3D Data Hiding for Enhancement and Indexation on Multimedia Medical Data

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Abstract. In medical applications, large quantities of multimedia data are exchanged such as 3D data acquired either by volume (CT-scan) or surface (laser range) scanning. The increasing of the numerical data using raises some unsolved issues. As for us, we are interested in the protection and the enhancement of multimedia content by insertion of hidden message. According to Koller *et al.* [7] some of these challenges are:

- Metadata embedding;
- Indexing and searching in database.

Data hiding may be a solution for these main applications in the medical domain. It is possible to embed metadata, with security for confidential data or for indexing area in a media, without increasing the size of the file.

1 Introduction

The main interest of data hiding is to embed additional information without increasing the file size and keeping the compatibility with the norms and the standards such as JPEG for image, DICOM for medical image, MPEG for video, etc.

In this Section, we propose to introduce briefly the data hiding principle and we present some medical application.

1.1 Data Hiding Principle

The principle is to embed a message into the useful data of the multimedia file and to be able to extract or recognize it from the watermarked file. We can divide the insertion process in two parts: the synchronization and the embedding.

Synchronization allows us to know where the encoded message can be embedded in the host signal. It can be considered as a preparation of the media to the embedding. The host signal can be represented in other domain, such as a frequential domain (Discrete Cosines Transform, Fourier Transform), a wavelet domain (Discrete Wavelet Transform) as a function of the application and the chosen method. The aim is to be able to recognize the same subspace, called insertion subspace, before and after the watermarking.

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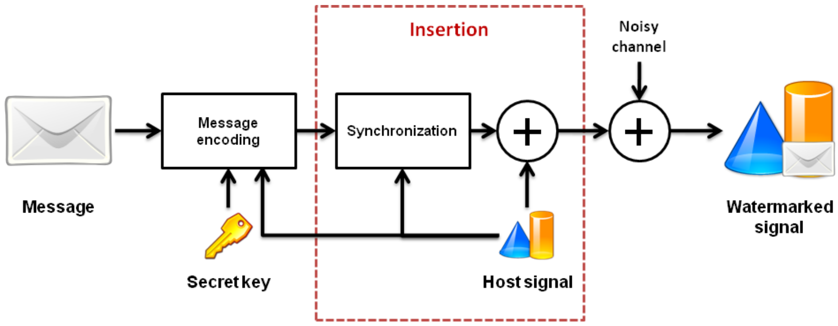


Fig. 1. Watermarking Scheme.

The message is encoded as a function of a secret key and the host signal. The embedding consists in merging the encoded message and the host signal in the subspace domain. The embedding principle is illustrated on Fig. 1.

On the watermarked data, we need to extract the embedded message. For the extraction process, first we synchronize the watermarked data to find the insertion subspace again and we extract the message depending on the insertion method. The extraction principle is illustrated on Fig. 2.

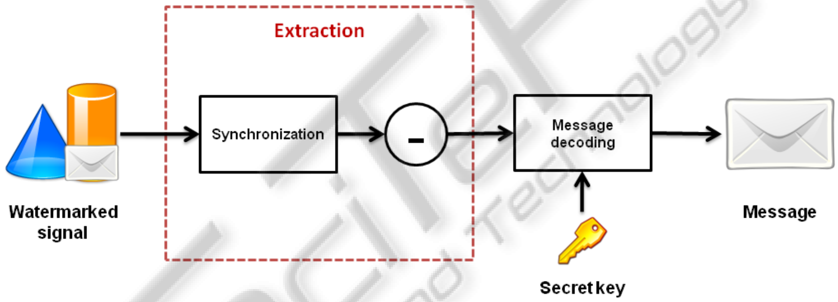


Fig. 2. Extraction Scheme.

1.2 Data Hiding Applications in Healthcare

The applications are various and depend on compromises between the capacity of the message to embed, the insertion robustness, the modification imperceptibility [11], the algorithm security [6] and the complexity. As the data are voluminous, the algorithms must be fast with a low complexity.

One of the main application of data hiding is communication, a transmission of a secret message. It looks like cryptography approaches. In data hiding we do not want to secure the media to transmit, the media is a carrier for the message we want to send. In this condition, the watermark algorithm must be robust and secured. For example, in a medical context, it could be interesting to embed the identity of the patient into the 3D image acquired by a CT-scan. For privacy, we need to keep anonymous its identity for a secured transmission of the data. We can note cryptography and data hiding can be combined for these applications [12].

Data hiding can be used for enhance the media with metadata. It is quite easy to add metadata in a file, but we do not want to increase the size of the media because more the data are voluminous; more it is difficult to store them. Such as the embedding of indexing information [3] in order to identify the media. It can be also possible to carry a diagnostic resume, a description of the image, some quotes or remarks in order to have all the main information available on the same file. But there are some constraints for example in ROI medical image, where the image must not be disrupt in the ROI areas [14].

For further information on data hiding application in healthcare, [5] made a review of image watermarking applications.

Data hiding is useful in medical application. Nowadays, there are a lot of well-known techniques in 2D watermarking. In the 3D domain, the topic is more difficult because the synchronization issue is more difficult. There is not any way to scan the 3D object obviously rather than in 1D scanning the audio with a pseudo-random clock; or in 2D scanning the image line by line for example.

In the following Section, we propose data hiding system for 3D objects. First, we introduce a watermark technique on 3D images acquired by CT-scan in Section 2 and in Section 3 we deal with a watermark technique applied on 3D meshes. The presentation of the techniques is validated by experimental results in the respective sections.

2 3D Image Data Hiding

2.1 2D Data Hiding on CT-scan before 3D Reconstruction

For this approach, the idea is to use well-known 2D watermarking technique for 3D object. First, the object is acquired by volume (CT-scan) in order to have a 3D image. Each slice is equivalent to a 2D image that we can watermark by classical techniques. We illustrate on Fig. 3 some slices of a 3D image acquired by CT-scan.

From the 3D image we are able to build a 3D mesh by computing the iso-surface. We illustrate the reconstruction of the skin (Fig. 4.a.) and the skeleton (Fig. 4.b.) from our 3D image. The aim is to watermark the 3D image such as there is no perceptual difference on the 3D object.

In our condition, we have 3D images[3] composed by 249 slices (512×512 pixels). We can watermark each slice with the same message, or independently with a different message for each one. It depends on the final application. For example, if we prefer to have a robust watermarking scheme, we will watermark the same message in each slice; else if we want to enhance the media with metadata, we prefer to have an high capacity watermarking scheme so we embed different message in each slice.

In that case, we just want to prove that the watermark keep a good quality on the 3D reconstruction. We choose a well-known technique, by substitution of the LSB value of the pixels [2].

When the images are watermarked, we reconstruct the object from the 3D image into a mesh [8].

[3] http://pubimage.hcuge.ch:8080/.

Fig. 3. An example of some 3D image slices: a) A represention of the slice $\#1$, b. the slice $\#130$, c. the slice $\#200$ and d. the slice $\#230$.

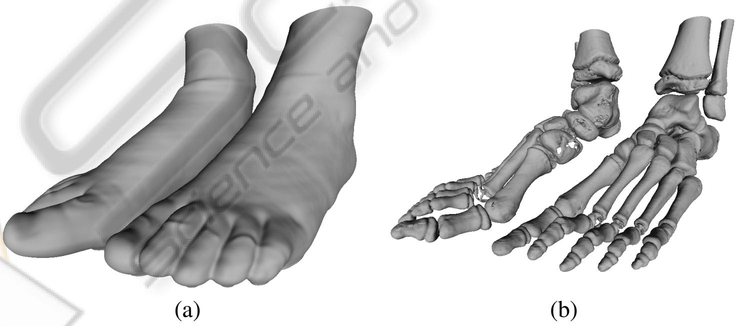


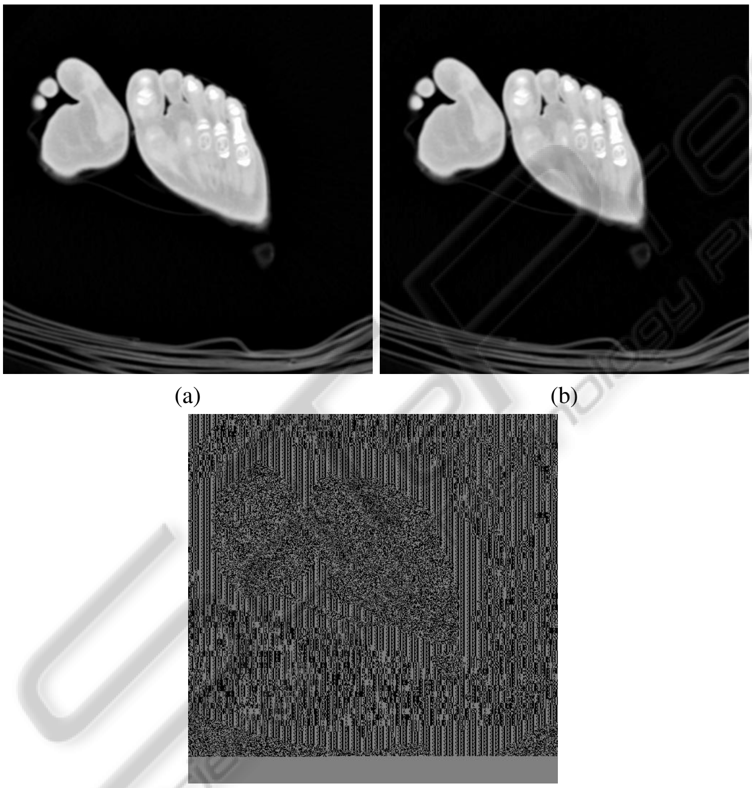
Fig. 4. An example of 3D mesh reconstruction from the 3D image: a) The skin reconstruction composed by $663'072$ vertices and $1'126'466$ faces; b) The skeleton one composed by $804'073$ vertices and $1'577'853$ faces.

For the extraction procedure, we just need to extract the message from the 3D image by reading the LSB value of each watermarked pixel. It is a fragile technique with high capacity, fast (low complexity) and quite efficient to enhance 3D images with metadata.

2.2 Experimental Results

From the 3D image composed by 249 slices (512×512 pixels) we embed in each slice 30ko. With the LSB watermarking method, associated with a pseudo-random image scanning; we can embed one bit per pixel. In these conditions, the capacity is fixed at 0.9265 bit per pixel.

First, we are looking for the quality of the watermark on each image. We compute the PSNR (Peak Signal Noise Rate) between the original slice and the watermark one. The results are very good, the PSNR equals to 51.63 dB in average for an high capacity application. There is no perceptual difference between a slice and the respective watermarked one (Fig. 5).



(a) (b) (c)

Fig. 5. Comparison between: a) The original slice #230; b) The watermarked image; c) The difference image.

The main aim is to know what is the impact of the watermark on the 3D mesh reconstruction. We build the 3D mesh, by computing iso-surface on the watermarked 3D image and we compare the quality of the mesh obtained by the original image and this one.

To quantify the quality we use the Hausdorff distance, that computes the longest distance of the shortest distance between a vertex in the first mesh to a vertex in the second one. For the skeleton mesh and for the skin mesh, the Hausdorff distance equals to 0.00. That means there is no difference between these two meshes and we are able to extract the watermark from the 3D image. It is a very high capacity technique, nevertheless we can not extract the message from the 3D mesh.

3 3D Mesh Data Hiding

3.1 3D Data Hiding using Euclidean Minimum Spanning Tree

In Section 2, we have presented a 2D watermark technique used for 3D objects. We remark the extraction process must be done from the 3D image and not from the 3D mesh. In this Section, we want to watermark the mesh. Various techniques exist, most of them are robust to geometrical rigid transformations. In this Section, we present an original 3D watermarking approach that does not move any vertex [1].

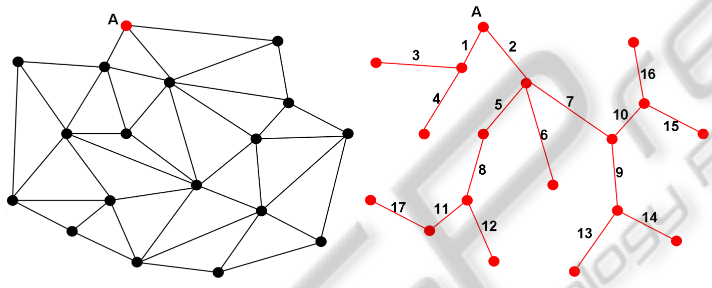


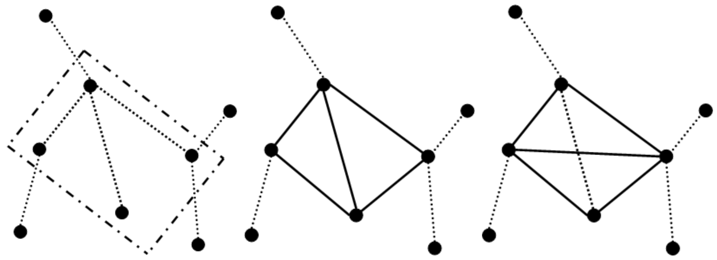
Fig. 6. An example of a mesh: a) The EMST of the mesh; b) We can remark connections in the EMST are not necessarily edges in the mesh.

Few 3D watermarking approaches do not move any vertex [1], [10], [9]. The originality of [1] is to watermark a message by editing the connections in the mesh without increasing the file size and without moving the vertices. In order to synchronize the message they compute an Euclidean minimum spanning tree (EMST) illustrated Fig. 6. The EMST is unique, and from a seed vertex v_0, the path of the vertices is also unique. This can be an interesting synchronization tool because we can cover the mesh with a unique path.

In the EMST, they are searching quadruples, a father-vertex and three sons, to embed one bit. The insertion is quite simple, if we want to embed a 0-bit the edge of the EMST is chosen. Otherwise, if we want to embed a 1-bit, the other edge is in the EMST. The insertion process is illustrated Fig. 7.

In order to not create important visual distortions and synchronizations issues, the quadruples must verify the following conditions:

- Coplanarity: the measure of the angle formed by the two triangles (Fig. 8);
- Convexity: the quadruple must be convex in order to cover quite the same surface (Fig. 9);
- Covering: if two quadruples are neighbours only one of them is used for the embedding.



(a) (b) (c)

Fig. 7. Illustration of the EMST (a), the mesh when a 0-bit is embedded (b) and when a 1-bit (c).

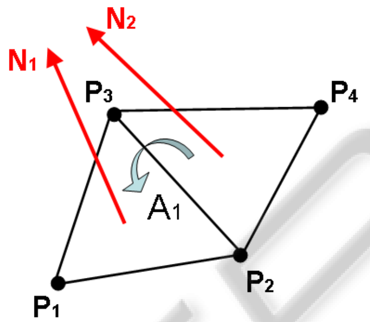
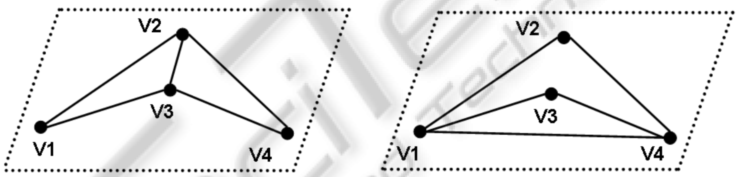


Fig. 8. Representation of the coplanarity condition.



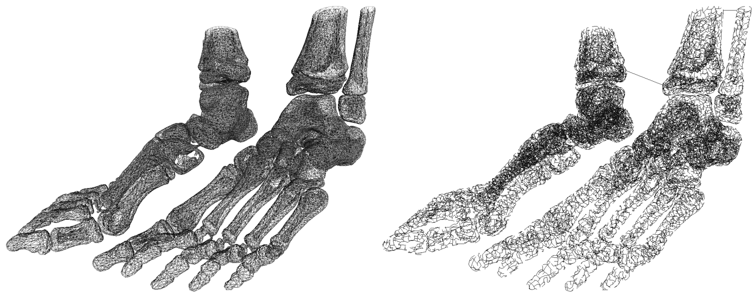
(a) (b)

Fig. 9. Representation of the watermarking impact on a quadruple not convex before the watermark (a) and after (b). The covered area is different and there is a topological problem: v_3 must not be inside of the triangle (v_1, v_2, v_4).

3.2 Experimental Results

We present some results on our 3D *Skeleton*. We illustrate, Fig. 10.a the simplified 3D mesh and its EMST Fig. 10.b. During the watermarking process, the vertices are not moving, the cloud is the same, only the connectivity is changed. Indeed, there is not any distortion due to the vertex displacement. So we compute the Hausdorff error, including the connectivity distortion. The Hausdorff distance is computed on the center of the triangles and not on the vertices and normalised as a function of the bounding box diagonal computed with METRO [4].

As a function of the coplanarity threshold, we can embed more information in the mesh. More the threshold is low, more the connectivity distortion is better but the capac-



(a) (b)

Fig. 10. An example of EMST applied on a simplified 3D mesh *Skeleton* ($48'711$ vertices and $98'614$ faces).

ity maximum decrease because we select fewer quadruples. For a coplanarity threshold fixed at $10°$ we can embed a message of 575 bits maximum in *Skeleton* and for $5°$ the maximum capacity is up to 264 bits.

In order to compare the distortion in the mesh, we fix the capacity of insertion to $4 \cdot 10{-}3$ bits per vertex (i.e. 216 bits on *Skeleton*). After the embedding we compute the Hausdorff distortion. For a coplanarity thresholds equals to $10°$ we get $3.94 \cdot 10^{-4}$ and $5°$ we have $1.08 \cdot 10^{-4}$. That means for a diagonal of 20 cm, the maximum error is 0.08 mm.

4 Conclusions

We have presented a watermarking overview for medical application, in order to protect the 3D images or to enhance the 3D object by embedding metadata. In medical application the data are large for each patient, so we need to develop fast algorithms without increasing the size of the data.

We have introduced 2D watermarking techniques used for 3D images. It is a low complexity algorithm with high complexity to enhance the 3D model. But it is very fragile to noise addition and it is impossible to extract the message from the 3D mesh.

Then, we have presented a 3D watermark method based on a mesh. The originality is to watermark a message without moving any vertices and without increasing the file size. The synchronization is made by the localization of quadruples in the EMST of the vertex cloud. The method is also fragile with low capacity of insertion, but the 3D mesh is watermarked. Nevertheless, the complexity is very high (quadratic as a function of the number of vertices).

It is very fragile to noise addition, so we focus on this method to improve it by studying the possible displacement of the vertex in order to be more robust. As a function of the Prim's algorithm and the seed vertex, we are able to know how can a vertex be moved without editing the connections in the EMST [13]. Indeed, we watermark our message in the most robust areas.

We study the EMST structure in order to find new robust criterion in order to select robust areas and improve the computational time.

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