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Data Hiding in 3D Model Based on Surface Properties

Nashwan Alsalam Ali
Department of Computer Sciences, College of Education for Women, University of Baghdad, Baghdad, Iraq

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Abstract

Data hiding strategies have recently gained popularity in different fields; Digital watermark technology was developed for hiding copyright information in the image visually or invisibly. Today, 3D model technology has the potential to alter the field because it allows for the production of sophisticated structures and forms that were previously impossible to achieve. In this paper, a new watermarking method for the 3D model is presented. The proposed method is based on the geometrical and topology properties of the 3D model surface to increase the security. The geometrical properties are based on computing the mean curvature for a surface and topology based on the number of edges around each vertex, the vertices that have negative mean curvature and an odd number of edges around the vertex are selected for embedding. Selecting the vertex with negative mean curvature value means the vertex located in the deep region of the surface, so it not noticeable change to human eyes. To evaluate the performance of the proposed algorithm, the PSNR, and CF are used as a measurement to evaluate the visibility and robustness of the 3D watermarked model. The experimental results have shown the proposed algorithm has good imperceptibility where the PSNR reach up to 44.41 and robustness against attack where the CF is one in many cases.

Keywords: Data hiding, 3D Model, Mean curvature, Geometrical, Topology

إخفاء البيانات في نموذج ثلاثي الأبعاد بناءً على خصائص السطح

نشوان السلام علي
قسم الحاسوب، كلية التربية للبنات, جامعة بغداد, بغداد, العراق

الخلاصة

اكتسبت استراتيجيات إخفاء البيانات مؤخرًا شعبية في مختلف المجالات؛ تم تطوير تقنية العلامة المائية الرقمية لإخفاء معلومات حقوق النشر في الصورة بشكل مرئي أو غير مرئي. اليوم ، تقنية النماذج ثلاثية الأبعاد لديها القدرة على تغيير العالم لأنها تسمح بإنتاج هياكل وأشكال متطورة كان من المستحيل تحقيقها في السابق .في هذا البحث ، تم تقديم طريقة جديدة للعلامة المائية للنموذج ثلاثي الأبعاد ، وتعتمد الطريقة المقترحة على الخصائص الهندسية والطوبولوجية لسطح النموذج ثلاثي الأبعاد الدمج بين الاثنتين من اجل زيادة الامنية. تحسب الخصائص الهندسية متوسط الانحناء للسطح وللطوبولوجيا بناءً على عدد الحواف حول كل رأس ، ويتم تحديد الرؤوس ذات الانحناء المتوسط السلبي ولهاعددًا فرديًا من الحواف حول الرأس للتضمين

*Email: nashwan_alsalam60@yahoo.com

تم استخدام المواقع ذات القيم السالبة للانحناء المتوسط لانها تقع ضمن المناطق العميقة ولذلك تكون التغيرات قليلة الملاحظة بالنسبة للعين البشرية. لتقييم أداء الخوارزمية المقترحة ، يتم استخدام PSNR و CF كمقياس لتقييم الرؤية والمتانة للنموذج ثلاثي الأبعاد ذو العلامة مائية . تم عرض النتائج في النتائج التجريبية أن الخوارزمية المقترحة لديها عدم إدراك جيد حيث تصل قيمة PSNR الى 44.41 وقوة ضد الهجوم تصل في اغلب الحالات الى CF=1 .

1. Introduction

The growth in the information field, especially networks such as mobile communication, Internet and digital multimedia applications has introduces new ways of data hiding, which includes steganography and digital watermarking techniques [1].

Ohbuchi developed the first digital watermarking method for 3D models in 1997. 3D model watermarking has been heavily studied since the early 2000s, due to the steady development and widespread use of 3D print technology [1, 2]. Digital watermarking technology was created as a useful method for identifying document or digital material origins, authors, owners, distributors, or authorized consumers.

In the digital watermarking process, there are two major steps: (1) embedding the watermark, which involves inserting the watermark into the carrier's content, and (2) extracting the watermark, which involves removing the watermark from the carrier [3, 4]. There are many kinds of watermarking, but visible watermarking technology offers a more active protection of digital material since it not only prevents pirates from stealing digital information, but it also visibly identifies the security of multimedia information. A visible watermarking technique should include content information to guarantee that security patterns are difficult to design, making it hard for unauthorized individuals to access watermarked material [5, 6]. Due to the experienced assault, the extracted watermark may or may not match the pristine watermark. As a result, there are three different kinds of watermarking methods that are used to assess their characteristics. Non-blind, blind, and semi-blind procedures are among them. The pristine object and secret key are required in the non-blind process to identify the extracted watermark, while the pristine object is not required in the blind approach to discover the extracted watermark. The secret key is solely used for extracting the data in the semi-blind process [7,8].

Watermark assaults on digital artefacts are divided into two categories: non-intentional and purposeful. If the watermark degrades beyond the permitted limitations, the assault attempts to damage the watermark outline [9, 10]. Digital watermarking has three major features:

A. Fidelity: After being watermarked, the image quality should not be changed; even watermarking should not make distortions apparent, since this would decrease the image's commercial worth.

B. Robustness: Image processing procedures erase watermarks intentionally or inadvertently. It should be able to withstand many assaults.

C. Capacity: This property specifies the quantity of data that must be embedded as a watermark for extraction to be effective [11, 12].

2. Related Works

V. Thang et al. in 2020 [13] proposed a watermarking method for 3D printing that depends on the mean distance of 2D slices. In the suggested approach, a 3D printing model is divided into a 2D series of slices, with each 2D series of slices including a bit of the watermark data inserted by altering the length of the slice's mean distance. Finally, the coordinates of points in each 2D slice will be modified in accordance with the changed mean distance value of the

2D slice in which the watermark bit has been inserted. The error of mean distance between the watermarked and the original was found to be extremely minimal in the experiments. The recovered watermark's Bit Error Rate (BER) approximate 4% is likewise extremely low when compared to the original watermark. Thus, the average accuracy of the method is 96%
N. A. Ali in 2019 [14] described a 3D watermarking approach based on the closest distance between two vertices in a mesh where the embedding route goes as deep as feasible until the embedding data is complete. In terms of invisibility and resilience, the suggested method performed well. The visibility was assessed using the Root Mean Square Error (RMSE) equal to 0.00000002 and Hausdroff Distance (HD) equal to 0.002 and the findings were positive. The suggested approach was resistant to geometrical attack (translation, scaling, and rotation) in terms of robustness.

Based on analyzing the geometrical features for the 3D model. N. Zainab et al 2018 [15] introduced a blind watermarking 3D model method. The Mean Curvature (MC) is shown to have an essential characteristic that may be utilized to categorize surface points in this study. In embedding process, the vertices of the surface are categorized based on the mean curvature values to choose an appropriate area for inserting and enhancing the watermarking algorithm's robustness and imperceptibility. The watermark is retrieved with no need for the original 3D model throughout the extraction process. By proposing a watermarking method that is resistant to many kinds of attacks without compromising the watermarked model quality, the suggested watermarking approach resolves the contradiction between robustness and imperceptibility. The performance assessment reveals a high level of imperceptibility and tolerance to a variety of attacks.

3. 3D Model Structure

In general, a 3D model made up of polygons contains geometrical data such as vertices' coordinates and topology (connectivity) between them. The collection of vertex coordinates and related edges define the surface [16, 17]. As shown in Figure 1, there are five vertices, from v1 to v5.

• Each vertex holds information about the x, y, and z coordinates, which are represented in the Table 1 as v_1: x_1, y_1, and z_1.

• A polygon edges information is stored in the second column (Edge) of Table 1. As shown, the Edge E1 is the connection between vertices v_1 and v_2 in the diagram below and is represented in the Table 1 as E_1: v_1, v_2.

• The data of polygons' surface are the number of surfaces in the polygon (S_n), where Surface S_1 is formed by the edges E_1, E_2, and E_3, in the Table 1 polygon surface as S_1: E_1, E_2, and E_3.

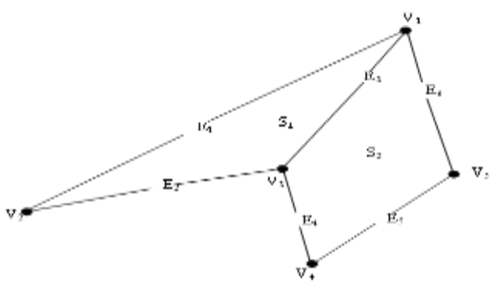


Figure 1: part from 3D mesh model

Table 1: Table for 3D mesh model

Vertex	Edge	Polygon- surface
V_1: X_1, Y_1, Z_1	E_1: V_1, V_2	S_1: E_1, E_2, E_3
V_2:X_2, Y_2, Z_2	E_2:V_2, V_3	S2:E_3, E_4, E_5,E_6
V_3:X_3, Y_3, Z_3	E_3:V_3, V_1	
V_4: X_4, Y_4, Z_4	E_4: V_3, V_4	
V_5: X_5, Y_5, Z_5	E_5: V_4, V_5	
	E_6: V_5,V_1	

4. Theoretic Concepts of Surface Curvature

Curvature is one of many closely related notions in geometry in mathematics. Curvature is the distance between a surface and a plane between a curve and a straight line [18]. It is often used in the analysis and processing of surfaces, Mean Curvature (MC) and Gaussian Curvature (GC) are the main kinds of curvature that resulted from this [19]

4.1 Principal curvatures

The principal curvatures are the maximum and minimum of a normal surface curvature at a given location. Normal curvatures are the Curvatures of the surface curves in planes that include the tangent vector at a given location. The Gaussian and Mean curvatures of the surface are computed using the principal curvatures, as shown in Figure 2 [20- 22]. MC and GC are the mean and product of principal curvatures, respectively. For any tangent vector, the Euler formula provides the continuous curvature at a point P explained by Eq. (1).

$$K_n(t_i) = K_{max}\cos^2(\Theta) + K_{min}\sin^2(\Theta) \quad (1)$$

Where K is the principal curvature

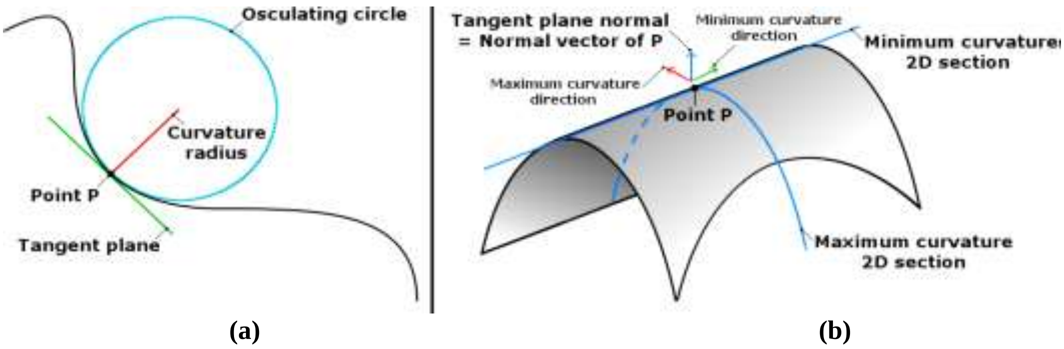


Figure 2: Curvature representation on: (a) 2D curves and (b) 3D surfaces [19]

4.2 Mean curvature

The sum of the principal curvatures at a location equals half the MC of the surface at that point. Negative or zero GC may be found at any location with zero mean curvature computed as in Eq. (2).

$$MC = (K_1+K_2)/2 \quad (2)$$

K_1 and K_2 are matrices representing the principal curvatures.

Surfaces having a zero mean curvature in all directions are known as minimum surfaces. Constant Mean Curvature (CMC) surfaces are surfaces that have the same mean curvature everywhere.

4.3 Gaussian curvature

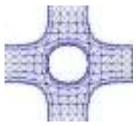
The product of the principal curvatures at a location determines the surface's Gaussian Curvature (GC). The point with positive (GC) has its tangent plane contact the surface at a single point; the point with (GC) has its tangent plane cut the surface. Negative or zero Gaussian curvature exists at every location with zero mean curvature, GC computed by Eq. (3) [23].

$$GC = K_1 * K_1 \tag{3}$$

5. Proposed System Design

The proposed system is based on the properties of the 3D mesh surface, which are the geometrical and the topology properties. The topology structure of 3D mesh contains the vertices and edges, the collection of edges surrounding each vertex form a 1-ring, and the number of edges in each ring either odd or even. Table 2 shows the 3D model and its mesh used as for experiment in this proposed algorithm. The embedding process start from the centre of the grave to ensure that the proposed algorithm is resistant to geometrical attack.

Table 2: The 3D model and its mesh

Name Of Model	Vertices No	Faces No	3D model Original	3D mesh model
mushroom	266	448		
Car	988	1763		
David-head	3889	47280		
Pipes	428	768		

Curvature is an important feature of a surface. Mean curvature values reflects the location of vertex in the surface, where the positive value of mean curvature means the vertex in the peak, zero means it is located in a flat, negative value means vertex located in the deep region of the surface, so its suitable for embedding in the proposed algorithm. One of the important issues in the embedding process is choosing the location for embedding. In this proposed algorithm, to increase the security, the embedding process depends on the combination of geometry and topology properties of 3D surface. The first condition for selecting the vertices for embedding depends on finding the mean curvature for each vertex in the 3D mesh and choosing the vertices that have negative mean curvature. Figure 3 shows the mean curvature for an example of the 3D models.

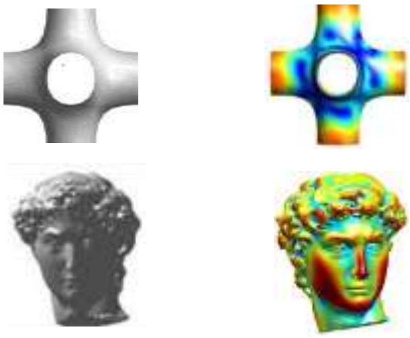


Figure 3: 3D model and mean curvature

Second condition for selecting the embedding region depends on the topology by choosing the vertices that have odd number of edges connected to the vertex. Figure 4 shows a part of mesh with vertex has odd number of edges.

Figure 4: part of mesh with vertex

The algorithm below illustrates the main steps of embedding process.

Embedding algorithm

Input: Original 3D model, Secret watermark text
Output: 3D watermarked model
Step1**:** input 3D model of type ‘. OFF' File format, save the vertices in V, faces in F.
Step2: convert to triangle mesh if it's not.
Step3: find the n-ring for each vertex.
Step4: store in edge No the number of edges connected to each vertex.
Step5: input the watermark text, convert to binary.
Step6: compute the mean curvature (MC) from equation 2, for all 3D mesh surfaces.
Step7: for i=1 to length ((binary bit (b (i)))) do
Step8: if MC (vertex (i)) <0 and odd (edge No (i)) then
embed the binary bit, b (i) in the x coordinate vertex.
Step9: go to next bit by i=i+1
Step10: end for
Step11: display watermarked model.

Figure 5 demonstrates the diagram for the suggested algorithm steps.

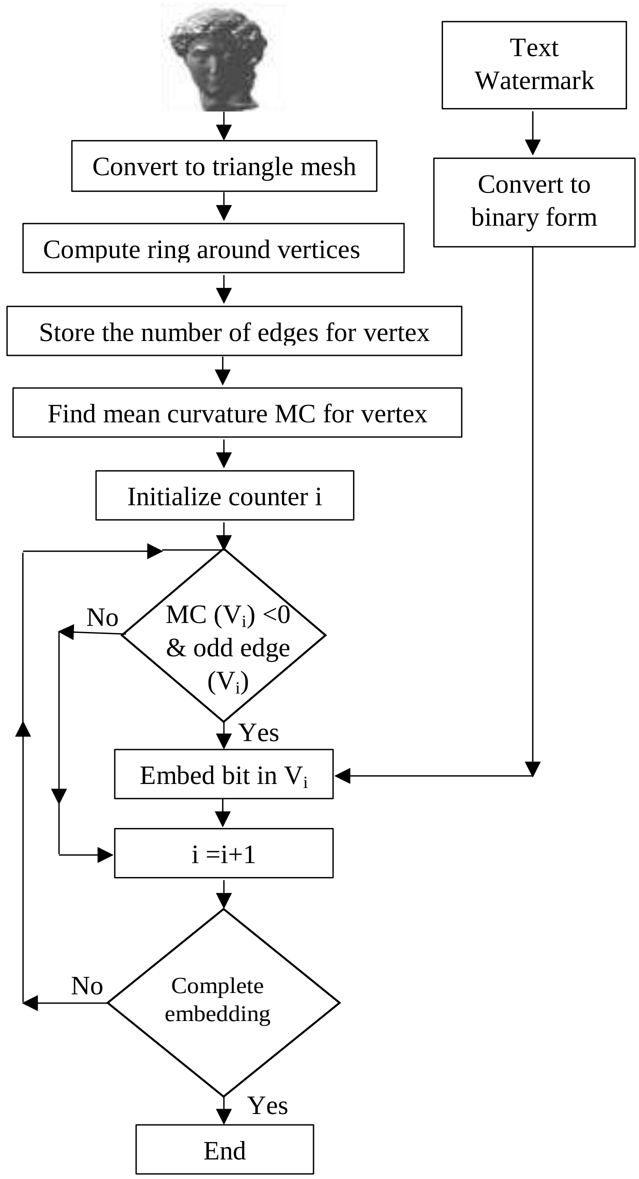


Figure 5: The block diagram of the proposed algorithm.

The watermarking system contains two processes, the embedding process, which is mentioned above, and the extraction process, where the extraction of the watermark from the 3D watermarked mesh model without loss is done. This proposed algorithm is blind because there is no need for the original 3D watermark in the extraction process. The following is the major steps for the extraction algorithm, which is similar to the embedding algorithm, but in reverse order.

Extraction algorithm

Input: 3D watermarked model.

Output: Original 3D model, Secret watermark text.

Step 1: Input 3D watermarked model '.OFF' File format, save the vertices in V and faces in F.

Step 2: convert to triangle mesh if it's not.
Step 3: find the n-ring for each vertex.
Step 4: store in edgeNo the number of edges connected to each vertex.
Step 5: calculate the mean curvature (MC), for all 3D mesh surfaces.
Step6: for i=1 to length (binary bit) do
Step7: if MC (vertex (i)) <0 and odd (edgeNo (i)) then
extract the binary bit, b (i) from the x coordinate vertex.
Step 8: go to next vertex i=i+1
Step9: end for
Step 10: convert binary to text.
Step 11: end.

The requirements that must be available in the watermarking system are the imperceptibility, capacity and robustness. To estimate the execution of the proposed algorithm different measurements are used. PSNR is used to estimate the imperceptibility and the effect of adding the watermark to the original 3D model. Correlation Factor (CF) is used to see if the watermark extracted from the watermarked model is identical to the original watermark before embedding, when there is attack or non-attack.
The PSNR is a measurement to find the effect of adding a watermark to an object. The watermark inserted is the type of noise that modify the object shape. To determine the watermarked model imperceptibility, Mean Square Error (MSE) metrics are shown in Eq. (4) [24-26].

$$\mathrm{MSE} = 1/\mathrm{m}\left(\sum_{i=0}^{m} \frac{v_i^2}{(v_i - v_i')^2}\right) \quad (4)$$

where v_i is the original 3D mesh vertex, while v_i' is the watermarked 3D mesh vertex, (m) is the vertices number of the model, and the PSNR can be calculated using Eq. (5) [27, 28].

$$\mathrm{PSNR} = 10\log10(\mathrm{MSE}) \quad (5)$$

Table 3 shows the PSNR for the 3D watermarked model.

Table 3: PSNR values for 3D watermarked model

Model name	Original 3D model	watermarked 3D model	PSNR
mushroom			37.23
Car			40.03
David-head			44.41
Pipes			38.34

The results in Table 3 indicates that the watermarked 3D model has good quality represented by the PSNR values, where all of them have values greater than 37, which mean they have good visualization and not recognized for data hiding.

6. Robustness Evaluation

Different types of attacks were used to evaluate the robustness of the proposed algorithm, which can be classified into:

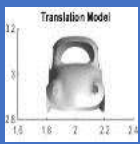
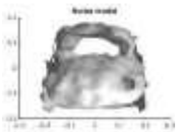
1- Affine Transformation attack: that includes i) translating the 3D watermarking model into one direction of any coordinates (x, y, and z) ii) scaling the 3D watermarking model by multiplying the vertices by a scaling factor. iii) rotation means rotate the 3D watermarking model in any coordinate based on angle [29, 30].

2- Noise attack: Adding the noise is changing the vertices value in 3D watermarked model by adding with noise level, the noise level ranges from 0.001 to 0.00001.

3- Cropping attack: cut some part of the 3D watermarked model, which is one of the difficult types of attack.

Table 4 shows the implementation of these attacks to car 3D watermarked model using the proposed algorithm.

Table 4: Different types of attack for 3D watermarked model

Car			
3D Model name	**watermarked 3D model**	**Translate x=2, y=3**	**Scaling y=0.4**
			
Cropp1	**Cropp2**	**Rotate z=90**	**Noise level 0.01**

The strength of the proposed algorithm by adding these attacks measured using the CF, where the best value is 1 or nearest 1, which means the proposed algorithm good robustness to attack and the worst value when reach to 0.

Table 5 explains the results of extracted the watermark after attack by (CF).

Table 5: The Results of CF after Geometrical Attack

3D model Name	Translation	Scaling	Rotation	Noise Level 0.01	Cropping 20%
Mushroom	1	1	1	1	0.8
Car	1	1	1	1	1
David-head	1	1	1	1	0.9
Pipes	1	1	1	1	0.82

In Table 5 The CF equal 1 when the 3D watermarked model attacked by Geometrical attack because the embedding process start from the centre of the grave that keep the proposed algorithm resistant to geometrical attack.

7. Conclusions

In terms of imperceptibility and robustness, the suggested approach is effective. One of the important things in data hiding is the selection of embedding area. The embedding area in the 3D mesh was chosen to improve invisibility. This is one of the most important criteria of any watermarking systems. For the proposed system, the selection of vertices for embedding is based on the geometrical and topology of the surface by selecting the vertices with negative mean curvature and odd number of edges around vertex. Thus, using the principle of both geometrical and topology to increase the level of security for the proposed algorithm.

The experimental results showed that the suggested approach is resistant to any geometrical attack (rotation, scaling, and translation), and have good resistant for noise and acceptable results for cropping attack.

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