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A New Watermarking Method of 3D Mesh Model

Liu Jing*, Wang Yinghui, He Wenjuan, Li Ye
Faculty of Computer Science and Engineering, Xi'an University of Technology, Xi'an 710048, China
*Corresponding author, e-mail: liujing@xaut.edu.cn

Abstract

A new watermarking method for 3D model robust to geometric attacks is presented. The algorithm firstly uses average normal of the part with the obivious geometric feature in the 3D model to establish coordinate system, which is not affected by geometric attacks such as translation, rotation and scaling; Embed the watermarking information into the appropriate vertices selected according to area of 2-ring neighbours of each vertex; Embedding strength adaptively adjusted in terms of curvature of the model facet. The choice of embedding position and the embedding strategy above effectively guarantee good transparency and maximum robustness of the proposed algorithm. Simulation results indicate the ability of the proposed method to deal with the some attacks more than satisfactory results.

Keywords*: 3D model, geometric feature, average normal, coordinate system, 2-ring neighbour*

1. Introduction

With many new technologies for representation,storage and distribution of digital media information becoming available, the applications of 3D model are quickly increasing in number and the necessity to protect copyrights of 3D model is becoming crucial. Watermarking has been considered a potential efficient solution for deterring illegal copies of 3D model.

In the last decades,numerous methods have been presented for the digital watermarking of 2D image, successfully solving a lot of difficult problems. But few algorithms of 3D model have been developed and tested with good performances. One of the main reasons is that many 2D image processing algorithms are very helpful to development of 2D image watermarking technology but these algorithms are not completely suitable for 3D model. At the same time, compared with 2D image, 3D model data are intrinsically complex to handle; There are more attacks to interfere with 3D model; There isn't a mathematical framework to provide an efficient tool for 3D model watermarking. So it is very difficult to develop robust watermarking algorithms for 3D model. At present, watermarking algorithms of 3D Model are divided into two categories according to the insertion area: spatial domain methods [1-7] embed the watermark by directly modifying invariants of the original model.For example, Ohbuchi [3] chose the ratio between the height of a triangle and its opposite edge length as primitive to construct a watermarking technique (TSQ). Benedens presented two techniques for embedding watermarks which are robust against remeshing and more specifically triangle reduction attacks,named Normal Bin Encoding [5] and Affine Invariant Embedding [6], respectively. The first method needs a model reorientation to provide successful detection. The second method withstands geometrical transforms but needs the original model for the detection. While in the frequency domain methods [8-16], the watermarking information is embedded by modifying coefficients of frequency domain which is wavelet analysis [8-10], Laplace transforms [11-13] or other transforms [14-16]. Frequency domain algorithms can provide better robustness ability.

In this paper, we proposed a new method for embedding watermark into 3D model represented as triangular meshes. Firstly, establish the reference frame by utilizing average normal of the area which has the obivious geometric feature; Project each component of the vertex coordinate separately onto the orthogonal coordinate axes in the reference frame; The positions embedded the watermarking information were selected according to area of 2-ring neighbous of each vertex; Embedding strength was adaptively adjusted in terms of curvature of the model surface. These strategies grant the method robustness to rotation, scaling and translation attacks.

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In the next section, based on the analysis of projective transformation, inserting position selection and inserting strength selection, we will introduce the embedding and extracting watermark procedure of our watermarking algorithm. Section 3 shows some of our experimental results and analyses. Finally, conclusion and some potential improvements in future work are given in Section 4.

2. A New Mesh Watermarking Algorithm

2.1. A Projective Transformation

3D model watermarking requirements are similar with those for 2D image watermarking. Such requirements include the non-perceptibility when watermark information is inserted into the 3D model.In addition, a watermark algorithm succesfully detects the watermark after the 3D model underwent geometric attacks and topological attacks. Geometrical attacks consist of rotation, scaling and translation. Topological attacks include changing the order of vertices in the 3D model, mesh simplification, mesh altering or cropping parts of the model. To settle above problems, numerous techniques can be applied. But these approaches have not achieved the desired effect. Our strategy is to convert the 3D data to the space which is invariant to rotation ,translation and scaling. Select a part with the obivious geometric feature in 3D model. The part is used to calculate the invariant space and not inserted the watermark. The average normal of the part is computed and decomposed into three components corresponding to the coordinate axes *u* ,*v* and *n* of the new reference frame; The center of the part is calculated using the following Equation (1), which is the origin of the new coordinate system.

$$v_c = \frac{1}{N}\sum_{i}^{N} v_i \qquad (1)$$

Suppose the original coordinate system is *Oxyz*, the new coordinate system is $\overline{O}uvn$. To invert the transformation, the orthogonal transformation $M_{Oxyz\rightarrow\overline{O}uvn}$ is computed as Equation (2):

$$M_{Oxyz\rightarrow\overline{O}uvn} = \begin{bmatrix} u_x & u_y & u_z & 0 \\ v_x & v_y & v_z & 0 \\ n_x & n_y & n_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \bullet \begin{bmatrix} 1 & 0 & 0 & -v_{cx} \\ 0 & 1 & 0 & -v_{cy} \\ 0 & 0 & 1 & -v_{cz} \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (2)$$

Multiply each vertex of the model with the matrix $M_{Oxyz\rightarrow\overline{O}uvn}$ to get the vertex coordinate in the coordinate system $\overline{O}uvn$. The watermark information is inserted in the coordinate system $\overline{O}uvn$. Divide the part into two using a plane which is perpendicular to the *u*,*v* or *n* axis and passes through the origin of the new coordinate system. Compute the mass center of each part Using the Equation (1). Obtain the distance between the mass center of the two part so as to achieve robustness against scaling attack.

2.2. Embedding Position Selection

In a watermarking algorithm, watermark information is added by modifying the vertex positions without causing the eye to perceive any change. The change is influenced by the surrounding geometry of the vertices. For example, perturbation of an isolated vertex in 3D model would not cause visual degradation in location of the vertex. However, if the isolated vertex is in the backdrop of a flat surface, the degradation is more perceptible. If the same vertex is on a bumpy surface, the degradation is invisible. Thus, the absolute position of the vertex is not important for watermarking, but its position relative to the local geometry determines whether the vertex is a good or bad candidate for watermark embedding. In this paper, the vertices to be inserted watermark information are selected from the positions where the vertices are densely distributed. Notice that the positions would not include the part of the 3D model which is used to calculate the invariant space in section 2.1. We selected 2-ring vertices [17] to represent the local set of each vertex.Suppose V_i is a randomly vertex in the 3D model, if an edge exists which connects V_i and V_k , the vertex V_k is a neighbor of the vertex V_i. The set of all neighbors of the vertex V_i is called 1-ring of the vertex V_i. The set of all neighbors of the 1-ring neighbors of the vertex V_i and its 1-ring neighbors are called 2-ring of the vertex V_i, which is expressed as T_{Vi} :

$$T_{V_i} = \left\{ V_k \middle| 0 \le \left| \overline{V_i V_k} \right| \le 2, k = 0,1,\cdots,T_i \right\} \quad (3)$$

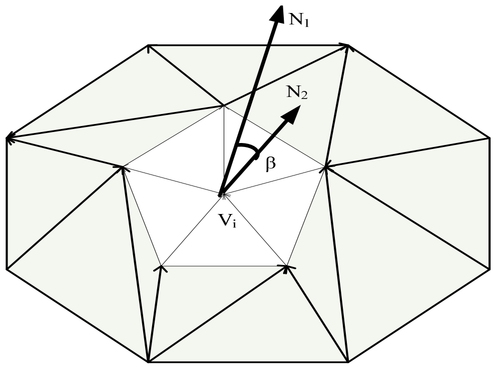


Figure 1. Neighbors of the Vertex V_i: 1-ring Displayed by White Patch, 2-ring Displayed by White and Gray Patches

Where $\left|\overline{V_i V_k}\right|$ represents the number between the vertex V_i and V_k, T_i expresses the valence of the vertex V_i. Figure 1 shows the 1-ring neighbours and the 2-ring neighbours of vertex V_i . The characteristics of the high-curvature area in the 3D model are that triangular patch area is relatively small and has relatively more vertex number. If watermark information is inserted in the neighborhood of the vertex located in the high-curvature area, the distortion can be masked by the surrounding geometric features. Suppose S_i is the local set area of the vertex V_i ,and represents the average area of all the triangular meshes in 2-ring of the vertex V_i . We can measure whether the vertex V_i is suitable for embedding watermark information by using the local set area S_i.

$$S_i = \frac{1}{N_i} \sum_{k=1}^{N_i} s_k \quad (4)$$

Where s_k is the area of the k_{th} triangular mesh in the 2-ring of the vertex V_i . Suppose that the three vertices of the k_{th} triangular mesh are $P_1(x_1,y_1,z_1)$,$P_2(x_2,y_2,z_2)$,$P_3(x_3,y_3,z_3)$, the area s_k is define as:

$$\begin{aligned} s_k &= \left|\overline{P_1P_2}\right| \bullet \left|\overline{P_2P_3}\right| \sin\theta \\ &= \begin{vmatrix} 1 & 1 & 1 \\ x_2 - x_1 & y_2 - y_1 & z_2 - z_1 \\ x_1 - x_3 & y_1 - y_3 & z_1 - z_3 \end{vmatrix} \\ &= \sum_{k=1}^{3} \left[\left(x_k y_{k+1} + y_k z_{k+1} + z_k x_{k+1} \right) - \left(x_{k+1} y_k + y_{k+1} z_k + z_{k+1} x_k \right) \right] \end{aligned} \quad (5)$$

Set a threshold value S_T, when S_k< S_T, the vertex V_i is a good candidate for watermark insertion. Notice that the vetices later selected can't fall within 2-ring neighbor of the vertex V_i .

In fact,we calculate the local set area of all vertices and order them from small to large according to their value and insert the watermark information into those vetices with smaller area of 2-ring. The capacity of the watermark information determines the threshold value S_T.

2.3. Embedding Strength Selection

Once vertices are selected for watermarking, the strength of watermark to be inserted in the vertex position depends on if there is perceptible degradation for the vertex. If a smaller watermark is inserted by modifying fewer bits in the vertex position, the watermark could be easily destroyed with watermarking attacks. If a higher number of bits are modied, the watermarked vertex could potentially cause perceptible degradation. Thus, the watermarking algorithm needs to be able to make a determination as to the maximum amount of watermark or bits to modify in the vertex without causing perceptible degradation. Curved surface is more curved, more the watermark information may be inserted. Curved surface consist of a number of smaller triangles. Normal variation usually gives a good indication of the surface curvature. For example, if the surface is flat, all the surface normals are parallel to each other and there is zero deviation of the average normal from each of the surface normals; If the surface is smooth, the deviation of the surface normal from the average normal is consistent with the deviation of the other surface normals from the average normal; If the surface has uneven curvature, the deviation of the surface normals from the average normal could be erratic [17]. In the paper,we are going to use curvature of the model surface to determine the amplitude of embedding watermark. We firstly calculate the average normal of the 1-ring and the 2-ring of the vertex V_i , respectively; Then, calculate the deviation angle β of the average normal of the 1-ring ($\vec{N}_1$, see Figure 1) from the average normal of the 2-ring ($\vec{N}_2$,see Figure 1); At last, use the parameter $\sin(\beta)$ to modulate the embedding watermark amplitude.In fact,when the deviation angle β is larger, it indicates that the surface is more curved, more the watermark capacity may be inserted.

2.4. Embedding Watermark

The watermarking algorithm of this paper embeds watermark by modifying the position of the vertices selected by using local set area. The data fomat of the 3D model to be embedded the watermark is triangle mesh, we assume that the watermark is a bit vector b ($b = \{b_1, b_2, b_3 \cdots, b_m\}, b_i \in (0,1), 1 \le i \le m$),and a seed number (stego-key k_w) generates pseudo random numbers $b'(b' = \{b'_1, b'_2, b'_3 \cdots, b'_m\}, b'_i \in (-1,1), 1 \le i \le m)$. Let us now consider modifying one component u of the vertex coordinate and modification processes for the other two components are identical. Let $V_{u,i}$ be the i_{th} vertex prior to watermarking corresponding to the coordinate axis u , $b'_i \in (-1,1)$ be the pseudorandom number sequence, and $\sin(\beta)$ ($\sin(\beta)$ >0) be the modulation amplitude. Watermarked i_{th} vertex $V'_{u,i}$ is computed by the following Equation (6):

$$V'_{u,i} = \begin{cases} V_{u,i} \times (1 + \sin(abs(\beta))) & if\ (b'_i = 1) \\ V_{u,i} \times (1 - \sin(abs(\beta))) & if\ (b'_i = -1) \end{cases} \qquad (6)$$

The extraction algorithm requires the same stego-key, which is a seed for the pseudo random number sequence used for the embedding. Applying the same procedure to v and n components of the vertex produces a set of watermarked vertices $V'_i = (V'_{u,i}, V'_{v,i}, V'_{n,i})$. Inverse-transforming the set of vertices ($\overline{O}uvn$) back into the original domain of vertex coordinates $V'_i = (V'_{x,i}, V'_{y,i}, V'_{z,i})$ by using the Equation (2) produces a watermarked triangular mesh.

2.5. Extracting Watermark

In this paper, watermark extraction is non-blind, that is, the detection procedure requires the original model. The extraction starts with searching the coordinate system by using the method presented in Section 2.1. The tested model and the original model are separately projected onto their corresponding to coordinate system; Calculate the local set area of 2-ring of all vertices, and the deviation angle β of the average normal of the 1-ring from the average normal of the 2-ring in the original 3D model. Then, produce two sets of vertices by choosing the smaller local set area. Compare the value of the two sets of vervices, get the difference $(V'_{u,i} - V_{u,i})$, sum over all of the three axes, and produce the overall sum ε:

$$\varepsilon = \frac{1}{3}\sum_{r\in\{u,v,n\}}(V'_{r,i} - V_{r,i}) \qquad (7)$$

$$b''_i = \begin{cases} 1 & if\ (\varepsilon / \sin(abs(\beta)) > 0) \\ -1 & if\ (\varepsilon / \sin(abs(\beta)) < 0) \end{cases} \qquad (8)$$

Where $V_{u,i}$ and $V'_{u,i}$ are the coordinate of the vertex V_i in the *u* axis of the original 3D model and the tested 3D model, respectively. b''_i expresses the watermark bit to be detected. Multiply with the same the pseudorandom number sequence b'_i as is used for the embedding, and produce the overall correlation ρ by the following Equation (9):

$$\rho(b', b'') = \frac{\sum_{i=1}^{m} b'_i \times b''_i}{\sqrt{\sum_{i=1}^{m} b'_i} \times \sqrt{\sum_{i=1}^{m} b''_i}} \qquad (9)$$

When $\rho > 0.5$, the watermark embedded is succesfully extracted.

3. Experiments and Results

In this section, we show some experimental results to verify the detection performance and robustness of the proposed method against various disturbances, including noise,smoothing, mesh simplification and similarity transformation (translation, rotation and scaling) [18]. The models used for testing were Cow (40286 vertices, 80422 facets), Standford Bunny (34834 vertices, 69451 facets).

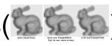
3.1. Watermark Invisibility

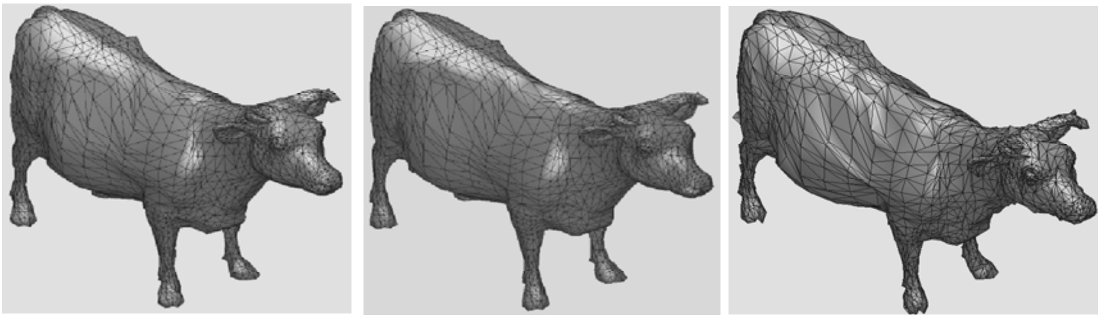
Figure 2 shows the model before and after embedding the watermark. The watermark is embedded in the 3D triangular mesh model. Figure 2(d), Figure 2(e) and Figure 2(f) are the rendering effect corresponding to their triangular mesh model (Figure 2(a) , Figure 2(b) and Figure 2(c)), respectively. Figure 2 illustrates the perceptibility of a watermark depends not only on the amplitude ($\sin(\beta)$) ,but also on the watermark capacity to be inserted. If we choose large embedding capacity, the difference of the original and watermarked model would be visible.In Figure 2, the 20% of vertices watermarked are less noticeable than the 50% of vertices watermarked.

3.2. Noise and Smoothing Attacks

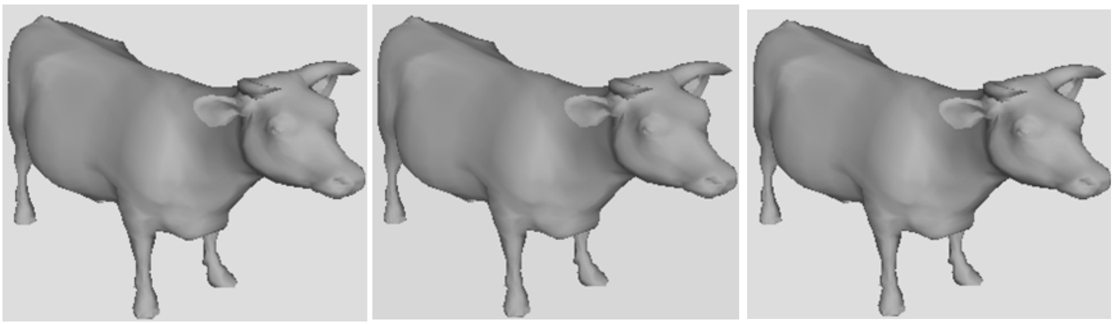
As discussed in Section 2, the choice of embedding position and embedding amplitude strategy meet several different robustness requirements, e.g., robustness against noise and robustness against smoothing. The embedding amplitude strategy makes the watermark more resistant to random noise added to vertex coordinates.However, the method of the local set area for choice that resulted from the embedding position would reduce the watermark's robustness against mesh smoothing.

Figure 3 shows the Bunny whose vertex coordinates are added with Gaussian noise with the different amplitude factor. The watermark could still be extracted despite the slight distortion of quality of the 3D model (see Figure 3(b)), But the watermarks failed to be extracted when the amplitude factor of Gaussian noise is more than 0.0005 () so that the degradations of quality is visible (see Figure 3(c)).

Figure 4 shows the method can resist against mesh smoothing as far as the smoothing does not degrade shape of the mesh too much. After an application of the Taubin's smoothing filter, the Bunny model looks smoother. Despite the changes(), the watermarks embedded into these models could be extracted.

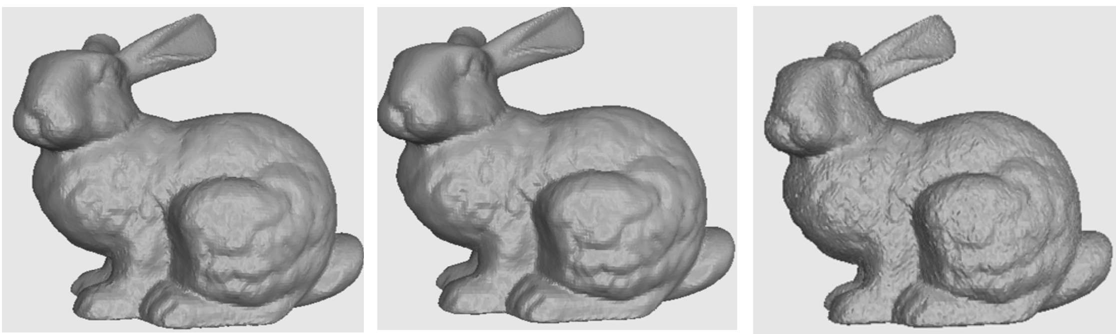


(a) The original 3D mesh model (b) 20% of vertices watermarked (c) 50% of vertices watermarked



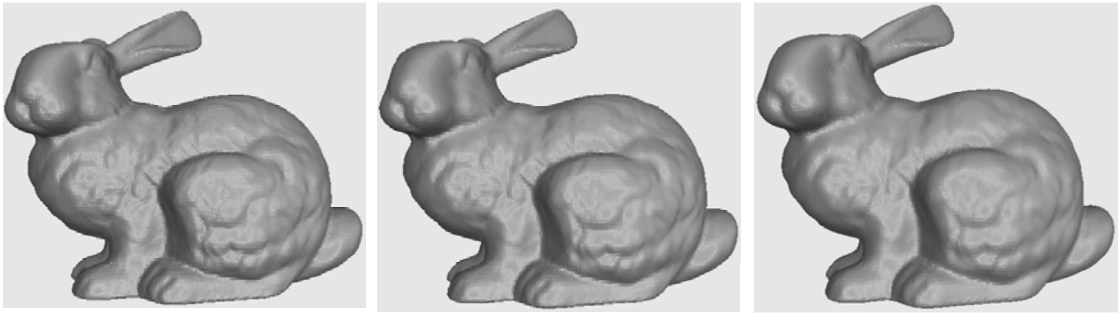
(d) Rendering effect of (a) (e) Rendering effect of (b) (f) Rendering effect of (c)

Figure 2. Visibility Tests of 3D Watermarking Method



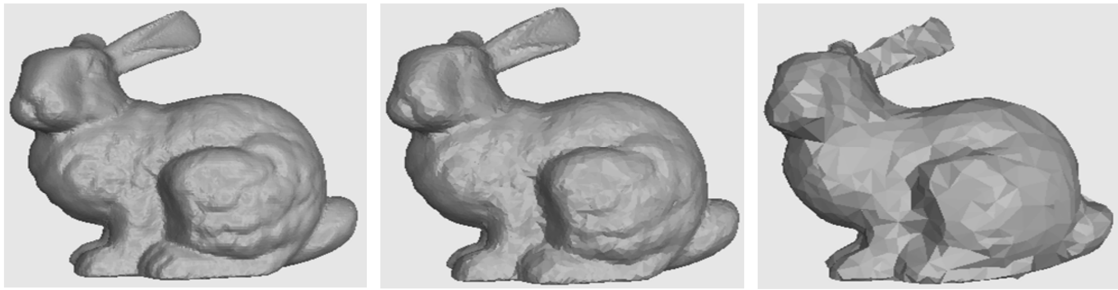
(a) The original Bunny (b) The noise Bunny (σ=0.0001) (c) The noise Bunny (σ=0.0005)

Figure 3. The Noise Attacks on Bunny



(a) The Smooth Bunny (k=0.08) (b) The Smooth Bunny (k=0.2)) (c) The Smooth Bunny (k=0.4)

Figure 4. The Smooth Attacks on Bunny



(a) Bunny (2% reduction) (b) Bunny (5% reduction) (c) Bunny (20% reduction)

Figure 5. The Simplification Attacks on Bunny

3.3. Mesh Simplification

As far as the mesh simplification attack, the algorithm makes full use of the average normal direction of a group of facets and the distances of a group of vertices to the mesh centre to resist it. Of course, the method is less robust because the geometric positions of the vertex are changed and the synchronization information is discarded. Figure 5 illustrates that the method can extract the watermark when less than 5% of meshes are simplified.

3.4. Similarity Transformations

Watermarks embedded by using the proposed method are robust against similarity transformation, for the transformation can be identified and inverted by using the method described in Section 2.1. Table 1 shows that the algorithm is able to extract the watermark when the tested models (Cow and Bunny) are subjected to mild acceptable scaling, rotation or translation attacks.

Table 1. The Correlation Value (ρ) of Extraction Watermark from the Various Attacks

Translation	Rotation			Scale			
	1^0	2^0	5^0	0.9	0.99	1.001	1.009
ρ>0.95	ρ>0.89	ρ>0.66	ρ<0.43	ρ<0.53	ρ>0.73	ρ>0.81	ρ<0.55

4. Conclusion

A novel 3D model watermarking method was proposed in the paper. The transfomation makes the method resist the geometric attacks such as rotation,translation and scaling. The choice of embedding position and the embedding strategy used in the paper help to guarantee good transparency and maximum robustness of the watermark. Simulation results demonstrate that the proposed method can give good results even for small values of the embedding power and deal with the geometric attacks more than satisfactory results. In the future, we would like to research mesh watermarking based on geometric feature which might allow the watermark method more robust yet less perceptible. Future work will also address the possibility of retrieving the watermark after that the mesh has been processed by re-triangulation or re-sampling.

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