DOI: 10.24996/ijs.2021.62.12.36

ISSN: 0067-2904

3D Model Watermarking based on Wavelet Transform

Muna M. Laftah
Department of Computer, College of Education for Women, University of Baghdad, Baghdad, Iraq

Received: 10/**8**/2021 Accepted: 20/10/2021

Abstract
In the last decade, 3D models gained interest in many applications, such as games, the medical field, and manufacture. It is necessary to protect these models from unauthorized copying, distribution, and editing. Digital watermarking is the best way to solve this problem. This paper introduces a robust watermarking method by embedding the watermark in the low-frequency domain, then selecting the coarsest level for embedding the watermark based on the strength factor. The invisibility of the watermark for the proposed algorithm is tested by using different measurements, such as HD and PSNR. The robustness was tested by using different types of attacks; the correlation coefficient was applied for the evaluation of the extracted watermark. From the results, it is clear that the proposed algorithm achieved good invisibility and robustness against the geometrical attack and the added noise.

Keywords: 3D watermarking, frequency domain, wavelet, 3D model.

اخفاء العلامة المائية بالنماذج ثلاثية الابعاد باستخدام تحويل المويجة

منى مجيد لفتة
كلية التربية للبنات، جامعة بغداد، العراق

الخلاصة
في العقد الماضي، زاد الاهتمام بالنماذج الثلاثية الأبعاد في العديد من التطبيقات مثل الألعاب ، والمجال الطبي ، والتصنيع ، بحيث أصبح من الضروري حمايتها من النسخ والتوزيع والتحرير. العلامة المائية الرقمية هي الطريقة الافضل لحل هذه المشكلة. في هذا البحث، تم تقديم طريقة قوية للعلامة المائية من خلال تضمين العلامة المائية في مجال التردد الواطيء ثم نختار المستوى الأكثر خشونة لتضمين العلامة المائية بناءً على عامل القوة.
تم اختبار عدم رؤية العلامة الخوارزمية المقترحة باستخدام قياسات مختلفة مثل HD و PSNR بينما تم اختبار القوة باستخدام أنواع مختلفة من الهجمات واستخدام معامل الارتباط لتقييم العلامة المائية المستخرجة. من النتيجة، حققت الخوارزمية المقترحة انتائج جيدة من ناحية عدم المرئية وقوية ضد الهجوم الهندسي وإضافة الضوضاء.

1. Introduction

Image, audio, and video are types of multimedia that have been focused on by extensive research during the last decade. The 3D mesh models are very important in the fields of virtual reality, Computer-Aided Design (CAD), games, and medical applications. Therefore, there has been a growing need to protect these models for copyright purposes. Watermarking

*Email: muna_majeed@yahoo.com

is an effective method to achieve this protection. The digital watermark should achieve imperceptibility, robustness, and capacity [1-3].

The watermark should be robust against different attack types, such as compression, addition of noise, and geometrical transformation. Blind and not blind watermarking are the main two types of watermarks, depending on the need for the 3D mesh to retrieve the original watermark [4-6].

The embedding process can be divided into a spatial domain and a frequency domain. In the spatial domain, the embedding is applied by changing the original 3D mesh directly. It is easy to implement but not robust to some types of attack. In the transform domain, the 3D model is converted to transform domains, as performed by the Discrete Wavelet Transform (DWT) and Discrete Cosine Transform (DCT). The watermark is embedded by changing the coefficients of the 3D mesh transform model [7-9].

Many different types of 3D file formats are found. The most popular formats are ".OBJ" and ".OFF". The structure of the 3D model includes vertices, faces, and edges. Each vertex contains three coordinates (X, Y, and Z) [10, 11]. Figure 1 shows a block diagram of the embedding and extracting modules of the watermarking scheme.

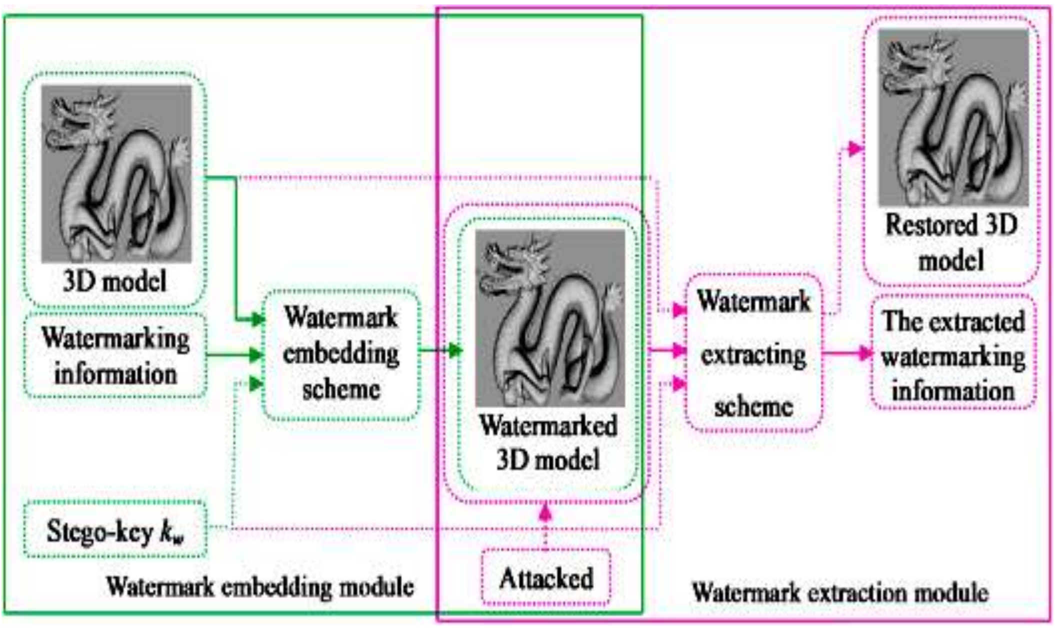

Figure 1- A block diagram for the 3D general watermarking scheme [12]

2. Related Works

Many related works have introduced watermarking in the 3D model.

A 3D watermarking, using saliency and wavelet transform, was introduced by changing the coefficients based on quantifying index modulation [13]. The results revealed good robustness against some types of attacks and imperceptibility. Multiresolution was implemented for a 3D semi-regular mesh, producing a sequence of approximation meshes and coefficients of wavelet. Then, the saliency was computed by applying 1^{st} level wavelet decomposition and salient points were extracted.

A 3D watermarking using frequency domain was proposed [4]. The region selected for embedding the watermark in the 3D model was robust, with the embedding being applied in the low frequency domain of the wavelet transform.

The pixels of the image were normalized and had a range of 0-255. Then, the wavelet transform algorithm was used to convert the 2D image to the image in the frequency domain, using a wavelet transform.

Another study proposed a 3D mesh watermarking for the triangle and the semi-regular mesh, according to the bit value. The watermark was embedded by changing the coefficients of wavelet [14].

Wavelet transform was applied to the original 3D mesh after a uniform scaling. The embedding process was performed by modifying the wavelet coefficients according to the bit to be inserted. Various attacks were used to test the algorithm's robustness, like translation, scaling, and rotation.

3. 3D Multiresolution

In the wavelet transform, the multiresolution is composed of the signal at different levels, which is considered a powerful tool that is widely used in the literature.

The wavelet transform is used to decompose a polygonal model and display it at several resolutions. A low-resolution portion and a detailed part are created from the high-resolution polygons. The detailed portions are represented by wavelet coefficient vectors, one for each resolution level, whereas the coarse model is represented by the low resolution component.

Different levels of frequency are produced, from the low resolution level (coarse) to medium and high resolution (detailed). The main reason for using multiresolution in 3D watermarking is the high robustness against attacks, especially when embedding the watermark in the coarsest level.

Figure 2 shows the multi-level decomposition of wavelet for a 3D mesh "Bunny model" [15].

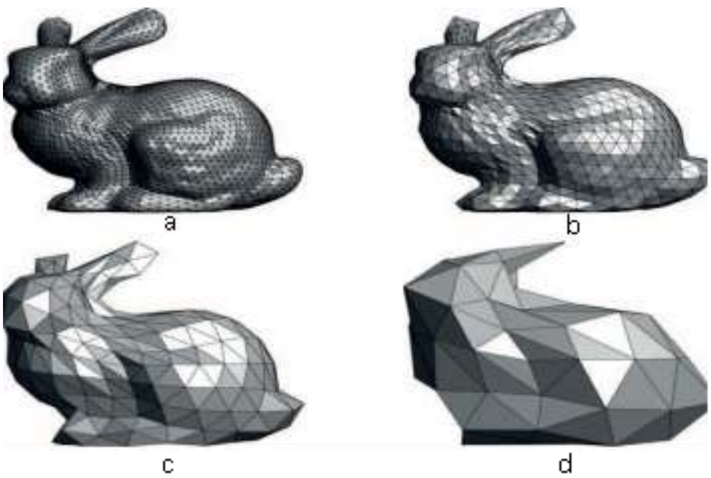

Figure 2- The Bunny mesh wavelet decomposition: (a) dense mesh; (b) first level wavelet decomposition; (c) second level wavelet decompositions; (d) Bunny representation of the coarsest mesh level.

4. The Proposed System

In this paper, a non-blind 3D model watermarking method dependent on 3D multiresolution analysis was introduced. The main idea of wavelet transform to 3D mesh is to decompose it into level resolution until it reaches the coarsest level of mesh. Decomposition of semi-regular triangle meshes is achieved by subdividing the surface and combining all the four triangles into one triangle, as shown in Figure 2.

In the proposed method, low- resolution is chosen for the embedding process by modifying the coefficients of the wavelet transform. The visible strength factor is used to control the imperceptibility of watermark chosen from experiments. The watermark is a text that is firstly converted to a binary stream before embedding.

The formula for altering the coefficients and embedding process is as follows:

$$C` = C + \alpha * bin \quad (1)$$

where α is the strength factor, "bin" is the binary string of watermark, C is the coefficient of the wavelet transform, and C' is the new wavelet transform coefficient. Figure 3 describes the block diagram for the main stages of the proposed algorithm. The following are the main steps of the 3D watermark embedding algorithm .

3D model watermark embedding algorithm
Input: 3D model**,** watermark.
Output: 3D watermarking model.
Step1: Read 3D model.
Step2: Convert to a triangle mesh.
Step3: Load watermark (text).
Step4: Convert the watermark to a binary string.
Step5: Apply wavelet transform for the triangle mesh by subdividing the surface until it reaches the coarsest level.
Step6: For each bit in the binary string do
Step7: Perform the formula (1) which modifies the coefficients for low level of mesh wavelet transform.
Step8: End For
Stpe9: Display the watermarked model.

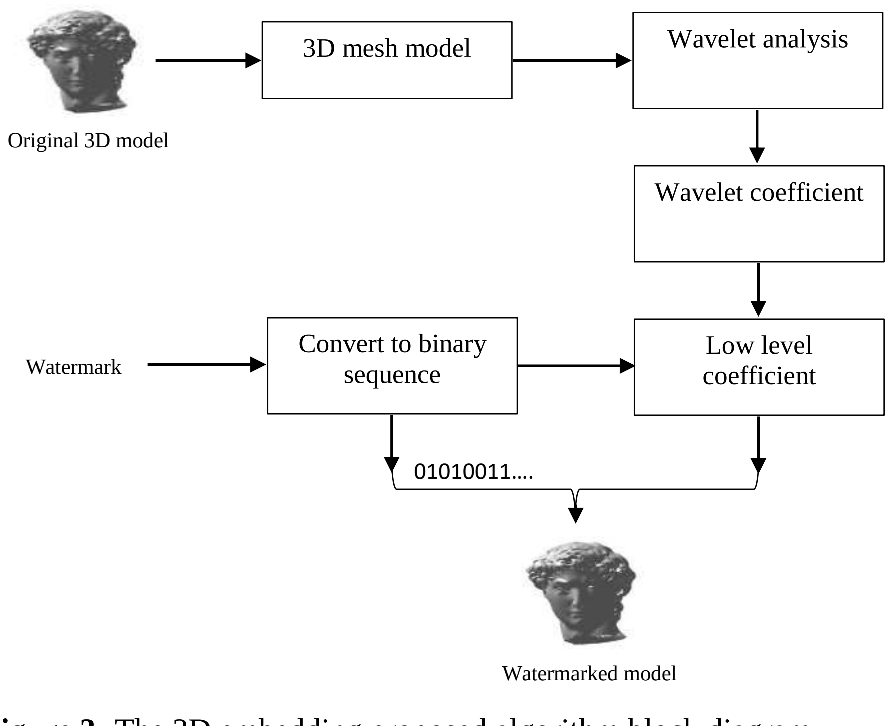

Figure 3- The 3D embedding proposed algorithm block diagram

For the extraction of the watermark from the 3D watermarked model, the same steps of the proposed embedding process are performed, but in the reverse order. Because the proposed method is not blind so that the wavelet coefficient for the original and the watermarked models are needed to extract the embedded binary stream, as in the following formula (2).

$$bin = C` - C/\alpha \quad (2)$$

5. Experimental Results

To evaluate the proposed method, different semi-regular mesh models are used. These include Bunny (34835, 69473), David-head (23889, 47280), and Pips (428,768), where the first value in the bracket represents the vertices number and the second is faces number.

Table 1 shows the original model and the watermarked model, i.e. after embedding the watermark, where the strength factor is (0.001) and the watermark is '**Copyright Protection**'.

Table 1- The original model and the watermarked model after embedding the watermark

Model name	Original model	Watermarked model
Bunny model		
David-head model		
David-head model		

Hausdorff Distance (HD) and Peak Signal to Noise Ratio (PSNR) were used as measurements to test the imperceptibility of the proposed method.

HD is one of the important metric tools used to measure the similarity between two sets of points representing two objects. HD is the maximum distance of a points in one set to the closed point in the another set [16, 17]. The purpose is to reduce the HD value between the original 3D mesh and 3D watermarked mesh to zero, as given in equation (3).

$$HD(A, B) = \max_{a \in A}\{\min_{b \in B}\{d(a, b)\}\} \quad (3)$$

where A is the original mesh, B is the watermarked mesh, and d(a, b) is the Euclidean distance from a to b in the 3D space [18].

The PSNR is another measurement to find the effect of adding a watermark to an object, embedding the watermark, and modifying the object shape by changing the vertices values. The PSNR can be calculated using equation (4) [19, 20].

$$PSNR = 10\log10(MSE) \quad (4)$$

To measure the imperceptibility of the watermarked model, the Mean Square Error (MSE) metric was used and computed as in equation (5) [21].

$$MSE = 1/m\left(\sum_{i=0}^{m} \frac{v_i^2}{(v_i - v_i')^2}\right) \quad (5)$$

where v_i is the original 3D mesh vertex, v_i' is the 3D watermarked mesh vertex, and m is the vertices number in the model [22-24].

Table 2 shows the values of PSNR and HD for the watermarked 3D mesh model.

Table 2-PSNR and HD values for the watermarked 3D mesh model

Model name	PSNR	HD
David-head	39.95	00.002
Pips	36.78	0.0125
Bunny	40.12	0.0002

Figure 4 elucidates a histogram for the original and the watermarked models for the bunny 3D model. The distribution of vertices for (x, y, z) are shown. It is clear that there is no noticeable change in the vertices' locations before and after the embedding process.

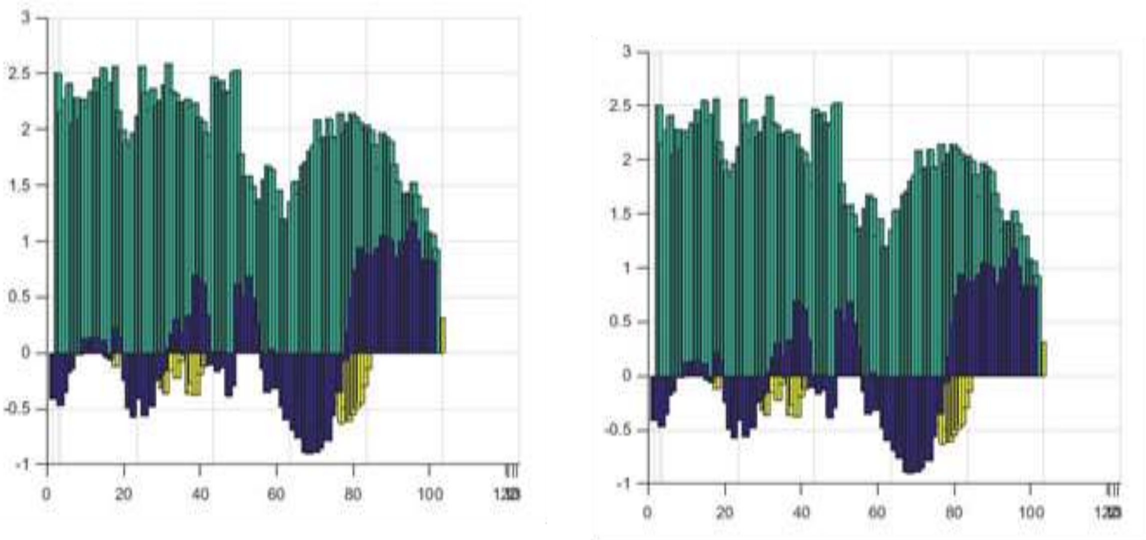

Figure 4- A histogram for the original model and the watermarked model after embedding the watermark

The main objective of the proposed algorithm is not only to embed a watermark in the 3D model, but the watermark must also be robust against attacks. Hence, to evaluate the robustness of the proposed algorithm, different types of attacks were applied to the 3D watermark model. These included the geometry transformation attacks (Rotation, Scaling, and Translation) and the adding noise attacks.

The correlation factor (CF) was used as a measure for the distortion in the watermark. If its value is close to 1, this means that the watermark's retrieval after the attack is good [25, 26].

$$CF = \frac{\sum_{i=1}^{N-1}(w'_i - \overline{w'})(w_i - \overline{w})}{\sqrt{\sum_{i=1}^{N-1}\left(w'_i - \overline{w'_i}\right)^2 . \sum_{i=1}^{N-1}(w_i - \overline{w})^2}} \quad (6)$$

where $\overline{w'_i}$ and $\overline{w}$ represent the mean values of the bit sequence w'_i for the recovered watermark and bit sequence w_i for the embedded watermark, respectively. This correlation value determines the similarity between two matrices and ranges between −1 and +1.

The geometric attacks were used to evaluate the proposed algorithms. Rotation is the process of rotating a 3D mesh in different directions with a specific angle, while scaling is modifying the vertices size values of a 3D object. Translation implies the process of moving a 3D mesh toward a specific direction. Figure 5 shows the Bunny model with the different geometrical attacks.

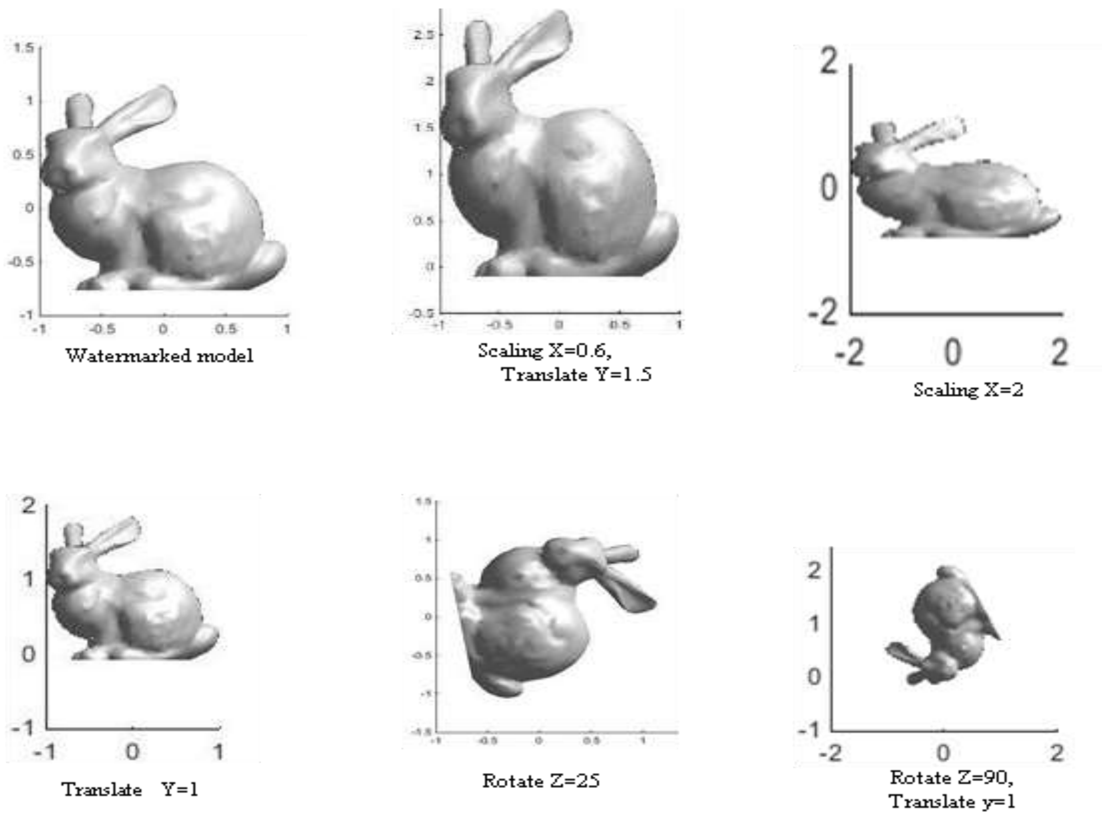

Figure 5- Watermarked Bunny Model with Transformation Attack

Adding noise is achieved by changing the location values of vertices for the mesh. Noise may be introduced either maliciously (intentionally) to destroy the watermark or not maliciously, i.e. from signal processing. Figure 6 shows the effects of adding noise to every vertex in the 3D watermarked models, with a noise level equal to 0.001.

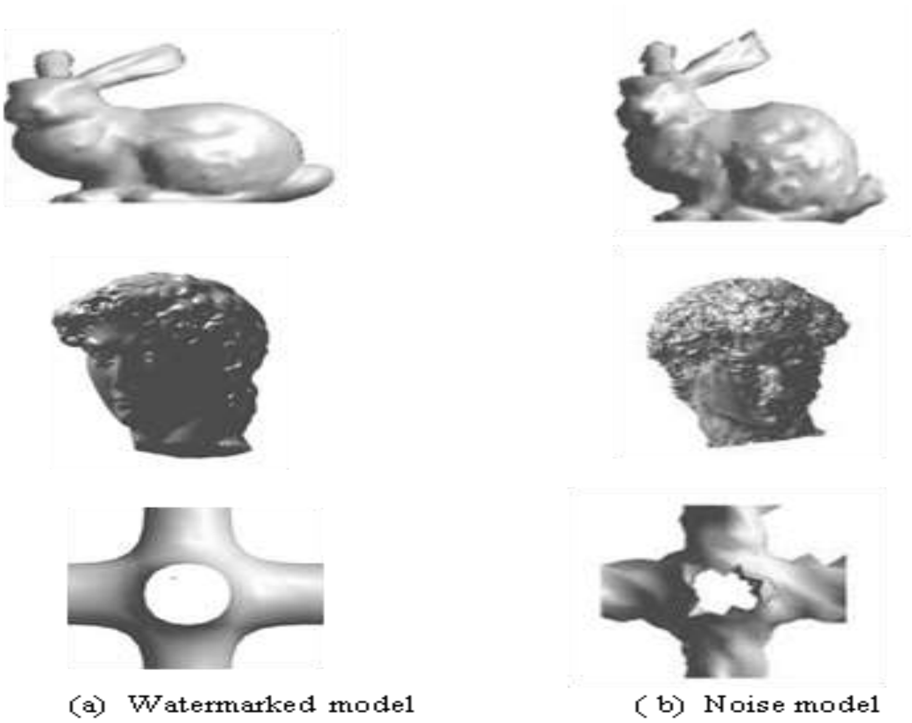

Figure 6- Adding noise to watermarked models

Tables (3) shows the results of CF for the 3D watermark model recovered after applying the geometrical attack and noise addition attack, with different levels of noise. From the results, we conclude that the watermark was extracted correctly from the 3D watermarked model following the applied attacks, without loss in the watermark.

Tables 3- The results of (CF) after applying attacksfor 3D watermarked model

Model name	Translation	Scaling	Rotation	Noise		
				0.01	0.001	0.0001
David-head	1	1	1	1	1	1
Pips	1	1	1	1	1	1
Bunny	1	1	1	1	1	1

6. Conclusions

In this paper, we presented a new watermarking algorithm for 3D meshes in the frequency domain. Our algorithm converted the original mesh into a 3D multiresolution by applying wavelet transforms for the semi-regular mesh. Each wavelet coefficient in the coarsest level was changed due to embedding and extracting the watermark based on the strength factor.

The results presented show clearly that our algorithm has good performance in terms of visibility and robustness. The watermarked model retrieves correctly with no error when various attacks (noise addition, translation, rotation, and uniform scaling) are applied.

ACKNOWLEDGEMENTS

The author would like to thank the University of Baghdad, Baghdad-Iraq, for its support in the present work.

REFERENCE

[1] M. Hamidi, M. El Haziti, H. Cherifi, and D. Aboutajdine, “A Robust Blind 3-D Mesh Watermarking based on Wavelet Transform for Copyright Protection,” 2019.

[2] P. S. Kumar, “Invisible Watermarking in 3D models,” vol. 119, no. 15, pp. 791–796, 2018.

[3] Z. N. Al-qudsy and S. Hameed, “Proposed an efficient blind digital 3D model watermarking algorithm using geometrical properties Proposed an efficient blind digital 3D model watermarking algorithm using geometrical properties,” no. November, 2018.

[4] L. Tan, Y. He, F. Wu, and D. Zhang, “A Blind Watermarking Algorithm for Digital Image Based on DWT,” J. Phys. Conf. Ser., vol. 1518, no. 1, 2020.

[5] Y. Y. Chen and K. Y. Chi, “Cloud image watermarking: high quality data hiding and blind decoding scheme based on block truncation coding,” Multimed. Syst., vol. 25, no. 5, pp. 551–563, 2019.

[6] O. M. El Zein, L. M. El Bakrawy, and N. I. Ghali, “A robust 3D mesh watermarking algorithm utilizing fuzzy C-Means clustering,” Futur. Comput. Informatics J., vol. 2, no. 2, pp. 148–156, 2017.

[7] M. Botta, D. Cavagnino, M. Gribaudo, and P. Piazzolla, “Fragile watermarking of 3D models in a transformed domain,” Appl. Sci., vol. 10, no. 9, 2020.

[8] M. Saiful Islam, M. A. Ullah, and J. P. Dhar, “An imperceptible & robust digital image watermarking scheme based on DWT, entropy and neural network,” Karbala Int. J. Mod. Sci., vol. 5, no. 1, 2019.

[9] M. Begum and M. S. Uddin, “Digital image watermarking techniques: A review,” Inf., vol. 11, no. 2, 2020.

[10] K. McHenry and P. Bajcsy, “An overview of 3D data content, file formats and viewers,” Tech. Rep. Image Spat. Data Anal. Gr. Natl. Cent. Supercomput. Appl., pp. 21, 2008.

[11] S. M. A. S. Liqaa A. Al-Hashime, Ghaida A. Al-Suhail, New Trends in Information and Communications Technology Applications. 2018.

[12] Y. Wang, J. Liu, Y. Yang, D. Ma, and R. Liu, "3D model watermarking algorithm robust to geometric attacks," IET Image Process., vol. 11, no. 10, pp. 822–832, 2017.

[13] M. Hamidi, A. Chetouani, M. El Haziti, M. El Hassouni, and H. Cherifi, "Blind robust 3D mesh watermarking based on mesh saliency and wavelet transform for copyright protection," Inf., vol. 10, no. 2, 2019.

[14] I. Sayahi, A. Elkefi, M. Koubaa, and C. Ben Amar, "Robust watermarking algorithm for 3D multiresolution meshes," VISAPP 2015 - 10th Int. Conf. Comput. Vis. Theory Appl. VISIGRAPP, Proc., vol. 3, pp. 150–157, 2015.

[15] F. Uccheddu, M. Corsini, and M. Barni, "Wavelet-based blind watermarking of 3D models," Proc. Multimed. Secur. Work. 2004, MM Sec'04, pp. 143–154, 2004.

[16] A. A. Taha and A. Hanbury, "An Efficient Algorithm for Calculating the Exact Hausdorff Distance," IEEE Trans. Pattern Anal. Mach. Intell., vol. 37, no. 11, pp. 2153–2163, 2015.

[17] D. Karimi and S. E. Salcudean, "Reducing the Hausdorff Distance in Medical Image Segmentation with Convolutional Neural Networks," IEEE Trans. Med. Imaging, vol. 39, no. 2, pp. 499–513, 2020.

[18] X. Li, Y. Jia, F. Wang, and Y. Chen, "Image Matching Algorithm Based on an Improved Hausdorff Distance," Proceedings of the 2nd International Symposium on Computer, Communication, Control and Automation, vol. 68. 2013.

[19] Z. Zhang, L. Wu, Y. Yan, S. Xiao, and H. Sun, "An improved reversible image watermarking algorithm based on difference expansion," Int. J. Distrib. Sens. Networks, vol. 13, no. 1, 2017.

[20] I. I. Khan, K. Ahmad, M. A. Rizvi, and K. A. Bin Ahmad, "Increased PSNR with improved DWT digital watermarking technique," Int. J. Innov. Comput. Appl., vol. 10, no. 3–4, pp. 185–193, 2019.

[21] M. S. Raval, V. B. Joshi, D. Gupta, and S. J. Kher, "Authenticating super-resolved image and enhancing its PSNR using watermark," Proc. - 2015 IEEE Symp. Ser. Comput. Intell. SSCI 2015, no. December, pp. 481–487, 2015.

[22] A. Naveed, Y. Saleem, N. Ahmed, and A. Rafiq, "Performance Evaluation and Watermark Security Assessment of Digital Watermarking Techniques," Sci.Int.(Lahore), vol. 27, no. 2, pp. 1271-1276, 2015.

[23] M. Haribabu, C. H. Bindu, and K. V. Swamy, "A Secure & Invisible Image Watermarking Scheme Based on Wavelet Transform in HSI Color Space," Procedia Comput. Sci., vol. 93, no. September, pp. 462–468, 2016.

[24] J. Liu, G. Liu, W. He, and Y. Li, "A new digital watermarking algorithm based on WBCT," Procedia Eng., vol. 29, no. February, pp. 1559–1564, 2012.

[25] M. M. Laftah, "Watermarking in 3D Model Using Dihedral," *Iraqi J. Sci., vol.56, no.4C, pp: 3546-3553*, 2015.

[26] N. A. Ali, "Watermarking in 3D models using depth path," *Iraqi J. Sci.*, vol. 60, no. 11, pp. 2490–2496, 2019, doi: 10.24996/ijs.2019.60.11.21.