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A Mesh Watermarking Approach using Subdivision Techniques

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1. Introduction

In recent years, with the fast development of Internet, more and more 3D mesh models are being spread on Internet. Like text, image, video, protect the copyright of 3D model is also important. 3D mesh as an important 3D geometric model is used widely. But, there are still many problems in the structure of 3D mesh. First, it is just only polygon surface that makes up the 3D mash, as a result, to form a high-quality model demands gigantic amount of data, which is not helpful for data to be transmitted on Internet. Second, 3D mesh is made up of vertex and surface. Such elements can be combined into various ways of presentation. Consequently, no fixed sequenced standard for each set of these elements of the 3D mesh data is achieved. In this case, the watermarking scheme for the sequenced data such as static image and sound cannot be directly used in 3D mesh. However, the multiresolution representation such as Subdivision Surface has provided a good way to cope with the problem of the amount of data representing and transmitting. Moreover, it provides a new way for the 3D mesh Watermarking technology. In order to be fit for a various change of 3D model, we propose a new mesh watermarking approach by modifying the feature vertex coordinates that was selected when models were subdivided. Results show our approach effectively improves the capacity and enhances the robustness of mesh watermarking.

2. Loop's subdivision with features

Subdivision Surface uses arbitrary polyhedron as control mesh, and forms smooth surface by subdivision according to control mesh automatically. Generally, a subdivision consists of splitting and positioning. Loop Subdivision Scheme[1] uses 4-to-1 subdivision connectivity schemes. While splitting, insert each edge a vertex to transform it into 2 sub-edges. As a result, each surface changes into 4 surfaces after one subdivision. And while positioning, each new vertex position is calculated by a linear combination of its 1-ring neighbor vertices.

Hoppe's new subdivision rules[2] produce commonly occurring sharp features that are called *creases*, *corners*, and *darts*, as illustrated in figure1. A crease is a tangent line smooth curve along which the surface is C_0 but not C_1; a corner is a point where three or more creases meet; finally, a dart is an interior point of a surface where a crease terminates.

Vertices are classified into five different types based on the number and arrangement of incident edges. A smooth vertex is one where the number of incident sharp edges s is zero; a dart vertex has s = 1; a crease vertex has s = 2; and a corner vertex has s > 2.

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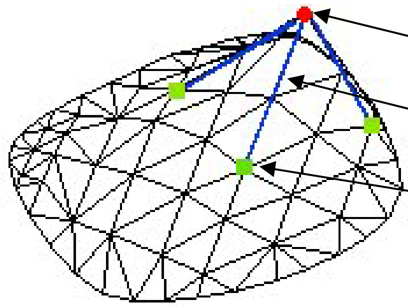


Figure1: features of subdivision

3. Embedding process

Subdivision: Subdivide original mesh twice by Hoppe's new subdivision rules, because a twice-subdivided mesh by the loop scheme is similar to its limit surface in most cases. And then we should finding out the feature vertices from subdivided model to embed watermark.

Feature Vertices: Select 256*256 vertices from corner and dark of the subdivided mesh for embedding watermark.

Watermark: The watermark that embedding to a mesh model will be got from a 256*256 image file. We embed the watermark into the image file by Fourier-Mellin transform[3], then thought compare with original image to watermarked image we can get the watermark that to be embedded into mesh model.

Embedding: Watermarks will be embedded into mesh model though modifying the feature vertex coordinates.

$$P(v_x^{\ f})' = P(v_x^{\ f}) + \alpha * w' \quad (1)$$

where $P(v_x^f)'$ are the x-axis coordinates of watermarked feature vertices,

$P(v_x^f)$ are the x-axis coordinates of original feature vertices,

w' is the watermark,

α is the energy of the watermark

4. Extracting process

Mesh Resampling: As part of the attack, the topology of the mesh may have changed. In this case, for the watermark extraction process, we need to obtain a mesh with the topology of the original and the geometry of the attacked mesh. If the suspect mesh that needed to be resampled is M_s, original modal is M_o, the resampling process following:

- Finding out all the nearest vertices from M_s to M_o, if $(v_s^*-v_o)$ is smaller than a given threshold, we assume that the two vertex are matching.
- Project the no-matched vertices in M_s to the nearest face in M_o.
- Join the vertex of incidence and the vertex of matching by the connectivity of M_o to form the sampling bash M_r.

Following the energy functional, we can get the M_r through minimized the energy $E(v_r,v_o)$ using a conjugate gradient method [4]:

$$E(v_r, v_o) = E_{dist}(v_r, v_o) + c_d \cdot E_{deform}(v_r, v_o) \quad (2)$$

where v_r are the vertices in M_r,
v_o are the vertices in M_o,
c_d is the relative weight, and set c_d=10^{-3}
E_{dist} measures the distance between the meshes. Specifically, it is the sum of squared distances between points randomly sampled on the attacked mesh and their projections onto the original mesh.
E_{deform} measures the deformation of the original mesh. A spring is placed on each mesh edge, with rest length equal to the original edge length.

Feature Vertices: Find out feature vertices from limit surface by subdividing watermarked mesh model.

Extracting: Compare with original model to watermarked model to get the watermark w'.

$$w' = (P(v_x^{\,f})' - P(v_x^{\,f})) / \alpha \quad (3)$$

where w' is the extracted watermark,
$P(v_x^f)'$ are the x-axis coordinates of the watermarked feature vertices.

Figure2: Recover watermark

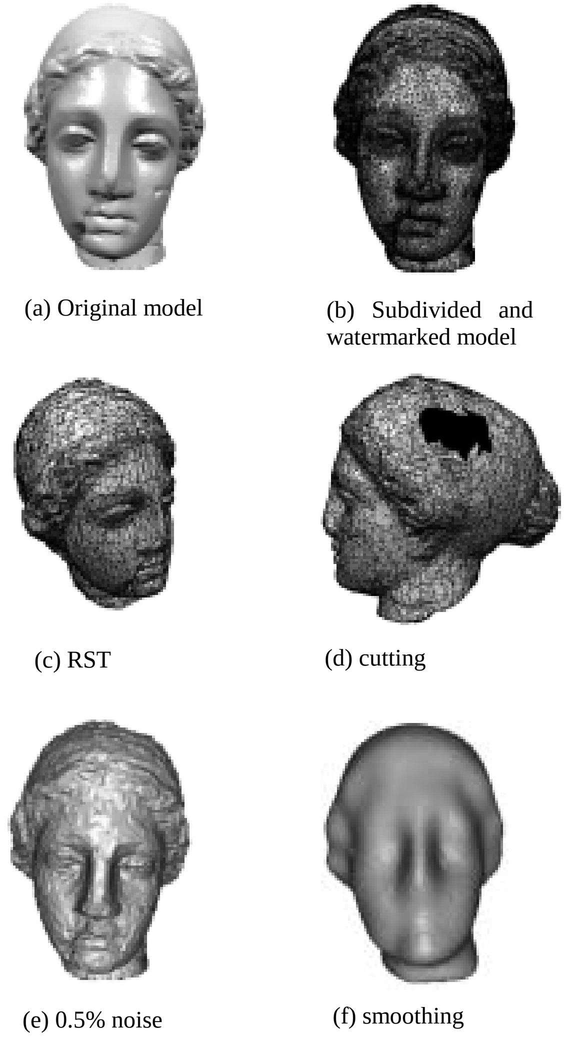
5. Results

The "venus" shown in Figure3(a) was used as an example of original mesh model which had 33591 vertices. And the original watermark was 24bit text.

As shown in Figure3(c)-(d), we had done the attack experiments about rotation, scaling, translation, cutting, adding 0.5% noise and smoothing. All the experiments could extract embedded text well. Results show that our approach is effective and robust for such attack methods.

6. Conclusion

In this paper, we proposed a new mesh watermarking approach by modifying the coordinates of feature vertices that were selected when models were subdivided. Generally, mesh will not lost its feature vertices like corner vertices or dark vertices, so we can catch the feature of mesh easily. Moreover, since we use the image watermarking method to processing the watermark information, the robustness of our approach is effectively improved.



(a) Original model
(b) Subdivided and watermarked model
(c) RST
(d) cutting
(e) 0.5% noise
(f) smoothing

Figure3: Experimental models

References

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