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Review on Different Types of 3D Watermarking

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Abstract : In this paper, an attempt has been made to summarise the work done related to 3D watermarking in past years. Here, the different types of watermarking methodology for 3D models have been presented. Focus on the 3D watermarking is ensured, ranging from the earliest time till present, regarding their nature and robustness against various attacks.

Keywords: Digital Watermarking, 3D models, 3D watermarking, Robustness

I. INTRODUCTION

WATERMARKING in the field of 3D models made in virtual space using various software like Computer-Aided Drafting (CAD) is still in a very less developed stage due to less or no research work done regarding this field of interest. However, there are still many important works done in this field. This paper tries to summarize the few important works done by people regarding this topic, starting from the beginning of the idea of 3D watermarking to the recent change in trends. Comparison between different types of watermarking based on their properties and robustness against various attack has been made in this paper.

This paper is organized as follow: Section 2 presents the related work that has been done in other fields. Section 3 present extensive review regarding the different types of watermarking

II. RELATED WORK IN OTHER FIELDS

Watermarking has been used in other field of work like images, audios etc. for the purpose of copyright related problems like- copyright protection, broadcasting monitoring. These digital watermarking methods have achieved new heights of development making the watermark more robust and imperceptible. These watermarking methods are also commercially available e.g. – Digimarc company.

In the past few years digital watermarking for 3Dimensional models has made noticeable progress. Unlike other digital watermarking schemes, several parameters have been made for 3D watermarking for measuring the imperceptibility for the watermark.

III. DIFFERENT TYPES OF WATERMARKING

A. Watermarking Three-Dimensional Polygonal Models through Geometric and Topological Modifications (1988)

This is the one the earliest watermarking scheme for 3D models. In this paper, [1] Ryutarou proposed technique of embedding data into the 3D polygonal models of geometry. Basically, data embedded into either their vertex coordinates, their vertex topology (connectivity), or both. A “polygonal model” containing one or more of the following geometrical primitives: points, lines, polygons, connected polygons, polyhedrons, and connected polyhedrons is required for the method.

In this paper, the author has given three algorithms for embedding of data in 3D model.

The Triangle Similarity Quadruple (TSQ) algorithm gives a quadruple of adjacent triangles that share edges in the configuration as embedding primitives. TSQ doesn’t require the original cover 3D model for extraction. TSQ can withstand translation, rotation, and uniform-scaling transformations of the stego-3-D-model, resection and local deformation.

Tetrahedral volume ratio (TVR) uses ratio of the volumes of a pair of tetrahedrons is the embedding primitive. TVR algorithm does not require a cover-3-D-model for extraction. The watermarks that it produces survive affine transformation, but are destroyed by topological modifications such as remeshing, randomization of vertex coordinates and geometrical transformations that are more general than affine transformation (e.g., projection transformation), among other disturbances.

Mesh density Pattern, algorithm tessellates given curved surfaces. It embeds a visible pattern by modulating the sizes of triangles in the output mesh. This pattern is hardly visible if displayed with a smooth shading (e.g., Gouraud shading) using proper vertex normal vectors calculated from the original curved surfaces, but becomes visible when displayed by using wire mesh rendering. This watermark withstands practically every geometrical transformation. The algorithm is resistant but not immune to polygonal simplification and other topological manipulations.

Combining multiple embedding methods, each with their own strengths and weaknesses, is a possible approach to increasing the utility of data embedding. However, they are not robust enough, for example, to prove that a theft has occurred. They lack many qualities, the most important of which is robustness, that are considered necessary for most applications of data embedding.

B. Geometry-based watermarking of 3D models (1999)

In this paper, [2] Oliver has proposed a watermarking system for a private watermarking. The idea is to use collections of surfaces as an embedding primitive.

The system proposed in this article introduces modifications in object-model normal distribution to achieve independence from one particular mesh representation. It requires a mesh representation of a 3D model consisting entirely of triangle patches as input. The watermark data is embedded in this mesh by performing certain displacements of points, which in turn introduces specific changes in mesh surface normal distribution. The resulting mesh again consists of triangle patches, with no topological or adjacency (vertices or faces) changes with respect to original mesh.

The system uses a collection of surfaces as an embedding primitive. These collections are generated by grouping model normal into distinct sets called bins. A bin is the entity for embedding one bit of watermark data. The bins can be constructed in a general way by tessellating the unit sphere.
The embedding and retrieval processes consist of several stages, as follows:

General outline of the embedding procedure: (El) Calculate consistent surface patch normals (E2) Sample model normals to bins

(E3) Apply core watermark embedding algorithm.
General outline of retrieval procedure:

(R1) Calculate consistent surface patch normals

(R2) Transform model into spherical representation (EGI) and adjust model orientation

(R3) Sample model normals to bins
(R4) Apply core watermark retrieval algorithm

The algorithm showed promising potential with respect to robustness against mesh simplifications. One drawback of the algorithm is the large amount of a priori data needed before watermark retrieval. For private watermarks, this is tolerable.

C. Wavelet-Based Blind Watermarking of 3D Models (2004)

In the given paper, [3] Uccheddu proposed a novel multi resolution mesh watermarking algorithm particularly designed to work with semi-regular meshes with subdivision connectivity. The algorithm embeds by the watermark modifying the wavelet coefficients of 3D models obtained by decomposing the host mesh by means of the algorithm proposed by Lansbury. Particular attention is paid to ensure that the embedding algorithm preserves the visual integrity of the models. The watermark is recovered by means of a correlation detector designed according to statistical detection theory. Their system does not require that the original non-marked mesh is available at the detector, thus resulting in a much more flexible system easily adaptable to practical applications.

The algorithm embeds the watermark by modifying the position of the mesh vertices in a transformed domain, i.e. wavelet domain. The 3D watermarking system presented in this paper embeds a numeric code into a semi-regular mesh with subdivision connectivity using multi-resolution framework. The algorithm presented in this paper belongs to the category of detectable watermarks. The watermarking embedding algorithm works according to three parameters (a secret key, the resolution level and coefficient determining the strength of the watermark.)

WATERMARK EMBEDDING

1) A particular watermark-dependent structure called watermarking map is generated according to Key.

2) The input model is decomposed into a set of wavelet coefficients and a base domain.

3) The vertices of the model and the wavelet coefficients at the same level are used by the embedding algorithm to embed the watermark by altering the modulus of a subset of the wavelets coefficients.

4) The watermarked wavelet coefficients and the other sets of wavelets are used to reconstruct the watermarked full resolution model.

WATERMARK DETECTION

The detection procedure works as follows: the user specifies the numeric key and the level of resolution where he wants to verify the presence of Key and the detector provides a positive or negative answer i.e.-if watermark is present or not.

The models used in the experiments are the semi-regular meshes made available to the public by the Multi-resolution Modelling Group of Caltech University. One of the main problems of 3D watermarking is the wide variety of different attacks possible on a polygonal mesh. The technique is specific for semi-regular meshes with subdivision connectivity, thus do not take into account those attacks that alter these properties of the mesh such as re-triangulation, simplifications or re-meshing. Instead the robustness of the algorithm against additive noise, low pass filtering, geometric manipulations, cropping and a combination of the above are tested.

D. Efficient Spectral Watermarking of Large Meshes with Orthogonal Basis Functions (2005)

In this paper, [4] Jianhua presented a novel spectral watermarking scheme using a new set of orthogonal basis functions derived from radial basis functions. The watermarking scheme embeds the digital watermarks by modifying the low-frequency components of a given shape in the spectral domain.

The watermark embedding phase computes a small set of new orthogonal basis functions. Then the geometry of the original mesh is projected to these basis functions spanning the spectral domain to acquire a set of corresponding spectral coefficients. Watermarks will be encoded into the leading coefficients which can be used later to reconstruct the watermarked mesh together with the unmodified coefficients. Thus, compared to related approaches, the algorithm runs much faster by two orders of magnitude, hence leading to efficient watermarking of very large models. Also as the watermarking scheme only modifies the “low-frequency” component of a given shape, the visual differences between the original mesh and the watermarked mesh are almost imperceptible.

As already told that watermarking scheme embeds the digital watermarks by modifying the low-frequency components of a given shape in the spectral domain. The new orthogonal basis functions derived via singular value decomposition will be used to decompose the input mesh into a spectral representation, and then the coefficients of the leading part of the spectrum which are more robust against attacks can be modulated. The watermarked mesh is later produced with an inverse transform using the same basis functions and is ready to be distributed.

After registration and resampling, the watermarked mesh is spectral analyzed to get a set of coefficients to extract the watermark.

The algorithm is robust against Similarity Transform, Cropping, Simplification, Additive noise, Remeshing and Smoothing.

E. An Oblivious Watermarking for 3-D Polygonal Meshes Using Distribution of Vertex Norms (2007)

In this paper, [5] *Cho* proposed two statistical watermarking methods for 3D polygonal mesh models, which modify the distribution of vertex norms via changing respectively the mean and the variance of each bin by Histogram mapping function for embedding of watermarking bit. Histogram mapping function are introduced to modify the distribution.

The two methods are proposed, one method is shifting the mean of distribution and another is to shift change of its variance.
In addition, *Cho* proposed an oblivious watermarking detection scheme, which can extract the watermark without referring to the cover mesh model.

Cho modified the distribution of vertex norm instead of normal distribution by *O.Benedens* to hide watermark information.

3D mesh polygonal model has no unique representation i.e. No implicit order and connectivity of vertices, while image data is represented by brightness (or amplitude of RGB component in the case of color images) of pixels sampled over a regular grid in two dimensions.

We analyze two parameters that can be adjusted to improve the robustness of the proposed methods. One is the watermark strength factor alpha, another is the size of bin**.** However, watermark transparency should be also carefully considered and the use of larger bins limits the number of watermark bits.

The methods show robustness against various kind of distortion attack such as addition noise, simplification, smoothing, re-meshing, and clipping and so on.

F. A New Approach of 3D Watermarking Based on Image Segmentation (2008)

In this paper, [6] *Saoussen Ben* proposed a robust 3D triangular mesh watermarking algorithm based on 3D segmentation, new approach of 3D image watermarking which combines three classes of insertion. This combination allows benefiting from the multiple advantages of each class. This is realized by segmenting the 3D image in unrefined regions having different values of curvature and by adapting every region to a class of insertion to obtain the maximum of invisibility of the mark.

The methods use the two possible domains of insertion:

spatial (geometric and topologic), and spectral domain

The segmentation decomposes a 3D mesh into connected subsets of mesh. The chosen algorithm that was implemented was proposed by L.Guillaume. It decomposes the object into almost constant curvature triangle regions with precise edge boundaries.

Firstly, discrete curvature is calculated for each vertex according to the work of Meyer et al. Then, vertices are classified into clusters according to their principal curvatures values. A region growing algorithm is then processed assembling triangles into connected labeled regions according to the vertex clusters.

Holes between regions are filled taking into account boundary criteria. Finally, a region adjacency graph is processed and reduced in order to merge similar regions according to several criteria (curvature similarity, size, common perimeter).

For robustness, to get the maximum efficiency, their idea was to profit from the advantages of many classes of watermarking. So, they choose to use three schemes in one algorithm.

(1) Geometric (2) Topologic (3) spectral scheme. First scheme permits getting robustness against geometric attacks, the second permits the signature to be robust against remeshing and simplification and the last scheme allows obtaining robustness against filtering and compression.

A quantitative evaluation in terms of "SNR" was used to measure the quality of the marked image. The robustness of new method was verified after application of various types of attacks such as RST transformations (rotation, scaling and translation), smoothing, random noise added to vertex coordinates, cropping vertices, simplification and remeshing.

G. A New Watermarking Method for 3D Models Based on Integral Invariants (2009)

In this paper, [7] *Yu-Ping et al.* proposed semi-fragile watermarking method based on integral invariants. It is a spatial domain method robust against rigid transformations and noise attacks and improves our algorithm by increasing its embedding capacity, currently limited to two integral invariants.

One solution would be using multi-resolution analysis methods to simplify the model and embed a watermark at the corresponding simplified model vertex. Another solution would be to find a method to simultaneously change four kinds of integral invariants.

It is desired that the hidden data be robust to unintentional changes like model compression, rigid transformation, and random noise originating from format conversion, similar to image watermarking nomenclature. They have characteristic watermarking algorithms showing this property as semi-fragile.

With each vertex that will undergo watermarking, the integral invariants of the unwatermarked model are calculated. These invariants are then slightly changed to embed the watermark image parts. In order to change the integral invariants to the new value, the positions of the vertex and its neighbors are modified.

The method is robust against rigid transformations and noise attacks. The method can recover only a fraction of the watermark, when model is cropped.

H. Constrained Optimization of 3D polygon mesh watermarking by Quadratic Programing (2009)

In this paper, [8] *Roland* propose a blind and robust watermarking method for 3D polygonal meshes by minimizing the mean square error between the original mesh and the watermarked mesh under several constraints using Quadratic programming.

In this paper, a histogram-based watermarking algorithm by globally optimizing distortions between the watermarked mesh and the original mesh is proposed, with several constraints to be satisfied. We take similar approaches as in the paper given by *cho* to modify the distribution of vertex norms, but the modification is executed by incorporating quadratic programming (QP) into the watermarking scheme to minimize the mean square error (MSE) between the original mesh and the watermarked mesh.

Three constraints are applied to ensure that the embedded watermarking bits are correctly decoded later. The first constraint ensures that the points belonging to the nth bin still belong to that bin after the watermarking process. The second constraint ensures that the mean of the transformed vertex norms in the nth bin is greater (or smaller) than a reference value when the embedded watermarking bit $\omega n = +1$ (or $\omega n = -1$). This constraint must be satisfied to ensure that the embedded watermarking bits could be correctly extracted later. Another constraint (3rd constraint) was proposed, to guarantee that the centre of gravity of the watermarked mesh is the same as the original one.

Thus, the problem of assigning distortions to an optimization problem is changed, with a quadratic objective function and three constraints. This is exactly a quadratic programming problem. The theory of convex optimization guarantees that such kind of problems can be solved reliably and efficiently, even in very large scales.

Compared with the watermarking schemes in paper given by *cho*, this method performs better in resisting Gaussian noise, thus potentially is a better watermarking algorithm. However, this method has difficulties in dealing with large meshes because of the complexity limitations of computers and existing QP solvers.

I. A novel semi-blind-and-semi-reversible robust watermarking scheme for 3D polygonal models (2010)

In this paper, [9] *Chao-Hung Lin* has introduced a novel semi-blind-and-semi-reversible robust watermarking scheme for three-dimensional (3D) polygonal models. The proposed approach embeds watermarks in the significant features of 3D models in a spread-spectrum manner. In this paper, novel semi-blind robust watermarking scheme for 3D polygonal models. Rather than requirement of the original models, only a small amount of information is needed to detect watermarks. The method embeds a watermark in the significant features of the models, which are detected by the proposed similarity-invariant curvature estimation approach. The approach embeds the watermark by deforming the significant features with shape constraints and successfully leads to imperceptible watermark embedding. Moreover, it can semi-recover the original models by deforming the watermarked models back using only a little information relative to the original models.

Embedding procedure
To consider perceptual invisibility, the watermark is embedded in significant patches, a curvature estimation approach to determine these embedding patches is proposed. To determine the embedding order, the embedding patches are sorted by geodesic distances that are insensitive to various aforementioned attacks. Finally, each bit of watermark is embedded in one embedding patch by a feature-preserving deformation approach

Detection procedure
In the detection procedure, the embedding positions and embedding order of the suspected models can be obtained in the same steps. The watermark is then extracted by comparing the embedding patch curvatures in the suspected model with the stored curvature information.

Model recovery
The proposed approach can semi-recover the original models after extracting the watermarks. It is achieved by deforming the watermarked model back.

The experimental results show that our approach is robust against a wide variety of attacks, including similarity transformation, noise addition, smoothing, cropping, vertex reordering, simplification, and even pose deformation. In addition, this approach has the ability to semi-recover the original models.

Currently, the proposed approach has the following two limitations. It is not suitable to handle the models that have smooth shapes as well as few protrusive patches, such as sphere and knot, since we select protrusive patches, i.e., high curvature patches, to embed watermarks. The other limitation is that our approach cannot resist the attacks of non-uniform scaling, shearing, and even free-form deformation since these attacks could cause severe alteration to the surface curvature.

J. Blind 3D model watermarking based on Multi-resolution and Fuzzy logic

In the paper, [10] Prof. Sharvari proposed a blind and robust watermarking system based on wavelet transform, a fuzzy inference system and a multi-resolution representation (MRR) of the 3d model. The method presented here is a combination of two algorithms proposed by Saeed K. Amirgholipour and Mukesh Motwani with some modifications. Paper given by Xavier represented a novel blind watermarking algorithm based on a joint DWT-DCT for 2D digital image. The idea of inserting watermark in the combined transform was based on the fact that, the joint transform can eliminate the drawback of each other and then, an effective watermark is embedded in the most robust and imperceptible parts of the image. Watermarking is done with embedding the watermark in the special middle frequency coefficient sets of 3-levels DWT transformed of a host image, followed by computing 4×4 block-based DCT on the selected DWT coefficient sets. Paper has proposed a non-blind watermarking algorithm based on wavelets and fuzzy logic, which inserts 8-bit grey scale image as a watermark into the 3D model.

The algorithm used in this paper embeds the watermark by modifying the wavelet coefficients of the 3 D model at third level and by using Mamdani’s fuzzy inference system, thus enhancing the robustness and making it more imperceptible as compared with other existing algorithms. Particular attention would be paid to ensure that the embedding algorithm preserves the visual integrity of the models.

Watermarking embedding
Haar wavelet transform on the 3d model is applied and four coefficients are generated, then Haar wavelet transform is applied again and again to generate level 2 approximation, level 3 approximations and detail coefficients. Total 16 matrices are generated in this process. Watermark image is converted into binary format and scramble watermark with Arnold transform Inputs (like Curvature, Area and Bumpiness) of 3d model are computed and Fuzzy Inference system (FIS) is applied and decide weight depending upon rules. Modify coefficients to embed the watermark into the model where the corresponding weighting factor has the values either high or higher. The watermark is inserted by adjusting the remainder of wavelet coefficient vector. Apply inverse DWT on the modified coefficients set up to level 3.

Watermarking extraction
Watermark can be extracted from the 3D watermarked model by using a blind method. Algorithm for extracting the watermark is as follows:

Step 1: Perform the first three steps of insertion process on 3d watermarked model.

Step 2: Use the same FIS as used in the embedding process and calculate the remainder of the coefficients for high and higher weight values of FIS. If the remainder of the coefficient is greater than reference value then the extracted watermark bit is 1 otherwise it is 0.

Step 3: The scrambled watermark is reconstructed using the extracted watermark bits with Arnold transform and calculate the correlation between original and extracted watermark.

The system has been proved to be robust against smoothing, similar transformations (Rotation, Translation and Scaling), noise and cropping attacks.

K. Optimized 3D Watermarking for Minimal Surface Distortion

In this paper, [11] Adrian has proposed a new 3D watermarking methodology which minimizes the object surface distortions by using the Levenberg–Marquardt optimization method for vertices represented in spherical coordinates. The proposed method is statistical, blind and robust 3D watermarking method.

The Watermark is embedded into histograms of distances from the object centre to vertices on its surface by slightly displacing the location of the vertices. The proposed method considers an error function consisting of three components measuring the distortion with respect to the original surface, the watermarked surface (updated surface) and the Euclidean distance from the original vertex location. This error function ensures both a minimal distortion with respect to the original surface as well as enforces smoothness in the object surface resulting after watermarking.

We provide a study of minimal object watermark embedding and a study of the watermark security for the proposed methodology. Here safety detection difference (SSD) represents the normalized difference between the distribution of the distance from the watermarked object surface to the center, and that of the uniform distribution. This SSD characterizes the level of distortion that the watermark object may undergo during an attack.

The security of the watermark can be improved if additional key-generated parameters would be added. the proposed watermarking methodology is better than other method like method proposed by Cho *et al.*, and the method using quadric error metric (QSP) has high robustness against common mesh attacks like additive noise, Laplacian smoothing, mesh simplification, quantization and uniform resampling, while ensuring object centre doesn't change. It can be observed that the distortion is increased when either Embedding Strength Factor α or the embedding capacity is increased.

L. Triangle Surface Mesh Watermarking Based on a Constrained Optimization Framework

In this paper, [12] Xavier Rolland proposed generalizing framework for 3D mesh watermarking, where the embedding process is formulated as a quadratic programming (QP) problem. This paper introduced three different extensions to the baseline system:

(i) The revision of the mathematical framework to support integral definitions of the centre of mass of a mesh.

(ii) The relaxation of the constraint on the direction of alteration to allow displacements deviating from the radial direction.

(iii) The integration of perceptual components in the cost function to better account for human perception during the minimization process.

Surface meshes are approximations of the surface boundary of 3D objects by M.Botsch and most 3D watermarking methods focus on the popular triangle mesh representation.

Non-blind 3D watermarking methods exhibit satisfactory robustness, but blind watermarking detection cannot leverage on recent advances in shape matching, which could help for registration e.g. when dealing with different poses of a model. Moreover, Xavier et al. review relevant state of art technique for 3D watermarking through special care to highlight their limitation. And introduce a mathematical framework that will serve to formulate our baseline 3D watermarking system as a quadratic programming problem.

M. Perceptual 3D watermarking using Mesh Saliency (2017)

In this paper, [13] *Jeongho Son* has proposed a novel blind and robust 3D Watermarking method which focuses on preserving the appearance of watermarking model using Mesh saliency. This paper used the vertex norm distribution and solved the quadratic error minimization problem to insert watermark bits.

It captures the visual appearance by preserving regions having high saliency by combining spatial domain- based watermarking and frequency-based weight map.

The proposed method shows a better result in terms of distortion metrics (The mesh Structural Distortion Measure [MSDM] and The Fast Mesh Perceptual Distance [FMPD]) compared to other methods like method proposed by *cho* and *Xavier*.

The proposed method shows good performance compared to the existing method in terms of robustness against Additive noise, Laplacian smoothing, Quantization and Mesh simplification in terms of averages of Bit error ratio (BER).

IV. CONCLUSIONS

This paper discusses and reviews various methods that have been introduced for 3D watermarking over the years, and discusses their merits and limitations in context to modern day technology.

REFERENCES

[1] Ryutarou Ohbuchi, Hiroshi Masuda, Masaki Aono. “Watermarking Three-Dimensional Polygonal Models through Geometric and Topological Modifications.” IEEE Journal on Selected Areas in Communications (Volume:16, Issue:4, May 1998), pp.561-560, 1998.Prasad SV Asthana R. (2004). Aluminum Metal-Matrix Composites for Automotive Applications: Tribological Considerations. *Tribology Letters 17:445-453*.

[2] Oliver Benedens. “Geometry-based watermarking of 3D models.” IEEE Computer Graphics and Applications (Volume:19, Issue:1, Jan/Feb 1999), pp.46-55, 1999.

[3] F. Uccheddu, M. Corsini, M. Barni. “Wavelet-Based Blind Watermarking of 3D Models.” MM&Sec '04 Proceedings of the 2004 workshop on Multimedia and security, pp.143-154, 2004.

[4] Jianhua Wu, Leif Kobbelt. “Efficient Spectral Watermarking of Large Meshes with Orthogonal Basis Functions.” The Visual Computer, Volume 21, Issue 8–10, pp.848–857, 2005.

[5] Jae-Won Cho, Rémy Prost, Ho-Youl Jung. “An Oblivious Watermarking for 3-D Polygonal Meshes Using Distribution of Vertex Norms.” IEEE Transactions on Signal Processing (Volume:55, Issue:1, Jan. 2007), pp.142-155, 2006.

[6] Saoussen Ben Jabra, Ezzeddine. “A New Approach of 3D Watermarking Based on Image Segmentation.” Computers and Communications, 2008. ISCC 2008. IEEE Symposium on, 2008.

[7] Yu-Ping Wang, Shi-Min Hu. “A New Watermarking Method for 3D Models Based on Integral Invariants.”IEEE Transactions on Visualization and Computer Graphics (Volume:15, Issue:2, March-April 2009), pp.285-294, 2008.

[8] Roland Hu, Patrice Rondao-Alface, Benoıt Macq. “Constrained Optimisation of 3D polygon mesh watermarking by Quadratic Programing.” Acoustics, Speech and Signal Processing, 2009. ICASSP 2009. IEEE International Conference on, 2009.

[9] Chao-Hung Lin, Min-Wen Chao, Chan-Yu Liang, Tong-Yee Lee. “A novel semi-blind-and-semi-reversible robust watermarking scheme for 3D polygonal models.” The Visual Computer, Volume 26, Issue 6–8, pp 1101–1111, 2010.

[10] Sharvari C. Tamane, Ratnadeep R. Deshmukh. “Blind 3D model watermarking based on Multi-resolution and Fuzzy logic.” International Journal of Computer Science & Information Technology (IJCSIT) Vol 4, No 1, pp.117-126, 2012.

[11] Adrian G. Bors, Ming Luo. “Optimized 3D Watermarking for Minimal Surface Distortion.” IEEE Transactions on Image Processing (Volume:22, Issue:5, May 2013), pp.1822-1835, 2012.

[12] Xavier Rolland-Nevière, Gwenael Doerr. “Triangle Surface Mesh Watermarking Based on a Constrained Optimization Framework.” IEEE Transactions on Information Forensics and Security (Volume:9, Issue:9, Sept. 2014), pp.1491-1501, 2014.

[13] Jeongho Son, Dongkyu Kim, Hak-Yeol Choi, Han-Ul Jang, Sunghee Choi. “Perceptual 3D watermarking using Mesh Saliency.” International Conference on Information Science and Applications: Information Science and Applications, pp.315-322,2017.