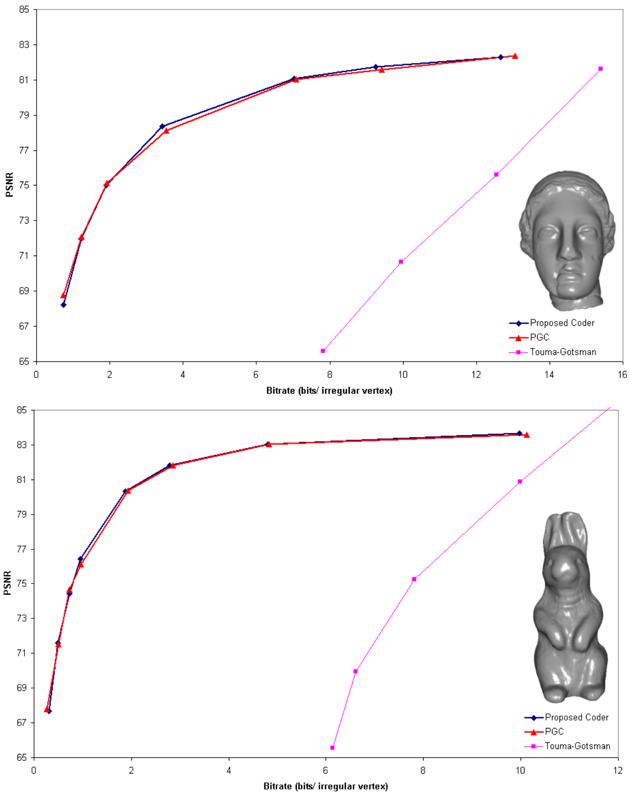

Fig. 3. PSNR vs Bitrate for Venus and Rabbit objects.

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