TOPOLOGICAL SYNCHRONIZATION MECHANISM FOR ROBUST WATERMARKING ON 3D SEMI-REGULAR MESHES

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ABSTRACT

This paper presents a contribution in matter of robustness of a previous method of 3D objects watermarking [10] based on wavelet decomposition on semi-regular triangular meshes. This decomposition gives rise to a multiresolution mesh where the watermark could be embedded at each level of resolution, in this case we talk about a hierarchical watermarking. In practice the robustness of the previous method against geometrical attacks was high only in the low resolution which makes it far from being a hierarchical method. Our analysis made on the fragility of that method allowed us to reveal the cause which was not primarily the bad bits quantization of the watermark, but rather the alteration of the sequencing of the embedded bits (synchronization). Our contribution is to replace the previous geometrical mechanism with a new topological synchronization mechanism, which has resulted a real hierarchical and robust watermarking.

***Index Terms*—** 3D object watermarking, wavelet analysis, multiresolution, robustness, blind, synchronization, attack, noise, topology, geometry.

1. INTRODUCTION

Protecting copyrights is becoming increasingly a major constraint for both publishers and authors, and types of theft of property of authors become more complex. For these reasons and in order to protect the scientific works, we must employ techniques of watermarking (digital watermarking), which themselves are included in a large class of techniques that is the data hiding.

Watermarking is a technique used, among other things, for protection of copyrights, and secure data transmission. It involves the insertion of hidden information in the useful part of a file. This watermarked file may surgery transmission to be received by the receiver, who will try to extract the hidden information (either based on the original file or not, the watermarking is called, not blind or blind watermarking). 3D scenes are represented often by a polygonal mesh, thus the watermark will be placed in different spatial primitives. These include the distance between a vertex and center of gravity of the mesh [11], the average normal direction of a group of facets [2], the projection of a vertex on its opposite edge in a triangle [7], the ratio between the height of a triangle and its support edge [9]. So that the receiver can extract the hidden mark correctly, the bits of the watermark should be embedded in a well defined order. This order is called synchronization. In fact there are several ways to synchronize a 3D object, either by establishing a geometric measure to sort the spatial primitives of the object, such as length of edge [10], the ratio between the area of triangles and area of the imaginary square having as a side edge of the triangle [3]. Or by traversing the graph of the mesh connectivity [9] with a global or local way, based on the topology. Generally for a given application, such as protection of copyrights, we ask the watermark to be robust and resistant to various forms of attack (noise, geometric transformations, remeshing, etc.), nevertheless, for using as transmission voluminous medical information, we ask the watermark rather to be of high capacity while keeping a minimum of invisibility, in other word, the distortion between the original model and the watermarked one must be small.

2. WAVELET DECOMPOSITION

The wavelet decomposition for three-dimensional meshes as it is defined by Lounsbery et al. [6] is restricted to a class of special mesh topology, called semi-regular meshes. In this type of mesh, the valence is not necessarily constant, and in fact, a semi-regular mesh is the result of a 1-to-4 triangular subdivision of an initial mesh, a number of times, as illustrated Fig. 1.

In order to be able to apply the wavelet analysis, the initial mesh must be semi-regular, therefore for an arbitrary mesh, we must transform it into semi-regular mesh, for that several methods have been developed [5, 4]. The operating principle of the wavelet decomposition of a semi-regular mesh is to apply a filter on a set of four adjacent triangles, which separates the vertices into two sets, the first triangle represents the coarse approximation of these four triangles, and the second set represents the displacement vectors of the midpoints of the edges of the coarse triangle, these vectors are the wavelet coefficients. (Fig. 2).

The implementation of the wavelet transform allowed us to have gradually an approximate mesh (coarse), plus details (wavelet coefficients) (Fig. 3). The 3D object chosen is a

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semi-regular fandisk with: 4802 vertices and 9600 triangles. Thus all the work which will come, is based on this model.

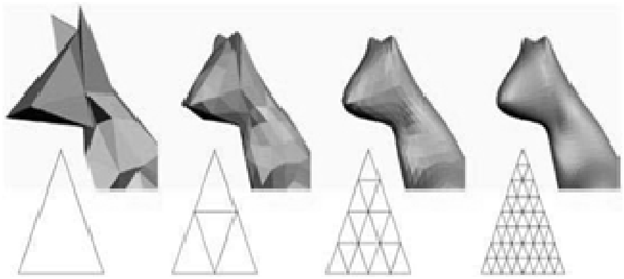


Fig. 1. Example of a semi-regular mesh.

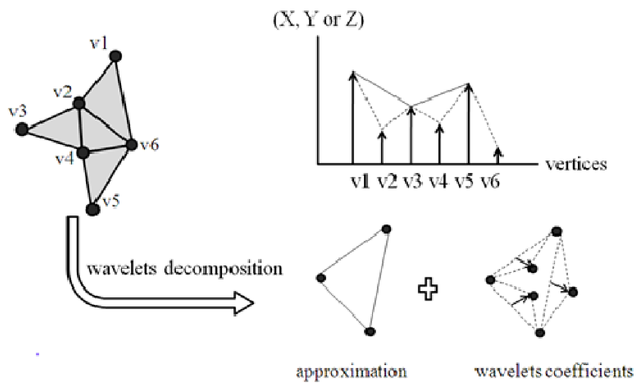


Fig. 2. Wavelet decomposition of a basic semi-regular mesh.

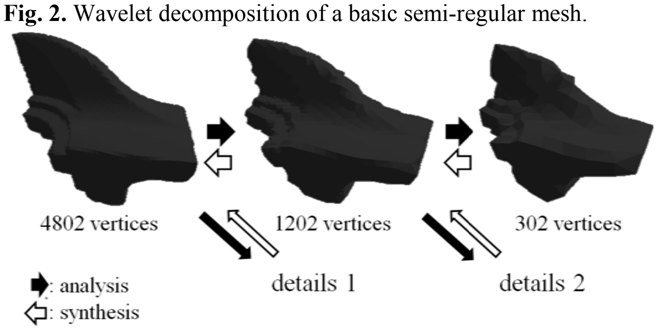


Fig. 3. multiresolution mesh of the fandisk.

3. BLIND & ROBUST WATERMARKING WAVELET-BASED (METHOD OF WANG ET AL.)

Recall that the hierarchical blind watermarking technique presented by Wang et al. [10], is based on embedding one bit in each wavelet coefficient, and for a given level of resolution.

3.1. Synchronization mechanism

It is the descending order of the edges with the wavelet coefficients according to their lengths.

3.2. Watermarking algorithm

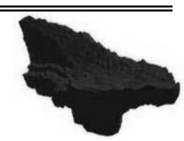
The watermark bits are inserted by quantifying the norms of the wavelet coefficients associated with edges (previously sorted in descending order). The norms of the wavelet coefficients are quantified, according to a quantization step which is the ratio between the average length of edges (of a given resolution level) and a control parameter ε1.

$$\text{step} = l_{moy} / \varepsilon 1 \qquad (1)$$

This quantization can be associated with each norms subinterval, a bit 0 and 1 alternately. From there, inserting bits of the watermark is done by changing the norm in the middle of the nearest interval corresponding to the bit we want to insert. The watermarking primitive here is the ratio between the norm of the wavelet coefficient and the quantization step (which depends to the average length of edges), and this is invariant to any similarity transformation. ε1 is a control parameter for adjusting the compromise between robustness and invisibility, which are inversely proportional. Once the wavelet coefficients are watermarked, the algorithm proceeds by inverse wavelet transform to find the watermarked model. At the extraction phase, the algorithm performs the wavelet transform up to the coarsest level, and it sorts the edges and through the quantization of the wavelet coefficients associated with these edges, it finds the message embedded. The maximum capacity of the watermarking method is not automatically deducted, and it depends on the nature of the hierarchical mesh, and it is equal to one bit per wavelet coefficient (thus superiorly limited at one bit per vertex). For our model, the maximum capacity is: 4725 bits (for 4802 vertices) below (Table 1) a table summarizing the results of a hierarchical watermarking with different measures (distortion, payload and robustness) and this for three different control parameters (*i.e.* three different quantization steps).

Note here that the distortion is expressed by the mean of the Hausdorff distance simplified in the discrete case [1] between the original model and the watermarked one. So when the distortion increases, the imperceptibility decreases, and vice versa. The distortion is calculated using the

Table 1. Summary of three measures made on three hierarchically watermarked models

Model			
Distortion	0.0000624	0.0008894	0.0107796
Payload	4725	4725	4725
Robustness	+	+++	+++++
ε1 = ε2 = ε3	100	30	10

following formula:

$$\text{distortion} = \frac{1}{N}\sum_{i=0}^{N-1} d(\mathrm{V_i}, \mathrm{V_i'}) \qquad (2)$$

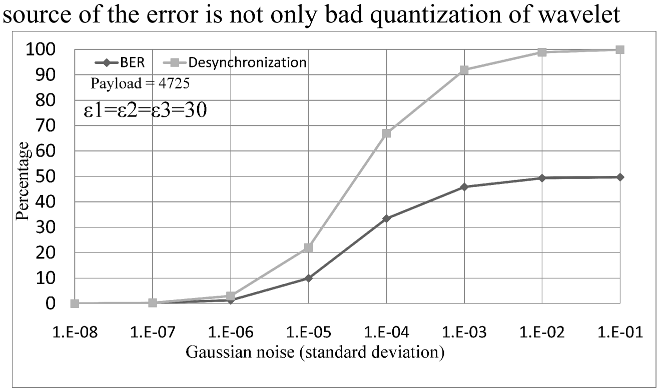
$$d(\mathrm{V_i}, \mathrm{V_i'}) = \sqrt{(\mathrm{X}-\mathrm{X'})^2 + (\mathrm{Y}-\mathrm{Y'})^2 + (\mathrm{Z}-\mathrm{Z'})^2}$$

N: is the number of vertices. Vi: is the vertex number i.
(X,Y,Z) : are the coordinates of the vertices of the original model.
(X',Y',Z') : are the coordinates of the vertices of the watermarked model.

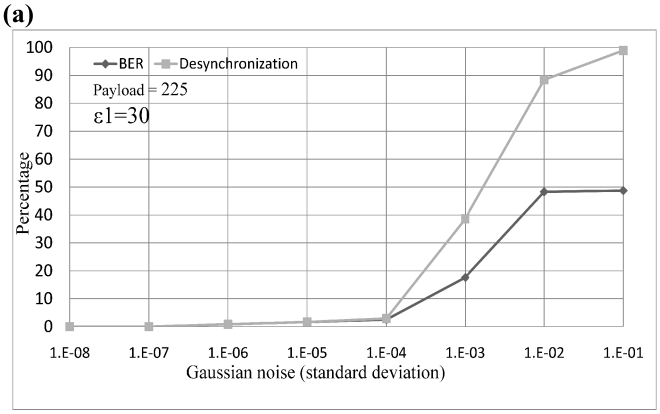
Thus we could reach the maximum payload for the three different control settings, but we note that the robustness and invisibility are inversely proportional, then the chosen compromise for the next experiments is set to 30 for $\varepsilon 1, \varepsilon 2$ and $\varepsilon 3$, which are the control parameters at the 1st, 2nd and the 3rd resolution level respectively.

4. EXPERIMENTAL RESULTS

The graph shown in Fig. 4. a. is obtained by submitting our watermarked model (hierarchically with three marks, each at one level of resolution, in total 4725 bits) to a Gaussian noise with standard deviations ranging from 1.0 E-08 to 1.0 E-1(see Table 2.). during this experiment, we measure the BER (Bit Error Rate), but also the desynchronization. This second measure is appropriate because we observed that the source of the error is not only bad quantization of wavelet coefficients, but also the loss of the initial synchronization, meaning the loss of the order in which the mark has been inserted (in descending order of the edges according to their norms). These measures have been redone for the same watermarked model only in each level of resolution.

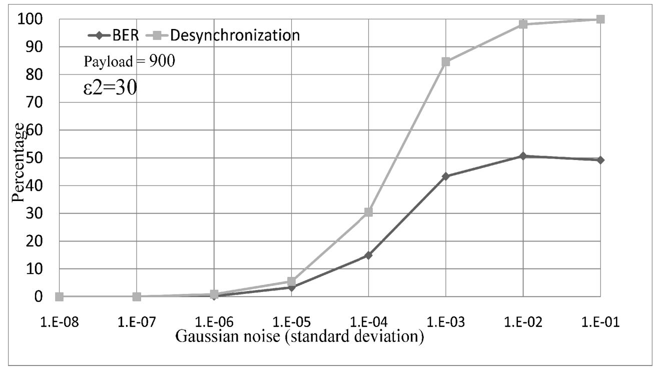


(a)

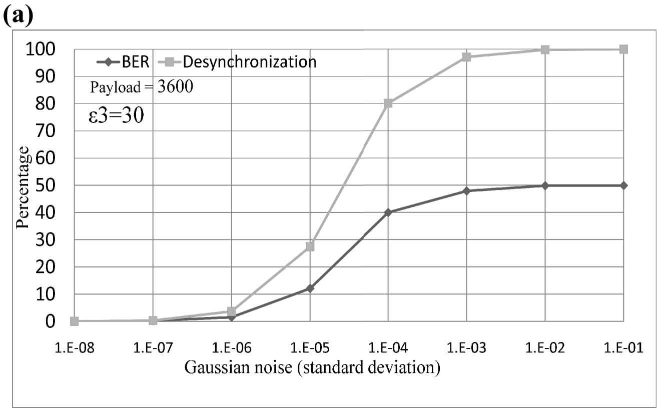


(b)

Fig. 4. Graph of curves : BER and desynchronization : **(a)** hierarchical watermarking. **(b)** watermarking at the first level.



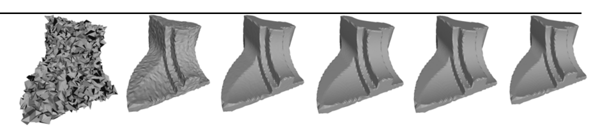
(a)



(b)

Fig. 5. Graph of the curves : BER and desynchronization (watermarking at : **(a)** second level. **(b)** third level).

Table 2. Distortion and visual effect of the Gaussian noise applied on the fandisk.

Noise	1E-01	1E-02	1E-03	1E-04	1E-05	1E-6 to 1E-8
Model						
Distortion	**0.06291**	**0.00642**	**0.00064**	**0.00007**	**0.00001**	**0**

4.1. Analysis

It is clear that the BER curve reaches its lowest values in the graph shown in Fig.4.b which corresponds to the watermarking at the 1st level of resolution, and this clearly

Table 3. Comparing the effect of the noise on the two sorting kinds

Order	Global sorting	Local sorting
Initial	{c1,d2,a3, b1,b2,d3, d1,c2,c3, **a1**,a2,b3}	{**a1**,a2,a3, c1,c2,c3, d1,d2,d3, b1,b2,b3}
Noise on a1	{c1,d2,a3, b1,b2,**â1**,d3, d1,c2,c3,a2,b3}	{a2,**â1**,a3, c1,c2,c3, d1,d2,d3, b1,b2,b3}

explains the robustness of the method of Wang et al. in the lower resolution (Fig.4.b). Contrary to low resolution, higher resolutions have high vulnerability (Fig.5. a. and Fig.5. b.).

It is obvious that the shape of the BER curve follows the desynchronization one, so if we can degrade this latter, we will have probably a smaller BER.

4.2. Proposition

Exploiting the hierarchical structure of semi-regular mesh will allow us to replace the global synchronization (which is the sort of descending of all the edges at such level of resolution) by a local sorting of edges at each triangle, and a sorting of children triangles at their father triangle, and this is feasible thanks to the tree mesh semi-regular. Consider the example shown in Fig. 6.

This will allow a limiting and a centralizing of one error per one triangle at most (see Table 3).

5. NEW SYNCHRONIZATION MECHANISM

In contrast to the synchronization mechanism used in the method of Wang et al. that is based on the geometry part of the object, more precisely, the edges norms, the latter is necessarily influenced and altered by different types of noise. The intrinsic connectivity of triangle meshes is used as basic element to traverse the whole 3D object. We distinguish three classes of approaches used to establish a

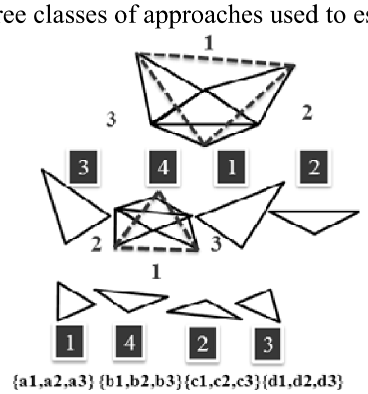


Fig. 6. Hierarchical sorting of the semi-regular mesh's edges.

traversal order, this includes, the faces [12], edges [13], and finally the vertices. We propose in this paper a new efficient and optimized traversal order approach face-based, and this by exploiting the particular hierarchical connectivity of semi-regular meshes. The synchronization mechanism proposed works in three steps:

1- Sorting the triangles of the lowest resolution mesh,
2- Sorting the children triangles (of the high resolutions) at their father's triangle level,
3- Sorting edges at their triangle level.

This new synchronization mechanism presents a high robustness against these types of noise.

5.1 Algorithm

1) Sorting the triangles of the coarsest level (mesh of the lowest resolution):

a) Fixing the starting configuration, *i.e.* the starting triangle (arbitrary taken), the support edge (one among the three edges of the starting triangle), and the starting vertex (one of the two vertices of the starting edge). Once the watermark was embedded, we will change the intrinsic normal of the grandchild triangle (who its grandfather is the starting triangle), that shares with the starting triangle the starting vertex. In order to be able to find the same starting configuration at the extraction phase, we search the starting triangle from the coarsest level, which is the triangle where one among its grandchildren has an inverse normal compared to its neighbors, the starting vertex becomes the shared one, and the support edge becomes the first edge encountered from the starting vertex in the inverse direction of the grandchild triangle, as illustrated in Fig. 7.a.

b) Traverse the triangles basing on the direction of the triangles (from the starting vertex towards the support edge)

i) Marking the starting triangle whose support edge is starting one.

ii) Repeat.

iii) Passing to the first neighbor triangle in the direction of the current one if that neighbor is not yet marked (the second vertex becomes the starting vertex of this neighbor, and the common edge becomes the support edge of this neighbor triangle) ; marking the current triangle; go to ii).

iv) Passing to the second neighbor triangle in the direction of the current one if that neighbor is not yet marked (the third vertex becomes the starting vertex of this neighbor, and the common edge becomes the support edge of this neighbor triangle) ; marking the current triangle; go to ii).

v) End of the loop if the current triangle is the starting one.

vi) Go back to the triangle which precedes the current one; Go to iv).

c) Triangle marking order is the final established order between the triangles (Fig. 7.b.).

2) Sorting children triangles in their father's triangle:

a) The first triangle is the middle one, which shares no vertex with the triangle father.

b) The traversal of the three remaining triangles in the direction of the triangle father, starting with the triangle that is not sharing any of its three vertices with the support edge of the triangle father, is the order of these triangles (Fig. 8. a.).

c) Fixing the starting vertex and the support edge of each child triangle as following:

i) The starting vertex of the first child triangle is the vertex that shares two edges with the two vertices of support edge of the father triangle.

ii) The starting vertices of the three remaining children triangles are the vertices shared with the father triangle.

iii) The support edges of the children triangles are the first edges encountered from the starting vertices in the direction of their father triangle (Fig. 8. b.).

3) Sorting the edges of the triangles:

a) The first edge is the support edge of the triangle.

b) The second edge is the first edge encountered from the support edge in the direction of the triangle.

c) The third edge is the second edge encountered from the support edge in the direction of the triangle (Fig. 8. c.).

Finally and for a given level resolution, the sort between edges will be established by the depth-first traversal of the hierarchy of semi-regular mesh (Fig. 9).

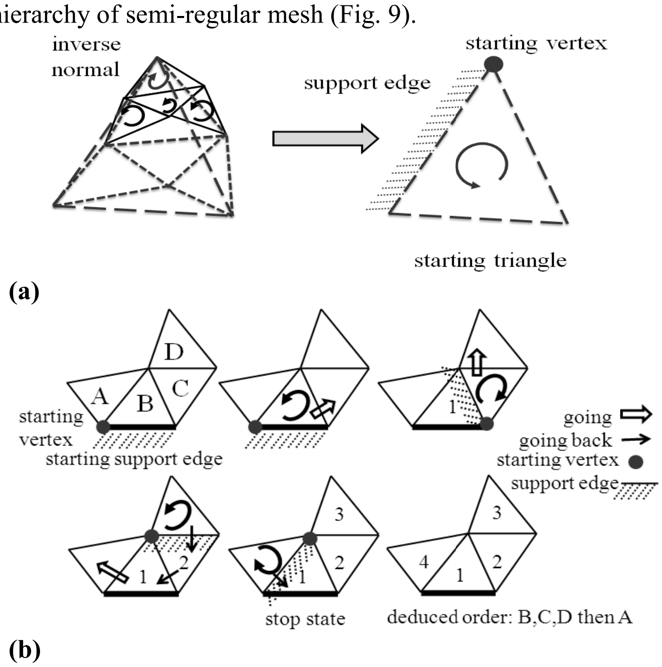


Fig. 7. **(a)** Starting configuration finding at extraction phase. **(b)** Triangles sorting of coarse mesh in their traversal direction.

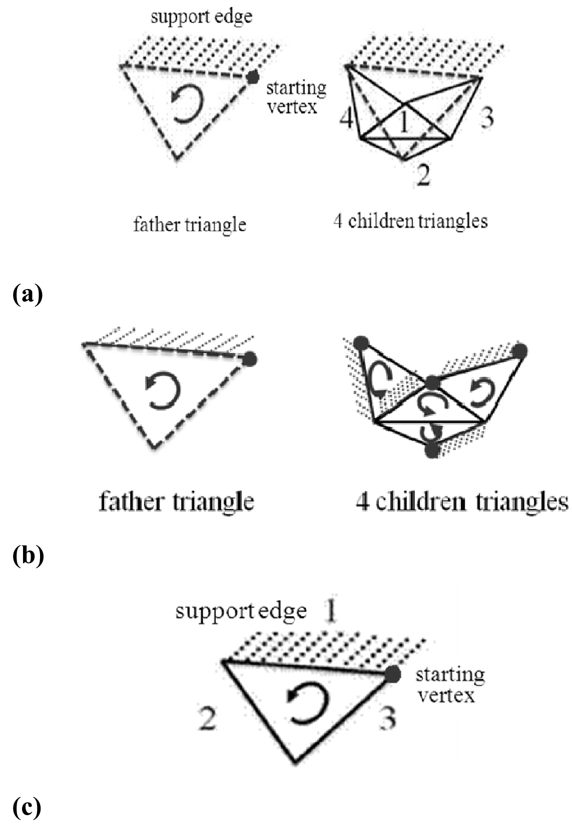


Fig. 8. (a) Children triangles sorting at their father's triangle. **(b)** Fixing starting vertices and support edges of children triangles. **(c)** Edges sorting of the triangles of the finest mesh.

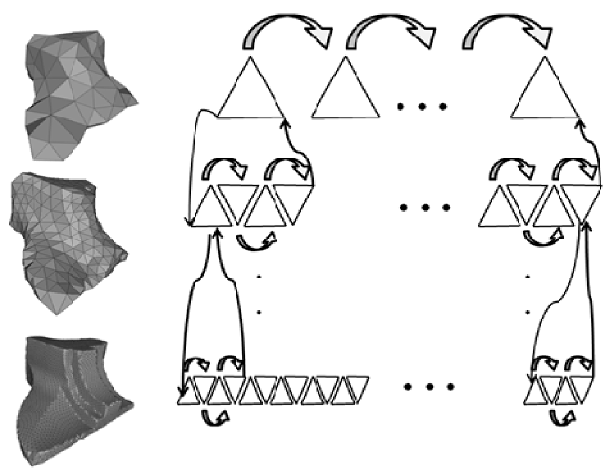


Fig. 9. Depth-first traversal of the hierarchy of semi-regular mesh, based on the sorting established by the proposed synchronization mechanism.

6. EXPERIMENTAL RESULTS OF PROPOSED METHOD

With the new synchronization mechanism, the desynchronization measure is null whatever the noise power

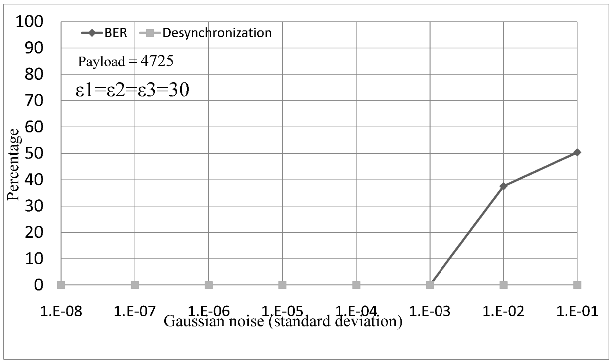


Fig. 10. Graph of BER and desynchronization curves of the hierarchical watermarking of the proposed method.

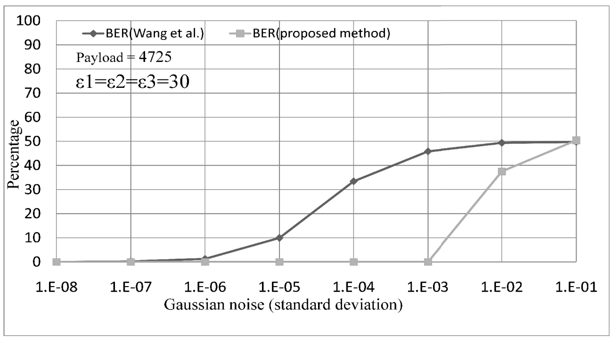


Fig. 11. Comparing graph of the BER curves of the method of Wang et al. and that proposed.

which proves the efficacy of the new synchronization. Indeed the BER curve is reduced with considerable way due to the non alteration of the initial synchronization (Fig. 10).

For noise power less than or equal to 0.001, the BER is completely null, and this shows a correct quantization, explained by the step quantization chosen (ratio between mean length and ε fixed at 30) which is as large as the noise (Fig. 10). And since the noise power is greater than 0.001, the BER gradually increases because only a bad quantizations (Fig. 10).

Comparing the results obtained by the old method and that proposed shows visibly the improvement in matter of robustness, and high resistance to noises, made by the new synchronization mechanism, which allowed a real hierarchical watermarking at all levels of resolutions, not only in the low resolution (Fig. 11).

7. CONCLUSION

We have presented an improved method for 3D objects watermarking based on wavelet decomposition. This improvement concerns the synchronization part of the embedding and extraction schemes of the blind watermark. This new synchronization is not based on geometric primitives, but rather on the triangles traversal of a semi-regular mesh, which makes the watermark robust to noise regardless of the level of resolution, in other word, it allows the making of hierarchical watermarking. This work needs to be followed by other improvements, such as robustness against other types of attacks as connectivity, cutting and remeshing attacks. As the wavelet analysis for 3D meshes is restricted to those where the topology is semi-regular, a fairly recent work suggests an approach to multiresolution analysis on an irregular mesh [8], which removes the obligation to transform an arbitrary mesh to a semi-regular one.

8. REFERENCES

[1] N. Aspert, D. Santa-Cruz, and T. Ebrahimi, "Mesh: Measuring errors between surfaces using the hausdorff distance," In *Proceedings of the IEEE International Conference on Multimedia and Expo*,volume I, pages 705 – 708, 2002.

[2] Oliver Benedens, "Geometry-based watermarking of 3d models," *IEEE Computer Graphics and Applications*, 19 :46–55, 1999.

[3] F. Cayre and B. Macq, "Data hiding on 3-d triangle meshes," *IEEETrans. Signal Process*, 51:939 ″U949, Apr 2003.

[4] Igor Guskov, "Manifold-based approach to semi-regular remeshing," *Graphical Models*, vol. 69, no. 1, pp. 1-18, Jan. 2007.

[5] Aaron W. F. Lee, Wim Sweldens, Peter Schroder, Lawrence Cowsar, and David Dobkin, "Maps: Multiresolution adaptive parameterization of surfaces," *Proceedings of SIGGRAPH 98*, pp. 95-104, July 1998.

[6] Michael Lounsbery, Tony D. Derose, and Joe Warren, "Multiresolution analysis for surfaces of arbitrary topological type," *ACM Transactions on Graphics*, Vol. 16, No. 1, pp. 34-73, January 1997.

[7] Y. Maret and T. Ebrahimi, "Data hiding on 3d polygonal meshes," In *MM& Sec'04: Proceedings of the 2004 workshop on Multimedia and security*, pages 68–74, New York, NY, USA, 2004, ACM.

[8] Sébastien Valette, and Rémy Prost, "Wavelet-based multiresolution analysis of irregular surface meshes," *IEEE Transactions On Visualization And Computer Graphics*, 10:113–122, 2004.

[9] Ryutarou Ohbuchi, Hiroshi Masuda, and Masaki Aono, "Data embedding algorithms for geometrical and non-geometrical targets in three-dimensional polygonal models," *Computer Communications, Vol.21, Issue*, 15:1344–1354, 1998.

[10] K. Wang, G. Lavoué, F. Denis, A. Baskurt, "Hierarchical blind watermarking of 3D triangular meshes," In *Proc. of the IEEE International Conference on Multimedia & Expo, Beijing, China*. pp. 1235-1238, IEEE. 2007.

[11] L.F. Kwok Z. Yu, H.H.S. Ip, "A robust watermarking scheme for 3d triangular mesh models," *Pattern Recognition*, Vol. 36, pp. 2603--2614(12), 2003.

[12] S. Gumhold etW. Strasser, "Real Time Compression of Triangle Mesh Connectivity," *Siggraph Conference Proceedings*, pages 133–140, 1998.

[13] M. Isenburg, "Triangle Strip Compression," *Proceedings of Graphics Interface 2000*, pages 197–204, 2000.