Adaptive Fuzzy Watermarking for 3D Models

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Abstract

Watermarking algorithms have a basic requirement that the watermark amplitude should be as high as possible for robustness and at the same time the watermark should not introduce any perceptible artifacts. Thus, the design of watermarking algorithms involves a tradeoff between imperceptibility and robustness. This paper proposes a novel state of the art algorithm, which is based on wavelet and fuzzy logic, to determine an optimal value for the watermark amplitude to be inserted in a 3D model. The system being adaptive to the local geometry of the mesh inserts an 8 bit grey scale image as watermark as compared to inserting a binary image in existing algorithms. Simulation results prove it to be robust against smoothing, cropping, affine operations and noise attacks.

1. Introduction

Watermarking of meshes provides a solution to copyright infringement of 3D data. In order to resolve copyright problem effectively, watermarks must be robust and imperceptible. To ensure imperceptibility of the modification caused by watermark embedding, a perceptibility criterion needs to be used. However, the Human Visual System (HVS) for 3D models is not well understood and neither mathematically modeled. As a consequence, the host data can only be modified by an amount relatively small to their average amplitude. Thus, there is a need for an algorithm to insert high energy watermarks which are imperceptible at the same time.

Benedens [1] has proposed selection of feature points on the 3D model and the comparison with the original model to determine whether the feature point has been moved inside or outside the surface along the normal. However, he demonstrates robustness only with simplification attacks. Praun and Hoppe [2] reported robust mesh-watermarking algorithm that works in a transformed domain but is applicable to polygonal meshes having arbitrary vertex connectivity. In his paper, it is suggested that, the number of coefficients should be model-specific, based on some “information complexity” of the model, and should be carefully selected to maximize robustness. Rondao Alface [3] has done a thorough survey with classification and critical analysis of watermarking algorithms for 3D models. According to [3], there is still a need for a more careful analysis on how to modulate the watermark strength accordingly with the local perceived distortion.

The proposed method takes inspiration from algorithm proposed by Kanai et al [4] as the watermark is robust to a large number of attacks as compared to other algorithms. Kanai uses wavelets which can only be applied to regularly subdivided meshes. As a limitation, Kanai’s method requires the mesh to have 1-to-4 subdivision connectivity. This drawback has been later removed by Min-Su Kim et al. [5] who extend this scheme to irregular meshes. The proposed algorithm outperforms Kanai's algorithm in terms of data embedding capacity by inserting 8 bits per wavelet modulus coefficient instead of 5 bits. Our algorithm also takes advantage of both spatial and spectral domain at the same time by using fuzzy logic.

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2. Proposed Method

2.1. Watermark Insertion

Fig 1 shows the block diagram for the watermark generation and embedding stage.

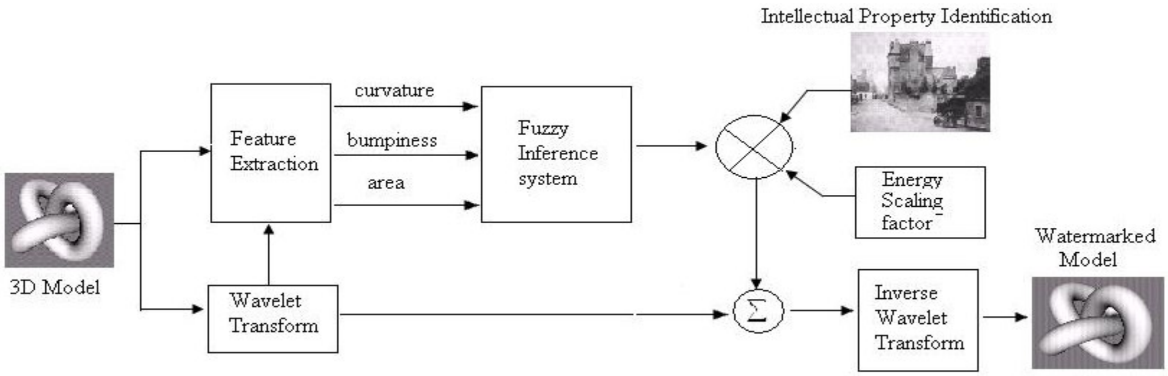

Fig 1. Block diagram for watermarking embedding

Step 1: Decomposition of 3D Model: Prior to wavelet transform, all mesh vertices are normalized between 0 and 1 by placing an imaginary bounding box to provide robustness against scaling attacks. Wavelet transform is then implemented using Lifting Scheme and Cohen–Daubechies–Feauveau CDF (2, 2) wavelet is used. Lifting scheme requires that the input signal samples be classified into even & odd for computation of scalar & wavelet coefficients respectively i.e. even samples are used for computation of scalar coefficients and odd for wavelet coefficients. Wavelet Transform is applied by using even vertices to compute scalar coefficients and odd vertices to compute wavelet coefficients [4, 6, 7].

Step 2: Computing fuzzy inputs: Fuzzy input variables are computed considering the geometry of the model such as area, curvature and bumpiness of the surface corresponding for each vertex. Area of the triangular face formed by 3 vertices is computed by the magnitude of the normal to the triangular patch. Curvature is the amount by which a geometric object deviates from being flat. Curved surface consist of more number of smaller triangles as compared to a flat surface. Since only semi-regular meshes are considered in the current system, each regular vertex is connected to 6 other vertices. Thus, 6 surface normals are computed for each corresponding neighbor's vertex. Curvature is computed by taking average of the angles between surface normals and the average surface normal. A bumpy surface is a surface which is not smooth but is irregular and uneven. A bumpy surface has more details associated with it and thus has more watermark holding capacity. Bumpiness is calculated by dividing the wavelet coefficient magnitude by the length of vector joining two EVEN neighbors as shown in Fig 2. Bumpiness, Area and Curvature are passed as fuzzy inputs to the Fuzzy Inference System (FIS) to compute a Fuzzy perceptual mask for each wavelet coefficient at each level. Curvature and area for the mesh vertices are computed in the spatial domain whereas bumpiness for the corresponding vertex is computed in the wavelet domain.

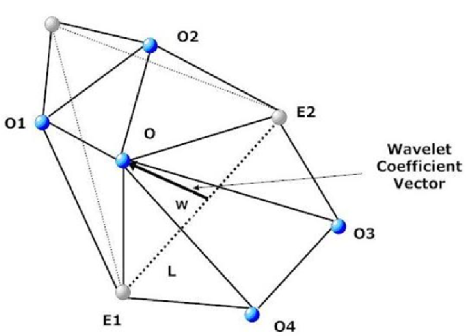

Fig 2. Bumpiness calculation using Wavelet Coefficient vector

Step 3: Computing Fuzzy Mask: The output of the fuzzy system is a single value which corresponds to a perceptual threshold for each corresponding wavelet coefficient. Thus, the fuzzy perceptual mask combines 3 nonlinear variables viz. Curvature, Bumpiness and Area to build a simple, easy to use model. Although the fuzzy output has 7 membership functions as shown in Fig 3, only the HIGH and the HIGHER fuzzy output sets are used for insertion of watermark in the 3D model. This is to make the watermark imperceptible and more robust.

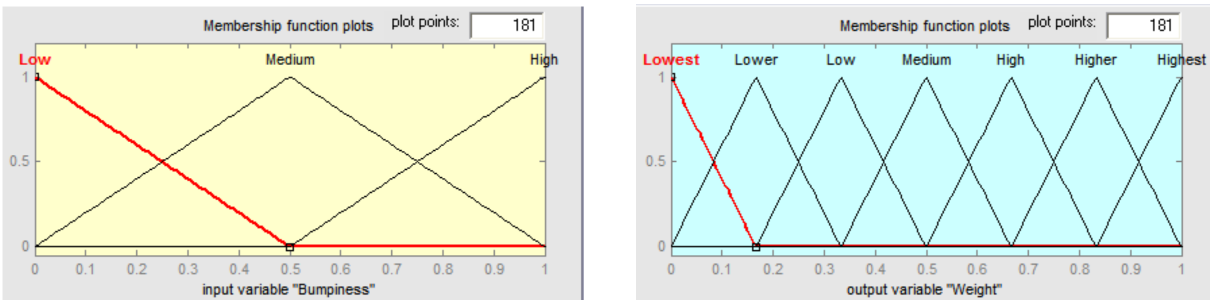

Fig 3. Membership functions for Fuzzy Inputs and Outputs

A total of 15 fuzzy rules are developed, some of the most important rules are as follows:
[Rule 1] IF [Curvature] is MEDIUM and [Bumpiness] is MEDIUM and [Area] is LOW THEN [Weighting factor] is LOW
[Rule 2] IF [Curvature] is HIGH and [Bumpiness] is MEDIUM and [Area] is LOW THEN [Weighting factor] is MEDIUM
[Rule 3] IF [Curvature] is MEDIUM and [Bumpiness] is HIGH and [Area] is HIGH THEN [Weighting factor] is HIGHER.

Step 4: Embedding watermark sequence: The watermark is inserted by modifying the magnitude of the wavelet coefficient vector in accordance with the following equation.

$$W' = W + f(F,B,K) \qquad \text{(I)}$$

Where W' = modified wavelet coefficient vector, W = original wavelet coefficient vector, F = fuzzy perceptual mask, B = 8 bit gray scale image, K = energy scaling factor

Step 5: Reconstruction of 3D model: Compute inverse 3D wavelet transform of W' to get the watermarked model.

2.2 Watermark Extracting Algorithm

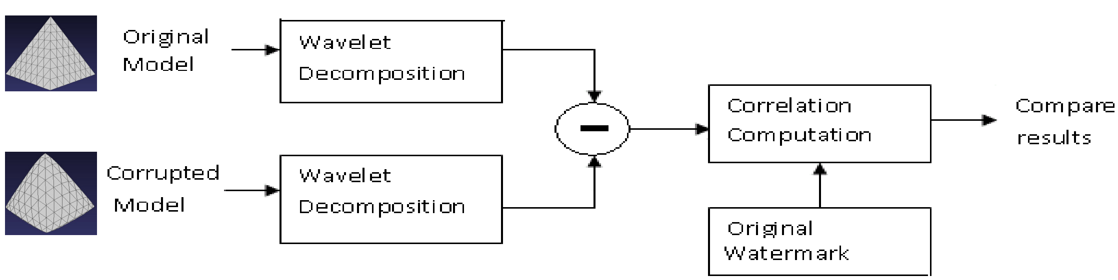

Fig 4. Block diagram for watermark extraction

Since our system is a non-blind watermarking scheme, original model and original watermark are needed to extract the watermark from the attacked model as shown in Fig 4. Correlation is computed for the original and attacked watermark and a threshold chosen to determine if the model is attacked.

3. Performance and Evaluation

The meshes as shown in Fig 5 used for analysis have different shapes to analyze the fuzzy mask behavior for all three fuzzy inputs viz. curvature, bumpiness and area. 8 bit gray scale images are used for watermark insertion in the meshes. The algorithm was tested with various gray scale images of diff sizes to evaluate attacks.

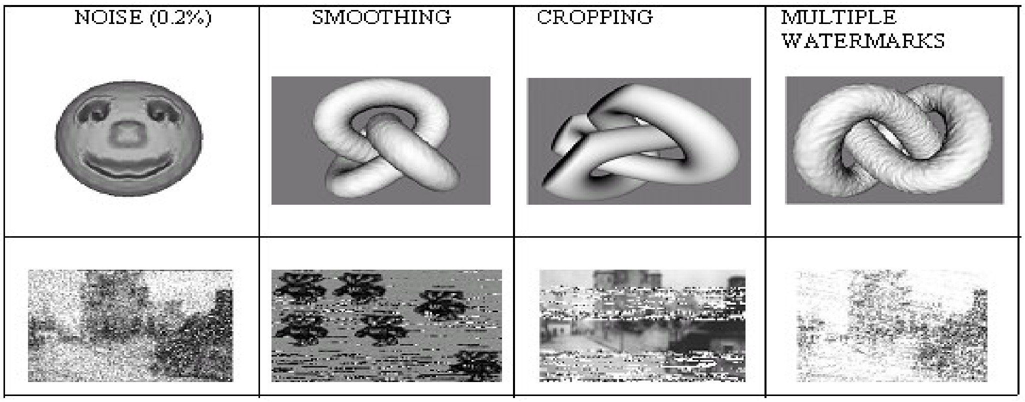

Fig 5. Attacks on 3D Models

As shown in Table 1 and Fig 5, the algorithm is robust to all kinds of attacks giving exceptional results.

Table 1. Correlation results with extracted watermark

Model	No. of Vertices	No. of polygons	Rotation, translation and scaling	Noise addition 0.2%	Smoothing (HC Laplacian Filter)	2^{nd} watermark	Cropping
Smiley	1026	2048	1	0.9829	0.9913	0.9995	0.9891
Super Pyramid	16386	32768	1	0.9919	0.9989	0.7108	0.9442
Doughnut	23040	46080	1	0.7988	0.9586	0.8365	0.9264
Super Smiley	16386	32768	1	0.8671	0.8985	0.8323	0.8011
Bumpy Doughnut	23040	46080	1	0.7144	0.8168	0.8332	0.9409

Rotation and Translation: The algorithm is completely invariant to rotation and translation attacks. The change in parameters does not affect the relative distance between the vertices and thus the magnitude of the wavelet coefficients remains unchanged. Thus our algorithm is invariant to rotation and translation.

Scaling: Although scaling modifies the magnitude of wavelet coefficients but due to normalization of the model during watermark insertion and extraction process, the watermark is unaffected. Thus our algorithm is invariant to rotation, translation, scaling or combination of geometrical transformations.

Noise analysis: As shown in Table 1, noise affects watermark the most in bumpy doughnut and doughnut. The watermark is less variant to noise in case of planar surfaces and more severely affected in case of bumpy surfaces. The reason is that during the watermark insertion process the change in entropy of the wavelet coefficients is most for surfaces with bumpiness and curvature and least for planar surfaces. In spite of the noise attack the extracted watermark is still recognizable in all the cases.

Smoothing: Smoothing attack affects the bumpiness of the model more than curvature. This is because it is nothing but low pass filter that removes the high frequency part which is bumpiness. Thus bumpy doughnut is more affected as visually shown in Table 1.

Second watermark: In case of second watermark, less number of wavelet coefficients are modified as compared to the first watermark. When we want to add second watermark the strength of it has to be less in order to have the change imperceptible. The first watermark extracted is shown in Table 1 and is still recognizable.

Cropping: In our system the watermark is inserted uniformly in the model. Thus even if the model is cropped the watermark is not completely destroyed. The amount of watermark destroyed depends upon the extent of cropping.

4. Conclusion

Our system has been proved to be robust against smoothing, cropping, affine operations and noise attacks. Our system also out performs all of the existing algorithms in terms of data hiding capacity by inserting an 8 bit image into the mesh and at the same time being robust against attacks. The future work will consist of extending the algorithm for fragile and robust blind watermarking. In addition, our system provides a scalable framework where more fuzzy inputs can be easily added.

5. References

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