Research Article

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Exhaustive study on post effect processing of 3D image based on nonlinear digital watermarking algorithm

https://doi.org/10.1515/nleng-2022-0288
received March 26, 2022; accepted March 12, 2023

Abstract: In this work, an exhaustive study on post effect processing of three-dimensional (3D) image is carried to solve the problem of nonlinear digital watermarking algorithm. First, through the feature space decomposition method of the host image, the embedded watermark is constructed with the full row or column rank of the matrix, and then the public key is constructed by using the existence of the unitary matrix of the full row rank and column rank matrix, so that the algorithm can embed and extract the watermark in an asymmetric way. Watermark extraction correlation coefficient ($\rho$) value is 1. When the deformation amplitude of the model is slight and the noise intensity is $\sigma = 0.0001$, the watermark can be extracted successfully, and the watermark extraction correlation coefficient ($\rho$) is 0.92. In addition, the security of the algorithm is analyzed from many angles, the theoretical analysis is given, and verified by the experimental results. The proposed 3D watermarking methods are used to examine the information capacity of various 3D meshes. The 3D watermarking methods’ resistance to noise perturbation and object cropping is also investigated.

Keywords: digital watermarking, three-dimensional image, post effect, special effect processing, Gaussian noise, random process

1 Introduction

The rapid development of computer technology and internet provides great convenience for the access and use of various forms of digital media products, but at the same time, there are also a series of problems, such as random copying, embezzlement, tampering, and so on. Like image, text, audio, and video, 3D model has some problems, such as copyright protection, infringement detection, and so on. Especially with the research and application of collaborative design and virtual products in the network environment, the copyright protection of 3D model is becoming more and more important. With the rapid development of network multimedia technology, the research on information security technology based on information hiding and digital watermarking technology has become a current research hotspot. In modern multimedia information, three-dimensional (3D) image information plays a very important role. However, its copyright protection method is far less mature than image, audio, text, and other media data.

Digital watermarking is a technology that embeds copyright information into multimedia data. It can play the role of copyright protection, secret communication, authenticity identification of data files, and product identification. Digital watermarks can be classified into text watermarks, image watermarks, audio watermarks, video watermarks, and graphic watermarks. Image watermarking refers to adding a watermark to a still image for image database, online image publishing, etc. Due to the wide use of digital images, image watermarking is the most fully researched digital watermarking technology. An effective image watermarking scheme or system generally includes several parts, such as watermark generation, watermark embedding, watermark detection, and watermark authentication, and should meet the requirements of some basic characteristics, such as authenticability, invisibility, robustness, and security. The research on image watermarking mostly revolves around the components of image watermarking. In order to meet the basic characteristics, various image watermarking algorithms are designed and implemented. With the gradual deepening of research, considering the complexity of the problems to be solved in image watermarking, in recent years, some researchers have applied chaos, shape, and other theories in nonlinear science to image watermarking, and proposed the concept

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of nonlinear image watermarking. At present, there is little research on nonlinear 3D digital watermarking algorithm. Around 3D grid digital watermarking, there are still a series of problems that need to be deeply studied, such as enabling the algorithm to resist more kinds of attacks to improve the application scope of the algorithm, and embedding image watermark information in 3D model is also an important research and development direction, as shown in Figure 1.

The World Wide Web and the internet have become extremely popular, which has led to an increase in the amount of multimedia data being constantly stored and exchanged digitally. However, growing popularity brings with it a fresh set of difficult security issues such as authentication, copyright protection, unauthorized copying, distribution, and tampering with multimedia. We must create methods to safeguard multimedia against malicious attacks and deliberate manipulations in order to address these issues. Digital watermarking, which makes it possible to identify the author, owner, distributor, or authorized consumer of the photographs, has recently been seen as a viable solution to the aforementioned problems. A method for adding information to multimedia is digital watermarking. The original multimedia must not suffer significant deterioration as a result of the embedding or insertion. This article addresses the issue of digital image content watermarking. Based on the current research, the research on post effect processing of 3D image is proposed. The basic idea of nonlinear digital watermarking is based on visual redundancy and data feature redundancy, using the method of signal processing to hide meaningful additional information in the original multimedia data, such as the author’s version serial number, the company’s special trademark logo, the text with extraordinary value, etc., which will be transmitted together with the original media data. This information will not affect the content of the original media data, will not cause loss to the value of the original data, and will not affect the use of the original data. Moreover, it is difficult for people’s perception system to detect or notice that there is information hidden in the original media data. Digital watermarking technology has broad application prospects and great economic value.

The rest of this article is structured as follows: review of literature is provided in Section 2 followed by research methodology, which involves the research on post effect processing of 3D image based on nonlinear digital watermarking algorithm, in Section 3. Section 4 provides the experimental results and discussion along with concluding remarks in Section 5.

2 Literature review

For 3D geometric model, the basic idea of the algorithm is to minimize the error energy brought by 3D model transformation to the embedded watermark. In order to make
the embedded watermark robust to the topological transformation and geometric transformation of the 3D model, the algorithm first sorts and selects the vertices of the 3D mesh. The principle of sorting and selecting is to make the selected vertices have the minimum sum, that is, by optimizing the selection of the vertices of the 3D model, the selected vertices are least affected by the topological attack. Then, in order to be robust to geometric attacks, the algorithm calculates and selects the disturbance mean square error energy of the later term point, and embeds the watermark into the space least affected by the error energy, so that the embedded watermark is least affected by geometric attacks [1]. Experimental results show that the algorithm has good resistance to geometric attacks and topological attacks.

In 1997, Tchoukaleysky [2] first proposed the concept of digital watermarking algorithm for nonlinear 3D models. On the basis of analyzing the data features of the 3D model, they designed the process of changing the geometric features of the 3D model and embedding the digital watermark, and specially provided the Triangular Similarity Quadrangle (TSQ) algorithm. Inspired by the Ohbuchi project, Hu et al. [3] applied a triangle vertex beam algorithm to adjust the vector distribution of mesh surfaces. In 2019, Lei et al. [4] of Arizona State University Computer Systems proposed a robust fluidization algorithm for polygonal meshes with arbitrary topology. Tang et al. [6] proposed an additional representation of nonlinear 3D mesh models, which can be considered as a multi-concept solution. Based on this principle, Liang Yong proposed a digital watermark based on an integrated model, which is superior to the watermark. In 2012, Tan et al. [7] proposed a digital watermarking algorithm based on grid spectral decomposition based on the spectral domain decomposition of 3D models. Deepika and others proposed a digital watermarking scheme based on integer wavelet transform and histogram technology. Integer wavelet transform based on lifting scheme is used to simplify the transform of compressed data and improve the data embedding ability. Histogram technology is a reversible data hiding technology, which is used to embed secret data into the original image and retrieve the original data after extraction [8].

A new transform-based, SVD-based [9] watermarking technique and its variations have recently been presented. These methods are based on the straightforward idea of calculating the singular values of a cover picture or each block of a cover image, and then changing those unique values to incorporate the watermark. Recent hybrid watermarking techniques that combine SVD with other current transforms have been presented by certain researchers. A number of assaults can be thwarted by an SVD-based system, although geometric attacks like rotation and cropping are not among them. In order to increase performance, hybridization is necessary. On the basis of DWT and SVD, Al-Afandy et al. [10] presented a hybrid watermarking system. The authors have developed and extended the grid watermarking algorithm in the abovementioned spectral domain, and obtained a new watermarking algorithm that not only improves the speed of watermark embedding, but also improves the robustness of the watermark to grid simplification and combinatorial attacks.

3 Research on post effect processing of 3D image based on nonlinear digital watermarking algorithm

3.1 Research status and development direction at home and abroad

Since 1994, international education has completed watermark publishing, and newspaper reports have grown rapidly. Several international conferences (such as IEEE ICIP, IEEE ICASSP, ACM Multimedia, etc.) have been included, and some international journals (such as IEEE process, configuration, IEEE Journal of Choice sites of Communication, Communication of ACM, etc.) have completed digital printing. So far, from the perspective of product research, digital watermarks usually include many things, such as watermarks, video watermarks, audio watermarks, text watermarks and 3D model data watermarks. Most watermarking research and documentation focuses on image research. The reason is that pictures are the most convenient multimedia files, and improvements on the internet directly provide many rules for the application of watermarking pictures. In addition, video watermarking has also attracted the interest of some scholars. Because video can be seen as continuous images in spatiotemporal registration, in a sense, it is similar to the principle of watermarking images. Many image watermarking studies can be directly applied to video watermarking. With the wide application of 3D materials in film special effects, animation, game production, mold design, and even military fields, the research on 3D digital watermarking has become a hot topic [11].

At present, most of the digital watermarking technologies are mainly about two-dimensional (2D) images, audio, video, and other multimedia data types. While
the digital watermarking technologies in these fields are relatively mature, the 3D model digital watermarking technology started late in China and has not yet matured. With the rapid development of 3D model data in the network and other fields, the copyright protection and content verification of this new multimedia product have become an urgent problem. Digital watermarking technology provides an effective method for copyright protection of digital products. This study introduces the principle and research methods of digital watermarking in detail, including the basic concept, classification, characteristics, and application fields of 3D digital watermarking, then introduces the commonly used 3D model digital watermarking algorithms, and expounds the advantages and disadvantages of each method. This study proposes a reversible watermarking algorithm for 3D model based on ratio preserving. This algorithm is aimed at the spatial characteristics of feature points. Using this method to add a watermark, the watermark model can still completely extract the watermark and the original model after translation, rotation, and scaling. After analyzing the performance of the algorithm, the experimental results show that the algorithm has good invisibility, high embedding capacity, and can resist a certain degree of noise.

3.2 Relevant theory and algorithm analysis of nonlinear 3D digital watermarking technology

Since the emergence of nonlinear digital watermarking technology, most of the work has focused on image digital watermarking, audio digital watermarking, and video digital watermarking technology. As a new type of media after audio, video, and image, 3D geometric model is widely used in many fields such as entertainment and manufacturing industry. The copyright protection of 3D geometric models has become increasingly important. There are many technical problems in the digital watermarking technology: 3D models, such as low watermark capacity, multiple representation of the same model, fixed sequence of model data, non-function transformation to frequency space, synchronization problem caused by topological relations, and a large number of attack modes can be used to attack the spatial location and topological relationship of models. Therefore, the research on 3D model digital watermarking technology has important theoretical significance and practical application value [12].

3.3 Representation of 3D model data

The representation of a 3D model typically deals with the geometric and topological data of the model. Geometric data usually refer to the shape, position, and size of objects in Euclidean space, while topological data refer to the number of components of an object and its composition. General 3D models can be divided into three categories: wireframe models, surface models, and product models.

3.3.1 Wireframe model

Wireframe model is the earliest model used to represent objects. Objects are only described by edges (lines, arcs, and circles), which requires less information and occupies the least storage space. Computer drawing is an important application of this model. The disadvantage of wireframe model is obvious. It uses vertices and adjacent edges to represent objects. Because there is no face information, it cannot represent objects with curved surfaces on the surface. In addition, it cannot clearly define the relationship between a given point and an object (the point is inside, outside, or on the surface of the object), so the wireframe model has polysemy, and its application scope is greatly limited. It cannot deal with many important problems, such as the inability to generate cutaway map, blanking map, light and dark color map, etc.

3.3.2 Surface model

Surface model is a representation method that describes various surfaces or surfaces of an object. Based on the wireframe model, it adds the information of the surface in the object, uses the set of surfaces to represent the object, and uses the ring to define the boundary of the surface.

3.3.3 Product model

In this representation method, many basic voxels with certain shape and volume (such as cube, cylinder, cone, etc.) are used to establish a 3D product model through Boolean operations such as union, intersection and complement, and basic deformation operations. The feature of product modeling is to establish a complete shape model of an object, which has a clear object containing space, and there is a strict topological relationship between all surfaces to form a whole [13].
3.4 Representation characteristics of 3D model

Compared with still image, audio, and video, the representation method of 3D mesh model has many differences, mainly including the following characteristics:

1) There is no inherent data order. The data of audio and video are arranged in chronological order, while the frames of still images and video are arranged in scan line order, and the 3D model does not have a fixed data order.

2) There is no clear concept of sampling rate. The data in 3D surface model do not have the convenient mathematical tools (such as cosine transform, Fourier transform, wavelet transform, etc.) like image, audio, and video.

3) The representation method is not unique. The same 3D model can be represented by many different models. In the process of conversion between different models, it is easy to cause attribute loss. There is no natural region suitable for embedding watermark in images and videos [14].

3.5 Algorithm principle

First, the coordinate transformation of non-linear 3D model is carried out: from Cartesian coordinates to spherical coordinates. Second, the local set area of a ring neighborhood of each vertex is calculated, and the smaller ring neighborhood is projected onto the tangent plane of this vertex. The third step is to extract the feature of the projected image of a ring neighborhood on the tangent plane. If there is a mesh segment matching the sample in the database in the projected image, the watermark information is embedded in the vertex opposite to the mesh line, and the distance between the new vertex carrying the watermark information and the two adjacent vertices is equal. Even if the position and scale of the model change with attacks such as rotation, scaling, and translation, the position of the feature grid line will not change as long as the central position of the model relative to the spherical coordinate system does not change. Based on this, the watermark synchronization information is located, which improves the robustness of the algorithm against geometric attacks. The watermark extraction does not need the original mesh model, and the algorithm is blind watermark extraction.

As an effective information hiding technology, digital watermarking technology has been widely used in recent years. Its basic idea is to embed hidden information in digital images, videos, audios, texts, and other digital products in order to prove the authenticity and reliability of products, provide additional information of products or track piracy, so as to protect the copyright of digital products. The hidden information can be copyright signs, product related information, or user serial number. It is to embed some identification information related or unrelated to multimedia content directly into the multimedia content, but it does not affect the value of the original content and cannot be detected or noticed by the human perception system. Through the information hidden in multimedia content, we can confirm the content creator, purchaser, or whether the content is true and complete. 3D model digital watermarking is a branch of watermarking technology. Its principle is to embed invisible watermark information in the 3D model to protect property rights and verify the authenticity of the model.

4 Experiment and research

4.1 Digital watermark embedding

The general watermark embedding process is shown in Figure 2.

In the embedding process, the length information of the watermark needs to be saved in order to extract the watermark correctly. Each calculated ratio can be expanded, so there is no need to save other additional information during embedding. The embedding process is as follows:

Step 1: Clear the marks of all points in the model and set V is empty. Traverse the points in the 3D model. If the mark of vertex v is 1, continue to traverse to the next vertex. Otherwise, traverse and search the adjacency points of V, if the mark bits of all adjacency points of v are 0, add v to the set V, and mark the position 1 of v and the surrounding adjacency points, otherwise traverse to the next vertex.

Step 2: For each vertex v in the set V, find the distance between v and all its adjacent points. Take the distance between the first stored adjacent contact and v as the standard, and divide each other by the standard distance to obtain the distance ratio.

Step 3: For the value of the previous step, the expansion method adds watermark and changes the distance ratio.

Step 4: Move the position of the point according to the change in the distance ratio to obtain the watermark model.
4.1.1 Digital watermark extraction

The digital watermark extraction is shown in Figure 3. In most digital watermarking systems, the watermark can be extracted accurately, which is called watermark extraction. For example, in the application of integrity authentication, the embedded watermark must be extracted accurately, and the integrity of multimedia data must be confirmed by the integrity of the watermark. If the extracted watermark changes even partially, the fragile watermark can also determine the location where the original data were tampered by the location of the changed watermark. Strong watermarks are often unable to accurately extract watermarks, as an important reason for using strong watermarks is because applications may be subject to various malicious attacks. After these operations, the extracted watermark of the model with digital watermark is usually completely different [15]. At this time, the detection process of watermark is often needed.

4.2 Nonlinear digital watermarking technology and its application

Nonlinear digital watermarking can be defined as the imperceptible operation of embedding information in works. The embedded watermark information is usually invisible, but the watermark signal can be detected or extracted by the digital watermark detection system. Digital watermarking is closely combined with the information in the work, so that the watermark signal can still be detected in the work after a series of processing.

Typically, the digital printers we are talking about have an embedder and a detector. As shown in Figure 4, the embedder has two inputs: one is the data to be encoded as a watermark, and the other is the carrier job to embed the watermark. The output of the watermark embedder, the watermarked work, can usually be transmitted or recorded. The product released by the embedder (or any other function not done by the watermark embedder) is then fed into the
watermark detector to check for the presence of watermark information. If available, the encoded watermark file is displayed [16].

### 4.2.1 Expression mode of 3D model

With the rapid development of 3D modeling technology, more and more products are digitized as 3D models. These patterns typically include the following structures: point cloud structure, mesh structure, and surface structure. Point cloud modeling refers to the design of points obtained by CMM or laser scanning and camera scanners [17]. The mesh structure refers to the structure obtained by fitting a surface with polygons. In design, polygons are usually made into triangles or rectangles. Surface patterns are structures modeled with non-uniform patterns, without splines. Their advantage is that they can be based on rule space and free form. In the field of 3D model digital watermarking, mesh modeling is often used to represent 3D modeling. 3D mesh models usually consist of triangles connected to points.

### 4.2.2 Digital watermarking principle of nonlinear 3D model

The nonlinear 3D model digital watermark technology embeds the digital watermark into the 3D model to achieve the purpose of custom protection. The digital watermark, as a special mark recognized by law, is embedded in the owner’s own watermark after the 3D model design is completed. On one hand, the embedding of the watermark does not affect the original vision of the 3D model, while on the other hand, the power of digital watermarking ensures that the graphic mark can still be extracted from the triangular structure after being attacked by criminals [18].

3D model digital watermarking technology usually includes embedding, extraction, and detection of watermark. According to the algorithm design, the watermark file is embedded in the old structure to obtain the structure with watermark. The detailed operations of watermark extraction and discovery are shown in Figure 5. In the watermark extraction process, the watermark data are extracted according to the steps of the extraction algorithm. By identifying the relationship with the original watermark data, relative values and errors are obtained to determine the owner of the model [19].

### 4.2.3 3D model watermarking system

3D model watermarking is a research on nonlinear 3D digital media watermarking technology. First, 2D image watermarking technology, which is the basis of 3D watermarking technology, has the same principle in terms of watermark embedding and extraction [20].
2D image, that is, 2D digital image, is obtained by digitizing analog image. It is a collection of analog images sampled at equal intervals in horizontal and vertical directions and composed of a limited number of pixels. The 2D image is represented by matrix or array, and its intensity and illumination position are discrete. Due to the large scale of image matrix, if the data are processed directly in the spatial domain, it will face the problem of large amount of calculation. Therefore, in the process of data processing, various mathematical tools are often used to transform the image, and the data processing in spatial domain is transformed into data processing in transform domain. This conversion can not only reduce the amount of calculation, but also obtain more effective processing results [21].

Due to the similarity of 2D image data, data relationships can be identified through mathematical tools such as wavelet transform. Therefore, 2D digital watermarking algorithms can be widely studied in digital media. Compared with the spatial domain watermarking algorithm, the watermarking algorithm based on the wavelet transform domain has some advantages: first, the spatial domain algorithm directly converts the gray value of the image according to the embedded stream data and the encoding algorithm. The algorithm has a positive effect on the image quality: the watermark name algorithm loads the watermark data by adjusting the frequency coefficient of the image during the conversion process, and the watermark data can be transmitted to the whole picture with little impact on people [22]. Second, in order to detect the invisibility of the watermark, the potential of the watermarking algorithm is small, while the frequency potential of the watermarking algorithm is large, and the ability to attack noise, cutting, compression, and other attacks is strong. Therefore, 2D digital watermarking algorithms are developing rapidly and becoming more mature. And the most important is a large number of 2D image analysis tools are available [23].

### 4.3 Watermark transparency

The practical application of watermark requires not only the watermark embedding capacity but also the minimum impact of watermark embedding on the fidelity of 3D model. If the visual quality of 3D model is reduced and the usability of 3D model is destroyed due to the embedding of watermark information, it shows that the algorithm is not feasible [24]. In this study, the visual quality of watermark 3D model is objectively evaluated by Hausdorff distance and signal-to-noise ratio (SNR). The evaluation results are given in Table 1. From the experimental results, the SNR of the objective measurement value is more than 50 dB, the Hausdorff distance value is within the order of $10^{-2}$, the two parameter indexes fall within the requirements, and the visual quality of the 3D model is not affected by the embedding of watermark information. And we cannot detect the obvious deformation of the model by subjective observation and subjective vision. These two aspects show that the algorithm in this study can better maintain the visual quality of 3D mesh model and will not affect the application of mesh model.

The experimental results show that the algorithm can resist typical geometric attacks such as noise, affine transformation, and vertex rearrangement. At the same time, it also has watermark transparency for model simplification attacks. But when the intensity of the above attacks increases or faces various combined attacks of affine transformation, the correlation coefficient value of the watermark extracted by the algorithm does not meet the threshold requirements, resulting in false detection. Therefore, improving the ability of the algorithm to resist various combined attacks of affine transformation is the direction of the next research work, as shown in Figure 6.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Hausdorff</th>
<th>SNR (dB)</th>
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<tbody>
<tr>
<td>M88</td>
<td>0.003</td>
<td>65.23</td>
</tr>
<tr>
<td>M223</td>
<td>0.558</td>
<td>75.26</td>
</tr>
<tr>
<td>M208</td>
<td>0.106</td>
<td>23.65</td>
</tr>
<tr>
<td>M230</td>
<td>0.005</td>
<td>73.56</td>
</tr>
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Figure 6: Watermark detection similarity.
When using the bounding ellipsoids and parallel planes algorithms to determine the watermark detection from the noisy 3D watermarked graphical objects, the average bit detection rates are as displayed in Figure 7(a) and (b). The standard deviation from the bit detection rate average for the perturbation brought on by a specific noise variance is displayed in error bars. In all the experimental findings, we found that both 3D watermarking techniques were resilient to geometrical disturbance brought on by noise, cropping, and other attacks. When using 3D graphical items that resemble works of art, watermarking outcomes are better than when using commercially produced graphical objects.

5 Conclusion

This work introduces a new digital watermarking algorithm for nonlinear 3D mesh modeling. The basis of the algorithm is to find watermark synchronization data according to the beamlet characteristics. The algorithm uses beamlet features to find watermark synchronization data. When the watermark model encounters an affine transformation stop, the actual position of the watermark data will change, but its relative position to the grid will not change. Therefore, the algorithm prevents the exchange of affine and their combinations. However, since the watermark data are drawn by modifying the vertex control of the structure, even the vertices carrying the watermark data are selected in the density of model vertices, they cannot prevent noise, smoothing, and mesh simplification. The experimental results also show that the algorithm is relatively easy to be challenged by theory-based mesh simplification. The improvement in the ability of the algorithm to resist grid simplification attacks is the next research focus. In comparison to the parallel planes approach, the bounding ellipsoids algorithm produces less deformation in the 3D stego meshes when watermarks are included. Numerous potential uses for the suggested watermarking approach exist, such as copyright protection, authentication, steganography, maintenance of object databases, encoding of behavioral patterns for digital cinematography, graphic characters, etc.

Funding information: There is no financial support for this study.

Author contributions: The author made significant contributions to this manuscript. Chunhua Wang: writing; data analysis; article review and intellectual concept of the article.

Conflict of interest: The author declares that they have no competing interests.

References


Figure 7: Robustness results of 3D watermarking after Gaussian noise application. (a) Parallel planes. (b) Bounding ellipsoids.


