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A Locatable Zero Watermarking Scheme and Visualization for 3D Mesh Models

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Abstract

Nowadays, most 3D mesh model protections are based on embedding watermarking system. These methods have to change the original mesh data to achieve the watermarking. Considering the sensitivity and complexity of 3D mesh data, this paper proposes a disturbing free 'zero-watermarking' algorithm, which is based on octree partition. For each octant, we employ parameterization and Singular Value Decomposition (SVD) to analyze the 3D geometry signal and construct the zero-watermark with corresponding octree-codec. The integrity of protected 3D mesh can be checked through computing the similarity of watermark between original and processed mesh. Moreover, the results are represented in a visual way, which means the tendency of deviation and changed region will be colored according to our merits of similarity. The Experiment results verify that the algorithm is robust to various attacks including affine transformation, vetex reordering, noise addition, cropping, simplifying, and even mixed attack.

Keywords--- Zero watermarking; Octree; Planar parameterize; SVD; SSIM; Visualization

1. Introduction

Along with the explosive growth of 3D products for the animation and CAD, the problem of copyright protection for 3D models has attracted more and more attentions recently. Digital watermarking is one solution for this problem. The basic idea of watermarking technique is watermark embedding and detection. However, since the process of embedding will disturb the data of 3D triangular mesh (the most prevalent presentation of 3D models), it is not appropriate for 3D mesh. For example, many kinds of 3D models, like the architectural ones, are very sensitive to microscopic changes, which could cause enormous altering of structural properties.

An approach called 'zero-watermarking' is needed to change the traditional methods that watermark is embedded into the objects, so that the watermarked item is distortion-free. There have been some achievements in the 2D image zero watermarking research [22][23]. But the research on zero watermarking for 3D mesh models is just at the beginning. In this paper, a robust zero-watermarking method based on octree-codec would be described, which can resist both global and local attack. On the whole, our scheme consists of two steps: generating zero-watermark of original mesh without embedding, detecting the zero-watermark from the processed mesh without the orginal one. We also visualize the changed-region on the original or processed 3D models after compute the similarity of watermarks between them. In this way, not only can we achieve the goal of integrity checking, but also locate the changed-region and visualize the tendency of derivation by means of our merit of similarity. There are many possible applications: mesh simplification, reverse engineering (comparison between a CAD model and a numerical model of the real object), mesh segmentation, mesh processing algorithm characterization, etc.

2. Related Work

In 1997, Ohbuchi [11] presented the first digital watermarking algorithm for 3D mesh models in the Proceedings of ACM Multimedia 97. This showed that digital watermarking technology had transferred from 2D multimedia to 3D polygonal models. In the following year, they published many correlative articles [9] [11] [15] [14] [10]on the mesh watermarking. Subsequently, many new methods were proposed. According to the domain which the watermark was embedded in, these algorithms can be classified into two categories: spatial domain watermarking and transform domain watermarking.

Two of the most representative and historic spatial domain methods are the Triangular Similarity Quadruple (TSQ) and the Tetrahedral Volume Ratio (TVR) [9]. Praun and Hoppe [16] applied Spread-spectrum filters to the triangular mesh. The basic idea of the Wanger's method [21] is embedding the watermark into the pixel value's lower bits. Benedens proposed two kinds of watermarking algorithms with high capacity [1]: Vertex Flood Algorithm (VFA) and Temporal Frame Averaging (TFA). Besides, he also developed other two methods named Normal Bin Encoding and Affine Invariant

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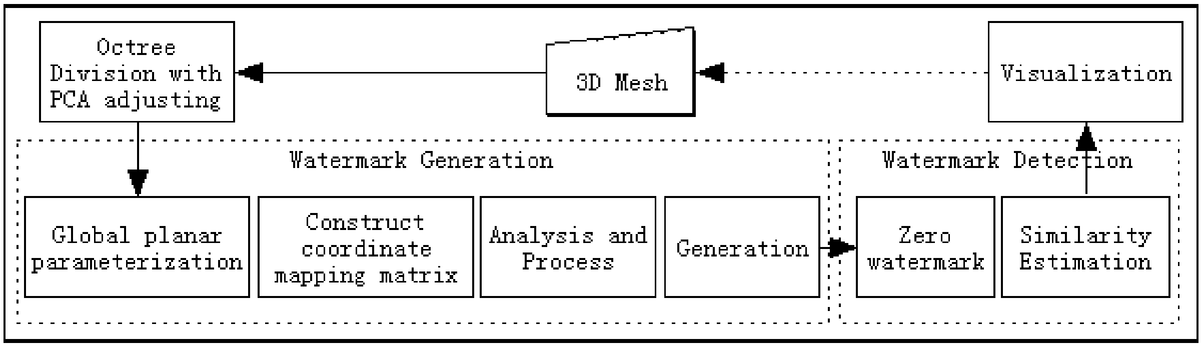


Fig1. Flow Chart of Algorithm Proposed In This Paper.

Embedding, both are based on the surface normal's alteration [12], which can withstand the simplification attack only. The first transform domain watermarking method was presented by [3], who implemented the lazy wavelet transform to decompose the mesh model into a spectral domain. Yin [25] employed the multi-resolution decomposition of polygonal mesh shapes to separate a mesh. Ohbuchi [13] used eigenvectors of the Laplace matrix as the orthogonal basis to get the pseudo spectrum of vertices' coordinates. This approach performs well but needs large amount of computation. Another method proposed in [19] was mainly based on two ideas: PCA (Primary Component Analysis) preprocess method for 3D meshes given in [7], and lossless octree coding theory proposed in [2]. It has a big embedding space and is robust against translation, rotation, uniform scaling and vertex reordering attacks with blind detection. But the way to present the relativities between two models is challenged and this method can not locate the changed-regions on the 3D models.

Nevertheless, all of the algorithms above have to disturb the data of meshes to perform embedding. In our zero-watermarking scheme, we use watermarking generation instead of embedding. Inspired by Zhou's framework [26] for geometric signal processing, we transform the original signals defined on meshes to planar signals. Therefore, we can easily generate watermark by using 2D multimedia watermarking techniques. Visualization is a more effective way to analyze and compare 3D meshes. Silva [20] provided a method to represent the computed figures of merit, but it fails in visualizing the differences between the merits of two meshes. We improve several steps and adjust it to showing our results.

3. Zero Watermarking Schemes for 3D Mesh Model

The method proposed in this paper is suitable for the triangular mesh model only. Figure 1 shows the process of this scheme.

3.1. Octree partition and codc

Various types of spatially-based tree structures have been found to be effective in supporting searching operations [17] and domain discretization operations [18] [24]. The specific tree structure investigated here is an octree structure. We introduce octree partition for four reasons:

1) Multi-scale solution;
2) Locate changed-region;
3) Low time complexity;
4) Invariant to uniform scaling and translation.

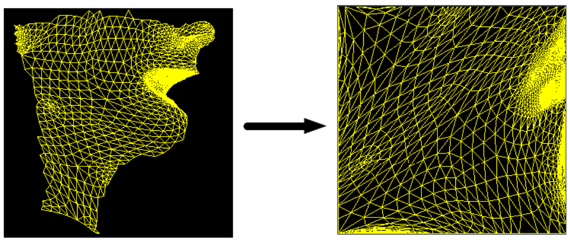
The octree structure can be defined by enclosing the domain in a mesh which represents the root of the octree, and then subdividing the whole mesh into the eight octants of the root by bisection in all three directions. Those octants are then recursively subdivided to whatever levels are desired (we specify the level to 5 in our experiment). However, there is an exception in the subdivision process when the octants turn out to be a disconnected or a non-convex 3D mesh, which is not isomorphic with any 2D plane. In that case, we continue subdividing until the all of the octants meet the requirements of a convex triangular mesh, serving as a proper input for parameterization. In addition, because octree partition is very sensitive to rotation of 3D meshes, PCA is used to preprocess 3D meshes to make sure the model at a unique posture [19].

3.2. Zero Watermark Generation

In this section, the methods used in generating zero-watermark will be described in detail. For each node in octree the following steps are performed:

(1) Planar parameterization. The mean value coordinates parameterization method is introduced by Floater [4] [5].

By deriving an application of the mean theorem for harmonic functions, the barycentric coordinates are unconditionally positive. This method is an approximation of the discrete conformal mapping, a guaranteed one to one mapping when the border is convex. Fig 2 shows the result of Floater parameterization with a square border. Points with three dimensional coordinates in space have been mapped to points on the plane.



Original Mesh   Parameterized Mesh

Fig 2. Floater Parameterization

(2) Construct coordinate mapping matrix. Setting the same interval in x coordinate and y coordinate, the parameterization plane is separated into blocks with the same size. Count the number of vertices which in the sub-block and construct the $N \times N$ mapping matrix by filling the amount of the points into the corresponding cell.

(3) Analysis and Process. The PCA and DWT have been used to preprocess image [6]S. However, singular value decomposition is a more effective feature extraction method because the singular values have such properties: 1) can capture the basic structure of the matrix data and represent the matrix's algebra nature; 2) are not sensitive to the distortion of the data. The SVD is performed on $M \times N$ matrix A:

$$A = USV^T \tag{1}$$

Where U and V are $M \times M$ orthogonal matrix and $N \times N$ orthogonal matrix, respectively, and S is a $M \times N$ diagonal singular value matrix. Elements on the diagonal line are named singular values of the image matrix A. We break the $N \times N$ mapping matrix into $K \times K$ sub-matrix, and then run the local SVD on these sub-matrices respectively. After that, the result will be $(N \times K)^2$ vectors which contain K singular values in the ascendant order.

(4) Generation. Loss of the significant information is inevitable along with the decrease of dimensions. Therefore, the high similarity between zero watermark vectors extracted from different 3D models is a big problem all the zero-watermarking methods are facing. There is a trend of rapid decay when sorting the Singular Values in descending order, so it is the previous largest singular value reflecting the main features of the matrix. We construct the zero-watermark using following formula:

$$WM = S_F \times W + S_S \tag{2}$$

Where S_F is the first biggest singular value, S_S is the second biggest singular value and W represents the weight of S_F. WM is the watermark of a single singular value vector and $(N \times K)^2$ numbers of WM construct the watermark vector. Due to characteristics of the mean value coordinates parameterization, the amount of points in the central part of the plane is larger than the boundary area. When converted to the mapping matrix, the values in the middle become bigger correspondingly. This will make some peaks appear in the watermark vector. The acme's value is so huge that the balance between each part is destroyed. We re-balance the watermark vector by limiting the biggest value of the vector. A threshold T_V is used. Once WM exceeds this threshold, set it to T_V S.

After generating the watermark vector for every node in the octree, we use the corresponding codec to encode and then register them in the IPR information database. Finally, the triangular 3D mesh model will be protected by the legitimate copyright.

3.3. Watermark Detection

First, the zero-watermark (a set of watermark vectors with corresponding codec) registered in the IPR information database will be extracted. Second, calculate the size of the sub-block $K = N / \sqrt{L}$ with the length of watermark vector L. Third, perform PCA preprocess described in [19]. Next, the watermark blind detection begins. See Tab. 1 for the pseudocode of this process.

Algorithm 1: WATERMARKDETECTION($ObjectMesh$)

$SubParts[8] \leftarrow OctreePartition(ObjectMesh, Level);$
for each $Mesh \in SubParts$
do
  if $!isConvex(Mesh)$ **or** $!isConnected(Mesh)$
  then $WmDetec(Mesh, Level + 1);$
  else $C_c \leftarrow GetCurrentCode();$
    $V_w' \leftarrow GenWmVec(Mesh);$
    $V_w \leftarrow ExtWmVec(C_c, RegWm);$
    $q \leftarrow SSIM(V_w, V_w');$
    if q = 1 **or** $Level >= 5^{th}$
      then $Q \leftarrow Save(q, C_c);$
      else $WmDetec(Mesh, Level + 1);$

The similarity of V_W and V_W' could be analyzed by correlation test [8]. However, it focuses on the difference between each other but ignores the structure signal inside the matrix. Instead of the correlation test, we use the Structural Similarity Index Method (SSIM) introduced in [27]. This theory assumes that the Human Visual System mainly depends on the structure information, and changes to the structure of the image will affect its quality. The similarity measurement system is a combination of three comparisons: Luminance Comparison, Contrast Comparison and Structure

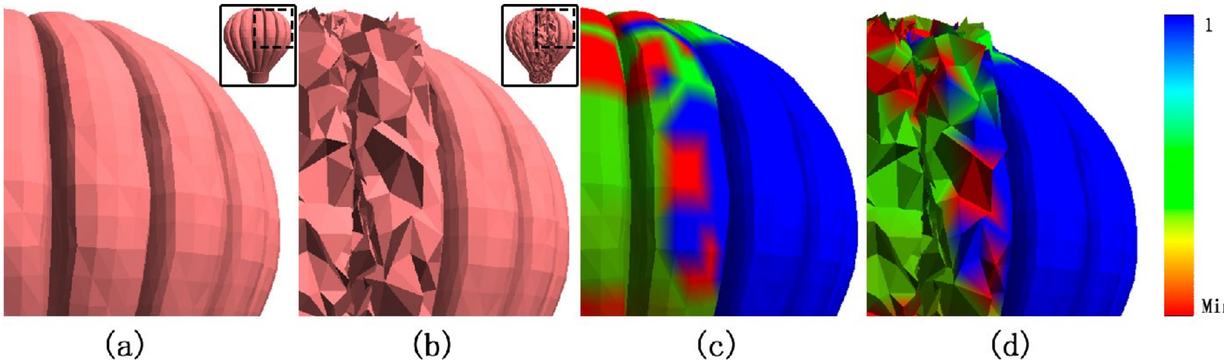


Figure 3: Visualization Mode with Color Scale. (a) is original mesh; (b) is deformed one. (c) and (d) are visualized results on original and deformed models. The whole mesh are showed on the top right corner.

Comparison. The overall structure similarity measure between signals X and Y is:

$$SSIM(x,y)=\frac{(2\mu_X\mu_Y+c_1)(2\sigma_{XY}+c_2)}{(\mu_X^2+\mu_Y^2+c_1)(\sigma_X^2+\sigma_Y^2+c_2)} \quad (3)$$

Where μ_X is the mean intensity, σ_X is the standard deviation. The constant c_1 and c_2 are included to avoid instability when both ${\mu_X}^2+{\mu_Y}^2$ and ${\sigma_X}^2+{\sigma_Y}^2$ are very close to zero. And the σ_{XY} can be estimated as:

$$\sigma_{XY}=\frac{1}{N-1}\sum_{i=1}^{n}(X_i-\mu_X)(Y_i-\mu_Y) \quad (4)$$

Psossible value of SSIM is a number between -1 and 1.

3.4. Visualization

After watermark detection, we get a set of SSIM values Q with octree-codec. However, it is still difficult to quantify the value of two meshes' difference because SSIM describes a general trend but not accurately. So we represent the difference in a visual way. In our visualization mode, we present the original model, the processed model and two colored model. Although the colored model is similar to the original model, the presence of color can mask some features, which is the reason why the original model is also presented. Figure 3 shows this visualization mode. (c)(d) are colored using a rainbow color scale, mapping the SSIM value 1 to blue and the minimum value obtained to red.

In fact, the rainbow color map should not be perceived as being linear, so mapping values linearly is not strictly correct. However, we use it because we are focusing on basically qualitative information rather than quantitative information.

4. Experiments

To evaluate the robustness of the proposed scheme, computer simulations are performed. In the experiment, the size of the mapping matrix is set to 512×512; and the size of the sub-block is set to 64 × 64. Correspondingly, the length of zero watermark vectors is 64. All the models selected in the test are the triangular mesh models.

There are two kinds of similarity: one is between the different models' zero mark, the other is between the same original model's zero marks. If the distinction between the two categories is not obvious, the algorithm's reliability will be questioned. So we test the SSIM values between 4 different models' watermark vector respectively, and all of these values are less than 10^{-2}, showing a good reliability of our algorithm.

To test the performance of the algorithm against the attacks, we examine lots of common attack methods. The following explains why the zero watermarking scheme show robustness against these attacks.

In general, we classify attack into two catalogues: the lossless attack and the lossy one. We regard translating, uniformed scaling, rotating and vertex reordering as lossless attack. Translating and uniformed scaling attack is invariant in the Octree partition step; rotating attack is adjusted in PCA preprocess; vertex reordering could be solved by parameterization, because the distribution of points in the plane and the relative position of each point are irrelevant to grid topological data which is changed. We regard cropping, tampering, simplifying and disturbing as lossy attack. Local attack, like cropping and tampering, can be accurately marked in our colored model; global attack, like simplifying and disturbing, will also be demonstrated according to the differentiation. Figure 4 illustrates our scheme on the evil head model. Our scheme has detected the deformed region, which is marked by rainbow color scale.

4. Conclusions and Further Work

This paper proposed a novel zero-watermarking scheme and visualization for 3D triangular mesh model. The proposed octree-based scheme can generate zero-watermarking and locate unauthorized modifications even if multiple illegal changes are made on a model simultaneously. For the zero-watermarking process, the proposed system parameterizes the 3D mesh into 2D

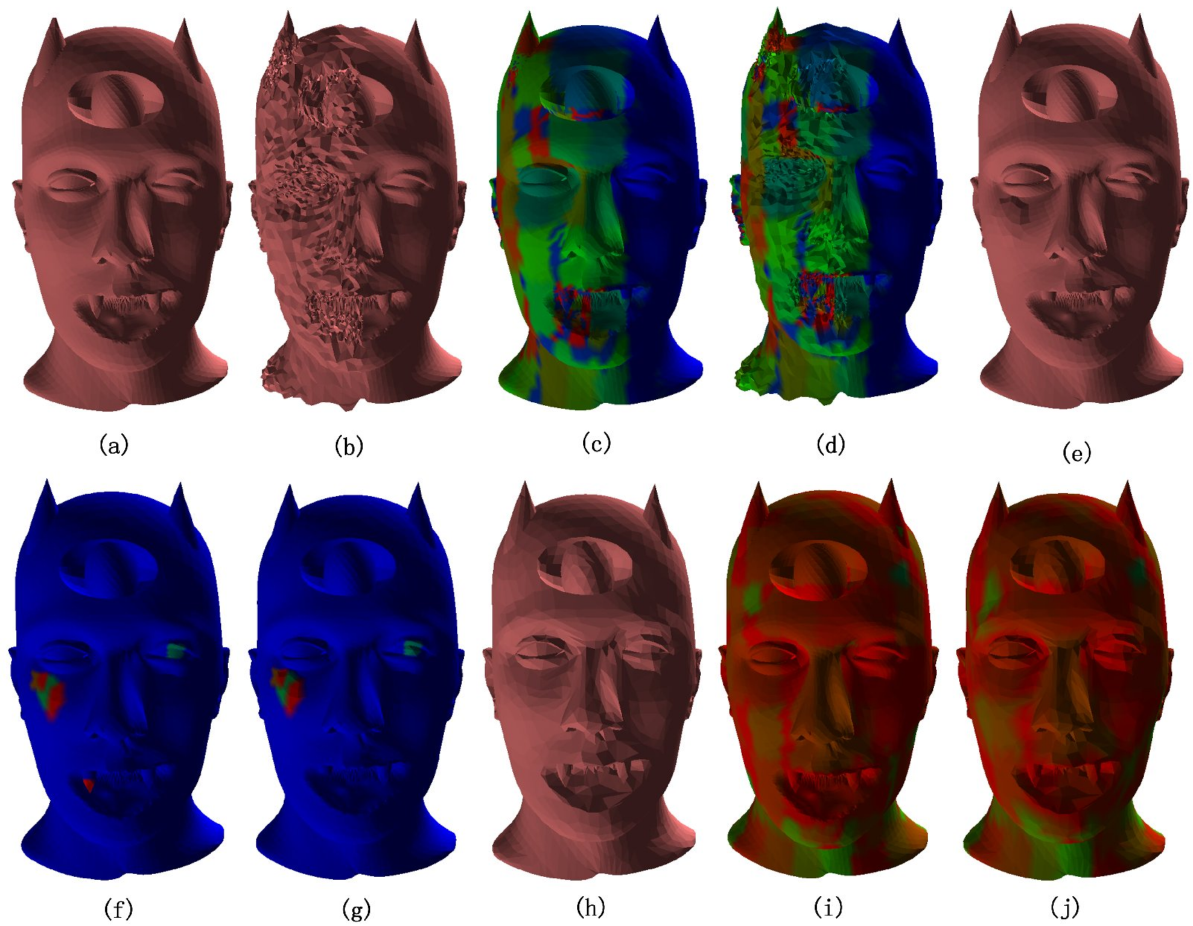


Figure 4: Results. (a) is the original model. The evil head model has 12,977 vertices and 25,888 faces. (b) (e) (h) are the same view of the deformed model. (c) (f) (i) and (d) (g) (j) are results visualized on original model and deformed one. (b) (c) (d) are half-global disturbed attacked models and its visualization,(e) (f) (g) are local attacked model examples, (h) (i) (j) are global simplifying ones.

mesh, and then transforms it into the coordinate mapping matrix, which is considered as the source signal of watermark construction. We employ the SVD to analysis the matrix and construct the zero-watermark. After that, we introduced a way how to use the SSIM to evaluate the watermarks' similarity. As a result, we locate unauthorized modifications on the mesh and color it using a common color scale.

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