PROTECTION OF 3D OBJECT THROUGH SILHOUETTE WATERMARKING*

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ABSTRACT

This paper describes a new approach for watermarking 3D objects via contour information. Unlike most conventional 3D object watermarking techniques, for which both insertion and extraction of the mark are performed on the object itself (3D/3D approach), we propose an asymmetric 3D/2D procedure. This procedure consists of watermarking 3D objects but retrieving the mark from represented views. In this paper we also propose an extension of 2D contour watermarking algorithm to 3D silhouette.

1. INTRODUCTION

Real applications show that watermarking can be useful for several purposes. For example, viewers would like to check if the use of a given object is legal or not, to access additional information concerning the object (e.g for authentication or indexing), the owner of the object (copyright), or even the buyer (e.g for non-repudiation).
Due to the Internet expansion and multiplication of high flow network, multimedia database contain more and more 3D objects. As a result, several 3D object watermarking algorithms have been proposed. In most of them, users need to access to the 3D watermarked data to extract/detect the mark. However, and based on our experience, it is usually more frequent to locate and recover suspect 2D images (images obtained after projection of 3D objects) than 3D object itself. As soon as the 3D object is displayed or inserted in a video, only one or several 2D projections are still available. Existing work on watermarking 3D objects (usually based on geometry), does not make possible the extraction of the mark from 2D views. In our approach, the mark is hidden in the 3D object apparent contour. So, it can -under certain conditions- be extracted from 2D views of the object in which watermarked contour information is present (see figure 1).

The rest of the paper is organized as follows : section 2 shortly describe the state of the art in watermarking of 3D object algorithms. Section 3 describes our approach and presents some results. Finally, a conclusion and possible future directions are given in section 4.

*THIS RESEARCH IS SUPPORTED IN PART BY THE FRENCH NATIONAL RNRT SEMANTIC 3D PROJECT [1]

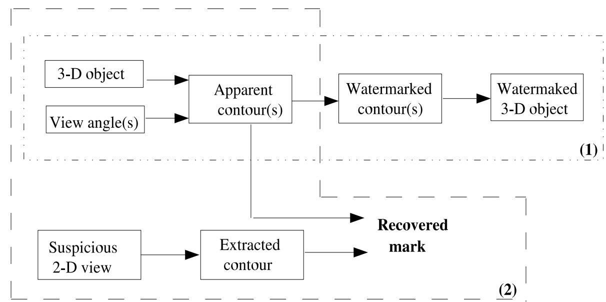

Fig. 1. Global system: 1-Insertion; 2-Detection

2. STATE OF THE ART

There are a wide variety of watermarking techniques in the domains of audio, video and image data [2, 3]. The number of watermarking techniques for 3D objects (so-called category of new objects in watermarking) has been continuously increasing since about 1998 but remains marginal.
To the best of our knowledge, most of previous works dealing with 3D objects are based on slight modifications performed on meshes via geometric and/or topological data of 3D objects. Typically, authors propose to modify either the 3D coordinates of some points or the connectivity of triangles with in a mesh. Interesting readers are invited to refer to the publications [4, 5, 6, 7, 8, 9].
Almost all these watermarking algorithms dealing with 3D objects do not allow users the extraction of the mark from 2D represented views of 3D protected object. In this quite particular context, we can cite [10] which protect 3D object usage through texture watermarking. We can then check if the represented object is protected by extracting the watermarked texture from represented views of it. This algorithm assumes that 3D objects are realistic or at least rich in texture, which is

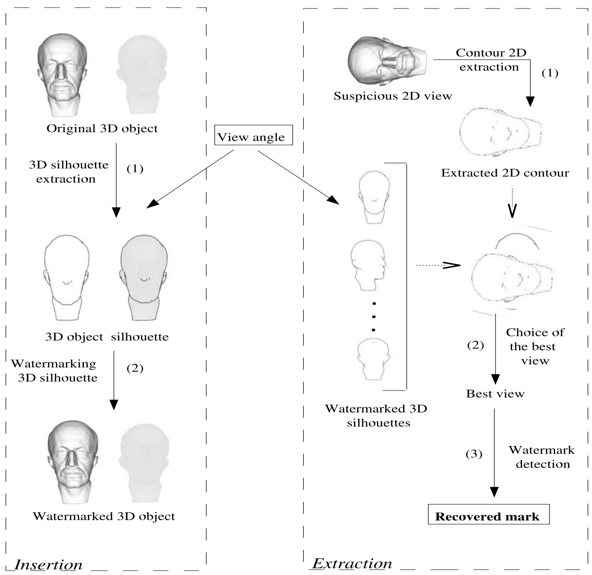

Fig. 2. Principle

not always the case, since objects used in our approach could be with or without texture.

3. OUR APPROACH TO WATERMARK 3D OBJECTS

This section is devoted to the description of our approach to watermark 3D objects. We first explain the whole process and then we describe in details the most important steps.

Given a known 3D object consisting of a geometric definition (represented by 3D polygonal meshes) we can protect it by watermarking its apparent contour. Then we seek for extracting the mark from represented views of the object.
The first problem we are faced with is how to align suspicious views and the original 3D object in order to extract the mark (the basic problem of 2D/3D alignment [11], [12]). In order to overcome this problem, we currently assume to know the original 3D object, the projection matrix as well as intrinsic parameters of the virtual camera.
Viewing angles associated with represented views are kept secret.

3.1. The whole process

Figure 2 shows an overview flowchart of our 3D object watermarking scheme.

3.1.1. *Watermark insertion*

- *Step 1*: We fix k viewing angles (see subsection 3.2) and we extract 3D silhouette of the object (see subsection 3.3).

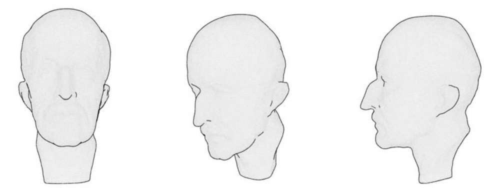

Fig. 3. Top view, side view and intermediate one.

- *Step 2*: We watermark extracted 3D silhouette to get watermarked 3D object (see subsection 3.4).

3.1.2. *Watermark detection*

- *Step 1*: Given a suspicious 2D view we extract its 2D contour.
- *Step 2*: We choose the most suitable silhouette among the k watermarked ones to extract/detect the mark. We call suitable silhouette, the one which is the most similar to the 2D contour to check.
- *Step 3*: We detect the watermark's presence (see subsection 3.4).

3.2. Selection of anchor point of views

The choice of characteristic views has a great influence on the performance and limits of our watermarking approach.
These viewing angles should satisfy the following practical constraints:

1. The represented views must cover all the 3D object.
2. Their number should be limited in order to avoid conflicting overlaps between parts of the watermarked signal, as well as to avoid excessive time computing.

For our first experiments we are interested in watermarking 3D faces. We chose k to be 3 : top view, side view and intermediate one (see figure 3). We estimate (according to previous studies in the field of biometrics) that these three views are the most important and enough to characterize a face. In future work, we plan to use some existing techniques to provide an optimal selection of 2D views from a 3D model, in particular the one developed in [13] is under investigation. In this technique, the selection of characteristic views is based on adaptive clustering algorithm and using statistical model distribution scores to select the optimal number of views and their positions.

3.3. Contour Extraction

The usual method for computing 3D object silhouette is to iterate over every mesh edge and check:

1. If the current edge is associated to only one triangle, it is a contour.

2. If the current edge is associated to two triangles F_1 and F_2,

   - We note $\overrightarrow{n_1}$ and $\overrightarrow{n_2}$ normal vectors of F_1 and F_2.
   - We note $\overrightarrow{v}$ a vector composed by camera position and one vertice of the current edge.

   If $(\overrightarrow{n_1}.\overrightarrow{v}) \cdot (\overrightarrow{n_2}.\overrightarrow{v}) < 0$ i.e. $\overrightarrow{n_1}$ and $\overrightarrow{n_2}$ have opposite direction on camera axis
   Then F_1 and F_2 are oriented one front to the camera and the other one back to the camera therefore current edge is a contour.
   Else it is not an apparent contour edge.

3.4. Watermarking 3D Silhouettes

To the best of our knowledge, there is no previous work dealing with watermarking 3D polygonal lines. As far as we are concerned we have extended to 3D silhouettes the existing algorithm described in the paper [14] and dealing with 2D contours . We first describe the main steps of 2D contour watermarking algorithm and then we present our extension to 3D silhouettes.

3.4.1. Watermarking 2D contour

Let L_{2D} be a 2D contour that consists of N vertices, each of them represented as $[x(n), y(n)]$. Coordinates can be combined to construct the complex signal:

$$s_{2D}(n) = x(n) + i.y(n), \quad n = 0 : N. \tag{1}$$

Such a signal can be represented by its Fourier transform coefficients $S_{2D}(k), \quad k = 0 : N$.

Watermark construction and embedding: We note W_0 a bi-valuated +/-1 random sequence with zero mean and unit variance.
The watermark is constructed as follows:

$$W(i) = \begin{cases} 0 & i < aN \ \ or \ \ bN < i < (1-b)N \\ & or \ \ (1-a)N < i. \\ W_0(i) & (1-b)N < i < (1-a)N \\ & or \ \ aN < i < bN. \end{cases}$$

The watermarked polygonal line is:

$$|S^*_{2D}(k)| = |S_{2D}(k)| + p|S_{2D}(k)| \cdot W(k). \tag{2}$$

a and b control the low and high frequency ranges that the watermark affects, $0 < a < b < 0.5$.
p determines the watermark strength and must be less than 1 to have $|S^*_{2D}(k)|$ always positive.

The inverse Fourier transform of $S^*_{2D}(k)$ produces the watermarked polygonal line L^*_{2D}.

Watermark detection: Let $|S^*_{2D}(k)|$ be the Fourier descriptor of the watermarked line. The correlation c between W and $|S^*_{2D}(k)|$ informs us about the watermark's presence.

$$c = \sum \left(W(k) \cdot |S^*_{2D}(k)|\right) \tag{3}$$

Instead of c, a normalized correlation coefficient c' equal to $c/mean(c)$ is used. The detection is performed by comparing c' against a properly selected threshold T:

- H_0: W watermarks L^*_{2D} if $c' > T$.
- H_1: W does not watermark L^*_{2D} if $c' < T$.

3.4.2. Extension to 3D silhouettes

Let L_{3D} a 3D silhouette that consists of N vertices, each of them represented as $[x(n), y(n), z(n)]$. Coordinates can be combined as follows to construct the complex signal:

$$s_{3D}(n) = x(n)/z(n) + i.y(n)/z(n), \quad n = 0 : N. \tag{4}$$

To watermark this 3D silhouette we replace the signal defined in the equation (1) s_{2D} with s_{3D} (equation.4), we obtain watermarked coordinates $(x/z)^*$ and $(y/z)^*$. The watermarked 3D silhouette L^*_{3D} is then defined by the N vertices:

$$[x^* = (x/z)^*.z, \ \ y^* = (y/z)^*.z, \ \ z]. \tag{5}$$

The choice of this complex signal s_{3D} to watermark 3D silhouettes L_{3D} is closely related to the main objective of our approach (watermarking 3D object and retrieving information from represented views). In fact, considering the basic case of perspective projection, 2D contour coordinates are defined as:

$$[x_p = f.x/z, y_p = f.y/z]. \tag{6}$$

3.4.3. Robustness to manipulation

Thanks to the adequate construction of the complex signal s_{3D} (eq.4) to insert/detect the mark, properties in term of robustness against manipulations demonstrated in 2D remains valid in 3D.

- Translation of the represented view only affects the first Fourier descriptor $S^*_{3D}(0)$, by choosing $a > 0$ the watermark is robust to translation.
- Rotation by an angle θ of the represented view results in a multiplication by $exp(i\theta)$ of the signal S^*_{3D}. The magnitude of the Fourier descriptors remains invariant. The algorithm is therefore robust to rotation.
- The normalization of the correlation coefficient c grants the robustness against scaling attacks.

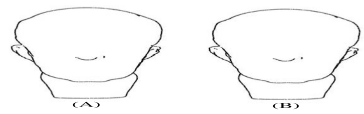

Fig. 4. a-Original 3D silhouette. b-Watermarked 3D silhouette

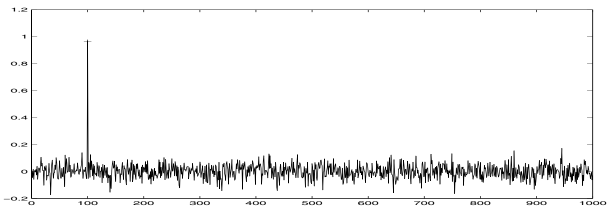

Fig. 5. Correlation score (eq.3); detection for 1000 different keys. The key 100 is the correct one, parameters (a,b,p) = (0.1,0.4,0.3)

3.4.4. Results

Some preliminary results of watermarking detection are shown on figure 5. The 3D silhouette used here is composed of $N = 3377$ vertices. The original and watermarked silhouette can be seen in figure 4.

4. CONCLUSION AND PERSPECTIVES

We proposed a new scheme to watermark 3D objects which is based on inserting the watermark in the 3D silhouette and extracting it from 3D object's represented views. This is an important approach since, as mentioned earlier, it is usually more frequent to locate and recover suspicious represented views of 3D objects than 3D file themselves. We have also proposed an extension of 2D contour watermarking algorithm to 3D silhouette.

Some steps of our approach are still under construction and are not yet fully designed and validated, e.g. the automatic selection of characteristic views, the exact way for the retriever to select the closest point of view and the possible conflicting overlaps between parts of the watermarked signal.

Mid term works will also concentrate on 3D object blind watermarking: the mark would be extracted from the 3D object's represented views without knowing the set of parameters used for the projection.

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