Copyright Protection: from 2D to 3D Watermarking

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Abstract

3D models are being readily used in a variety of applications including mechanical engineering simulations, virtual museums and archeological sites reproduction for Cultural Heritage, scientific visualizations, entertainment industries for movies and video-games and so on. Since these data sets involve investment in terms of money, time and human effort preserving them is important. For these reasons, this kind of data need IPR protection. Usually watermarking technology is adopted for this purpose; however, only few works on 3D watermarking have been carried out. This paper presents a general review of the recent mesh processing tools and tracks some lines in the development of new 3D watermarking algorithms, proposing some ideas for future investigations in this field.

Keywords: Intellectual Property Rights (IPR), Intellectual Property Management and Protection (IPMP), Cultural Heritage, Computer Graphics, 3D Model, Robust Watermarking.

1. Introduction

Today, computer graphics power of a standard personal computer is becoming so high that applications requiring an extensive use of graphics are growing very fast in several fields, like in the field of Cultural Heritage (archeological site reproduction, virtual museums, etc.), Entertainment (games, animations, special effects) and Internet (enhanced user navigation, e-commerce, virtual reality). This process is pushing towards a large diffusion of 3D model more and more complex and detailed. For this reason in the last years the computer graphics research community has developed a lot of tools and algorithms to manage the huge amount of data an high detailed 3D model involves. So, it is now possible to quickly render a model managing its level of detail, it is possible to make an efficient storage of the model, and so on. But since now only a few attention has been paid to the issue of the IPR protection of this kind of data. In fact, while a lot of techniques and methods exists to embed copyright information in image, audio and video data, only a few algorithms to hide confidential information (for IPR, authentication and so on) into a 3D model has been developed. Furthermore, 3D watermarking has much robustness problem than image or video watermarking algorithms due to the different kind of attacks that are possible on a 3D model. In the following we present some of recent 3D processing tools. Next we provide a panoramic of 3D watermarking paying attention to the problem of attacks in 3D model. Finally we propose some future working lines that appear to be promising in the area of robust watermarking technology.

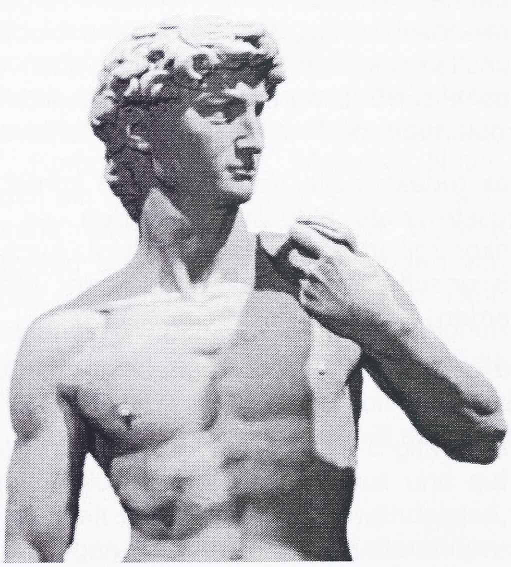

Figure 1 Digital Michelangelo Project (David, 56 millions of faces)

2. Multiresolution Representation of Meshes

2.1 Multiresolution Signal Processing for Meshes

One of the main problems in the development of mathematical tools and algorithms to manipulate 3D model is the extension of basic signal processing algorithms like downsampling, upsampling, DCT, wavelet, etc, to the model space representation. In fact, a 3D model can be represented in several ways, for example as a collections of parametric curves (e.g. NURBS), or as a set of implicit surfaces. More usually, a 3D model is represented by a mesh, i.e. by a tuple (K,V) where V is the set of the vertices of the model and K is a set encoding the connections between the vertices (i.e. the topology of the model). Often the vertices of a mesh are characterized by other attributes such as colors and textures and almost always the vertices of the mesh are connected to form triangles. In the following we refer to mesh representation because it is easy to convert others 3D model representation (NURBS, implicit surfaces, etc) to a mesh.

Before describing some advanced tools for 3D processing, let us underline that many of the most powerful mesh processing tools (e.g. wavelet decomposition and BA pyramid) concern a multiresolution representation of the model [5].

2.2 Level of Detail and CLOD

By level of detail (or LOD [14]) a collection of techniques and methods for managing the complexity of a model is meant. Usually these techniques are used to speed-up the rendering of a synthetic scene composed by hundred of complex models.
One of the easiest way to manage the level of detail is the *static* LOD: for every model to be rendered, it is possible to store different versions with different accuracy and complexity and use the most appropriate depending, for example, on the distance of the observer. It can be argued that static LOD is not a good solution: it is space-consuming and changes between different versions of the same model can cause low quality results in a dynamic context. What we need to really manage the details of a model is a CLOD (Continuos Level of Detail).
A lot of multiresolution representations of meshes has been studied to allow a CLOD representation of the model. Thanks to these representations it is possible to manage the detail of the model in a very flexible way, using only the detail it is needed in the given application. It has to be underlined that this is true not only for the rendering process but even for other kinds of 3D processing, not last for 3D watermarking.

2.3 Wavelet Decomposition of a Mesh

2.3.1 Subdivision Surfaces

Subdivision surfaces is the name of a modeling technique allowing a designer to draw complex tridimensional curves by means of a control model. This control model can be thought as the set of control points of a spline curve. Different kinds of subdivision rules exist; for a complete review see [2].
This modeling method is a powerful tool in mesh processing and can be represented as a signal processing tool composed by an upsampling operation followed by a filtering process. The upsampling operation is the same for every kind of subdivision surface rules, while the filtering step depends on the subdivision and provide different properties to the limit surface, that is the surface obtained by applying the subdivision infinite times.

2.3.2 Wavelet decomposition and 3D watermarking

One useful multiresolution representation is given by the wavelet analysis of a mesh. Lounsbery et al. [7][8] studied a wavelet decomposition applied to a mesh with subdivision-connectivity (i.e. it has been obtained by subdivision surface modeling technique) that allows the invertible decomposition of a original mesh in another mesh with a small number of faces and a set of wavelet coefficients. In this way a sequence of wavelet coefficients representing the details of the model can be obtained.
In our opinion this is one of the best tools to develop 3D watermarking techniques in particular for imperceptible watermark because it is possible to control the manipulation of the detail coefficients

at various level of detail, providing a better visual quality for the watermarked model.
In the following this issue will be debated in depth.

2.4 Burt-Adelson Pyramid

BA pyramid [2] is a powerful image processing tool. For an irregular triangular mesh it is possible to build an analogue algorithm using a combination of subdivision surfaces (upsampling) and decimation (downsampling) step.
The decimation step can be performed by an edge collapse operation, derived by another multiresolution representations called PM (Progressive Mesh, [1]).
Even this multiresolution mesh processing tool can be useful to develop new 3D watermarking techniques. In fact one of its applications is the interactive multiresolution editing [6], and a 3D watermarking method can be considered as a special editing process of the original mesh.

3. 3D Watermarking

A digital watermark is an identification code carrying information about the copyright owner, the creator of the work, the authorised consumers and so on, that is permanently embedded into digital data for copyright protection or for checking possible data modifications. The main goal of 3D watermarking is the production of a stego-model, i.e. a 3D model containing some hidden data. As already said, in this paper a mesh representation for the 3D model is considered.
An easy way to develop a 3D watermarking technique is to extend an image technique to 3D, since image watermarking is an already mature research field. However, in image watermarking the information can be hidden only by changing the value of a subset of image pixels, or of the coefficients of some mathematical transformation (e.g. the Fourier Transform).
On the contrary, a mesh can provide more features to manipulate such as vertices positions, connections between vertices (topology) and other surface properties like texture or vertex colors. This property apparently allows a lot of possibilities for watermark embedding, but we have to take in account that 90% of the model information is coded by its vertices, whereas the topology and the other properties provide only a small amount of information. Before other considerations, let us examine the attacks a 3D model can suffer.

3.1 Attacks

One of the main problems in 3D watermarking is that a lot of complex attacks can be carried out on a mesh (see the table below). As it can be seen, most of the attacks have a corresponding attack in image watermarking, but we have to notice that, given the more complex nature of the data itself, an attack in 3D data is more complicated than in image data. In fact, an image is a bidimensional, regular sampled collection of values, while a mesh is a collection of 3D space points (not regularly sampled) with a particular topology. So there is more than one degree of freedom of difference between mesh and images: it is not a simple 2D to 3D extension!

Image Attacks	Mesh Attacks
Cropping	Tridimensional Cropping
Translation/Rotation/Scaling	Translation/Rotation/Scaling
Noise	Noise
Compression (e.g. JPEG)	Mesh Optimization
Downsampling	Simplification
Upsampling	Refinement (e.g. subdivision surfaces)
Bidimensional Free form Deformation	Tridimensional Free Form Deformation
Filtering	Mesh Filtering (e.g Taubin smoothing [4])
---	Topology Changes (e.g. Remeshing)

Table 1 Image watermarking and 3D watermarking attacks comparison.

For this reason the extension of the image watermarking techniques is not immediate, but requires additional study, so that in many cases it is preferable to develop a specific watermarking technique for mesh.

3.2 3D watermarking algorithms

Some of the most cited algorithms for watermarking 3D model (in particular for mesh representation) are the works of Ohbuchi et al. [9], Benedens with his GEOMARK systems [11-13] and the method based on wavelet decomposition of Kanai et al. [10] as well as the more recent work of Uccheddu et al. [17].

The Kanai's work is based on the wavelet decomposition of a mesh: the watermark is properly coded in the wavelet detail coefficients. This algorithm can have many improvements: the approach proposed in this paper is based on the same idea, as detailed in the next section.

The watermarking algorithms developed by Ohbuchi et al. are based on topological and geometrical modifications. In particular the TSQ (Triangle Similarity Quadruple embedding algorithm) modifies vertices coordinates of four adjacent triangles to encode the watermark, by properly setting the value of ratios between edges length of the triangles group. Another algorithm codes the hidden information by varying the ratio of tetrahedral volume (TVR). The last algorithm proposed by Ohbuchi et al. is the TSPS (Triangle Streep Peeling Symbol) that uses topological modifications to embed a public watermark. These algorithms have high capacity but are not robust to some attacks; in particular they suffer remeshing attack.

The GEOMARK system developed by Benedens implements three different algorithms: Vertex Flood Algorithm (VFA) for model authentication (fragile watermark); the Affine Invariant Embedding algorithm (AIE) robust against affine transformation of the model, and the Normal Bin Encoding (NBE) robust against complex model modifications such as simplification and remeshing. The power of this system is the combination of these three algorithms to obtain a robust watermarking scheme.

4. Investigated Approaches

Two different kinds of robust 3D watermarking approaches are under investigation. A brief description of both will be presented in the sequel.

The first algorithm, sketched in figure 2, is basically based on the one developed by Kanai et al. [8].

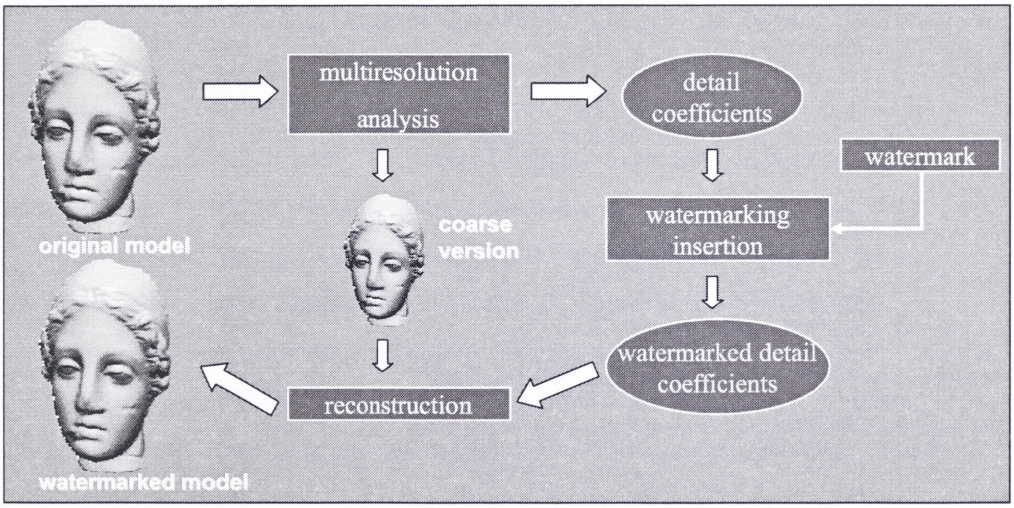

Figure 2 Sketch of 3D watermarking algorithm based on Kanai et al.

Given an original 3D model, a multiresolution analysis by wavelet decomposition is performed providing a set of detail coefficients and a coarse version of the original model; the watermark, bringing the IPR information, is inserted by appropriately changing the wavelet coefficients, thus resulting in a set of new watermarked ones. These new coefficients are used to obtain the watermarked model by means of their reinsertion in the unmodified coarse version.

The main difference, with respect to Kanai algorithm, consists in a different method to embed the watermark within the wavelet coefficients. Based on the experience developed on watermarking technologies for images and video [15][16], disparate techniques are under extension and verification.

The second approach is a variation of the previous one. In this case the watermark insertion is performed by perturbing vertices coordinates of the coarse version and leaving unaltered the wavelet coefficients, as depicted in figure 3.

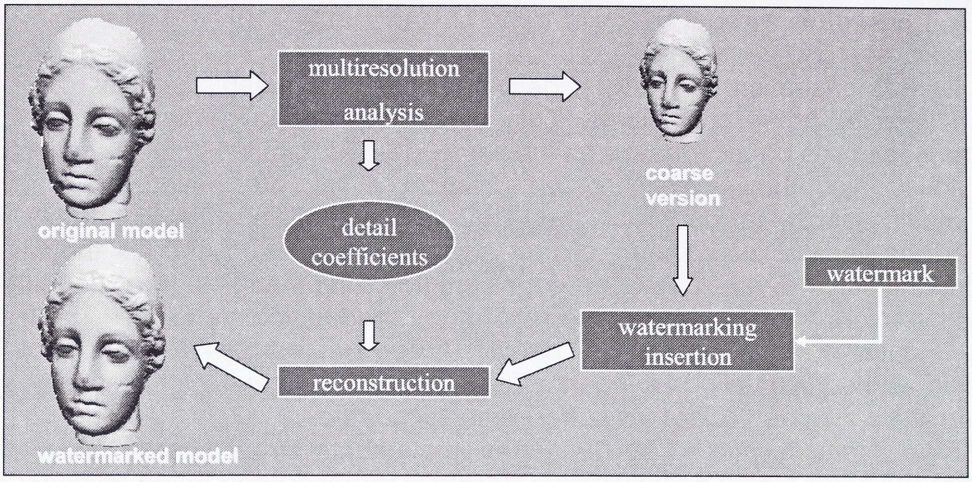

Figure 3 Sketch of 3D watermarking algorithm based on the proposed approach.

In this case the multiresolution analysis could be performed through other tools (not necessarily by wavelet decomposition). The basic requirement to be satisfied is the possibility to reintroduce, into the modified coarse version, the unchanged details relative to the original model.

5. Conclusions

In this paper a general review of the recent mesh processing tools has been presented. Moreover some general lines in the development of new 3D watermarking algorithms have been described and finally some novel 3D watermarking approaches for 3D model with mesh representation have been debated. This kind of technology offers a promising tool to safeguard intellectual property rights (IPR) of 3D models, particularly useful in Cultural Heritage domain.

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