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Wavelet-Based Medical Augmented Reality CSG Objets Watermarking

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Abstract: Augmented reality systems can lead to major improvement of patient care by using the preoperative CT-Scan or MRI medical data intraoperatively during the intervention. In this study we propose to model human organs and laprosocpic instruments using constructive solid geometry (CSG) objects and we give some algorithms to watermark CSG modelled objects by finding an empty box in the bounding box of the object, then considering another CSG modelled object. We create a new CSG object with left leaf the original object and right leaf the other one, linked by minus operator. A great deal is to multi-resolution analysis and trees.

Key words: Watermarking, copyright, CSG modeling, security, wavelet, multi-resolution analysis

INTRODUCTION

The numeric marking is a relatively new and very attractive research domain that can be applied on a multitude of formats[1-3] and presentations of pictures and images. Its objective is to solve problems related with security and protection of publications and the numeric productions that can be stored on supports not secured as Internet. Fields landed by the numeric marking cover all formats that can exist practically: text, audio, picture, video[3-8], but few works have been led for watermarking geometric 3D objects[9-11,7].

Watermarking a media is hiding information in the media itself without major modification. Thus, we don't need supplementary elements like header files or plug-ins added to documents to contain the mechanism of security or to change the structure and the format of documents completely as with the cryptography. The exponential evolution of Internet and the necessity to present the conceived electronic work the most quickly give back watermarking the more profitable economically and technically with regard to competitor solutions.

In augmented realilty systems[12,13] applied on medical imagery such as MRI or CT-Scan as principal sources of preoperative data and video-coloured images in the case of laparoscopic mini-invasive surgery, watermarking techniques can be used to control the 2D/3D registration step or embedding medical information such as surgical planning actions or physical an chemical properties.

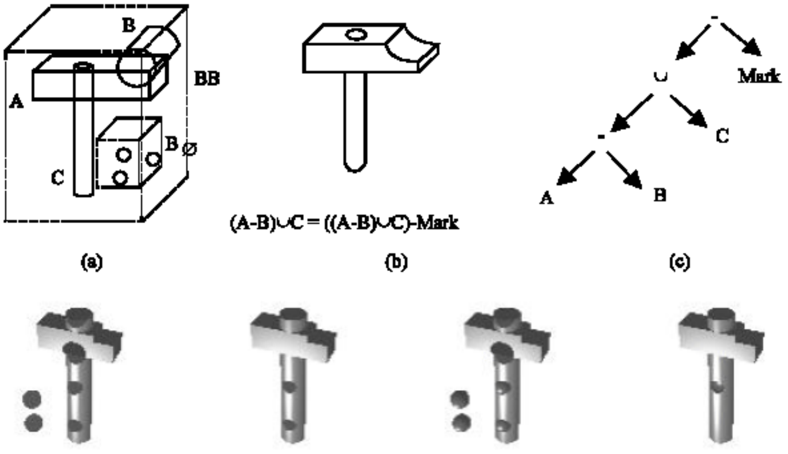
The watermarking must be the most robust against all types of attacks. Therefore, transformations as rotation, translation, scaling or cropping applied to the original work must not destroy the hidden information. In addition, the system of marking must be able to mix the added information intimately and to recover it without damaging the quality of the original media.

This study deals with watermarking CSG modelled objects[1,14]. We propose new methods for public watermarking 3D objects based on solid modelling using either CSG objects or numerical data represented by a collection of spheres. In the second section, we use multi-resolution analysis by wavelets for more robustness against local attacks and transformations. The method of analysis by wavelets is relatively new although its theoretical foundations come back to the works of Joseph Fourier in the 19th century (see[2,15,17,18] for more details).

Watermarking algorithms for CSG modelled objects: Four steps are needed for watermarking: finding an empty bounding box in the hull bounding box of the object, positioning the mark, choosing and extracting it.

Finding an empty bounding box: In order to embed the watermark data, an empty bounded volume is selected so that it will not be deformed by topological and set operators. For the watermark to be robust, we prpose to bound the CSG primitves (CSG tree leafs) using boxes. Then, by making a projection on the laparoscopic view plan we can find the totally empty bounding boxes in which the surgical planning or the physical constraints can be hided.

Positioning the mark: In this study, we suggest to put the mark in any empty box B_e included in the bounding box BB of the CSG object. This technique may be used to mark every 3D object or even a scene if one can find such a B_e in the bounding box of the object or the scene (for example: by subdivision). For this aim, we create a new CSG object whose left leaf is the object and right leaf is the mark.



(d) Union/transparent (e) Minus/transparent (f) Union/opaque (g) Minus/opaque

(h) (i) (j) (k)

Fig. 1: Marked object

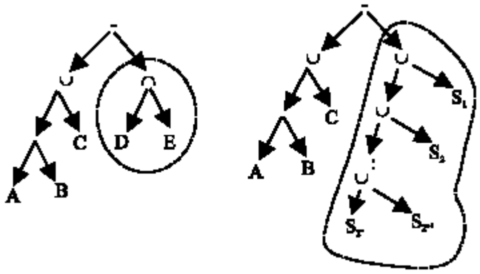
Figure 1(d-g) (resp. (h-k)) shows a marked hammer (resp. a single object) with four spheres in the four cases: (union/minus) operator with (opaque/transparent) spheres. Two of the spheres do not intersect the objects, while the two others intersect them. Holes appear in each of Fig. 1 (f,g,j,k). Then, to mark efficiently the objects, the spheres (either opaque or transparent) must not intersect them, so they must be in an empty box included in the bounding box.

Choosing the mark: We choose another fictive CSG object as the mark with $B_{\varnothing}$ as its bounding box. Then we create a CSG object whose root is minus operator, left leaf is the original CSG object and right leaf is the mark. This method does not affect the original object.

The mark may be any CSG object like in Fig. 2(a) or a set of 2^n fictive spheres sufficiently near from each other with sufficiently small diameter (Fig. 2(b)). This case is treated by a multi-resolution analysis like in wavelets techniques.

To ensure properties of a good watermarking, we propose using distances between the spheres.

Let $S_0 = \{1,2, \ldots,2^n\}$ be an ordered set of 2^n spheres and x_i be the x-coordinate of the ith centre, $i=1,\ldots,2^n$. Let $R_0 = D_0 = \varnothing$ and for $i = 1,\ldots,n$, $S_i = \{1,2,\ldots,2^{n-i}\}$, $R_i = \{2^{n-i}+1, 2^{n-i}+2,\ldots, 2^{n-i}+2^{n-i}\}$, $D_i = \{d_{2^{n-i}+1}, d_{2^{n-i}+2}, \ldots, d_{2^{n-i}+2^{n-i}}\}$, where $d_{2^{n-i}+j} = x_{2^{n-i}+j} - x_j$, $j = 1,\ldots,2^{n-i}$. S_i is the first half of S_{i-1} and R_i is the second. D_i is a set of distances between centres of the spheres in x-direction. We note that the order in S_0 induces the same order in all the S_i's, R_i's and $S_i \cup R_i \cup R_{i-1} \cup \ldots \cup R_1$. Table 1 shows how to store these data. However, same tables can be created for y,z-directions.



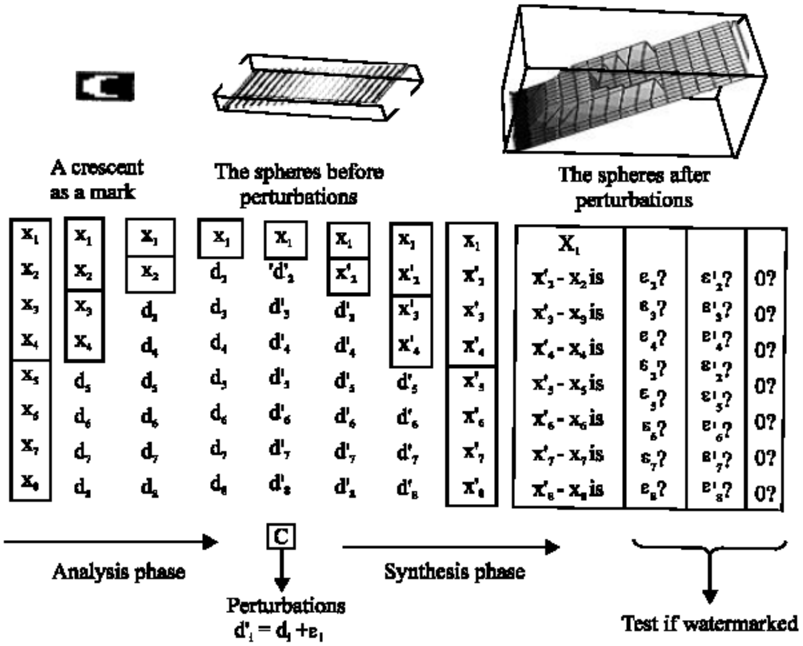
(a) A CSG object mark (b) A union-spheres mark

Fig. 2: Possible mark types

Table 1: Data for 2^3 spheres

x_1		X_1		x_1	S_3	x_1
x_2		X_2	S_2	x_2	R_3	$d_2 = x_2 - x_1$
x_3		X_3		$d_3 = x_3 - x_1$		d_3
x_4	S_1	X_4	R_2	$d_4 = x_4 - x_2$		d_4
x_5		$d_5 = x_5 - x_1$		d_5		d_5
x_6		$d_6 = x_6 - x_2$		d_6		d_6
x_7		$d_7 = x_7 - x_3$		d_7		d_7
x_8	R_1	$d_8 = x_8 - x_4$	D_1	d_8		d_8
		D				

Table 2: Perturbations of the spheres in x-direction using a cresent as a mark



If I_r denotes the identity matrix and Θ_r the null matrix with order r, then S_j and D_j , j = 1,…,n, are computed as follows in the analysis phase:

$$S_j = (I_{2^{n-j}}, \Theta_{2^{n-j}})\, S_{j-1}$$
$$D_j = (-I_{2^{n-j}}, I_{2^{n-j}})\, S_{j-1}$$

while S_{j-1}, j = n,n-1,…,1, is computed as follows in synthesis phase:

$$S_{j-1} = \begin{bmatrix} I_{2^{n-j}} & \Theta_{2^{n-j}} \\ I_{2^{n-j}} & I_{2^{n-j}} \end{bmatrix} \begin{bmatrix} S_j \\ D_j \end{bmatrix}$$

Insertion of the mark: Now, let us perturb last column D in Table 1 by adding (or subtracting) a small vector ϵ in such a way that the spheres stay in B_o (Table 2). Some types of perturbation exist[3,7,8,2], we give another ones:

- Let ϵ be the maximal authorized error vector. The mark $M = [b_0\ b_1\ \ldots\ b_m]$ is a binary representation of the mark. Then, D_i is replaced by $D_i + \epsilon_i$ if $b_i = 1$ and by $D_i - \epsilon_i$ if $b_i = 0$, i=0,…,m. This method requires $m = 2^n-1$.
- Another method consists of representing each line L_i of the mark by a sequence of bits $M_i = [b_{i0}\ b_{i1}\ \ldots\ b_{im}]$ and embedding M_i in the decimal part of D_i, i=0,…,m.
- ϵ may be respectively the red, green, blue-component of pixel colors in an image in the x, y, z-direction.
- A method of perturbations based on trees and multi-resolution techniques.

Robustness: The method is robust against rotation and translation attacks since distances are not affected by these transformations.

If a scale transformation with factor α in x-direction is applied, then we show easily that distances are multiplied by α. So, column C in Table 2 will be multiplied by α and it is easy to make the test.

Extraction of the mark: If the mark is any CSG object, it is extracted by only considering the right leaf of the new object. The mark is inserted in the bounding box of the initial object but is not concerned with ray tracing. So, the extraction does not need the original object, this technique is robust and rotation, translation and scaling have no effect, invisibility is ensured since the root of the CSG tree is minus operator.

If the mark is the set of spheres, Table 2 is all what we need. The object is watermarked if the last column is ϵ, not watermarked if it is 0 and attacked otherwise.

CONCLUSION

In this study, we propose new methods for very high capacity watermarking 3D objects using multi resolution techniques based on wavelets. The mark is embedded in topological properties of the model. Our algorithms give robustness to various attacks like affine transformations. However, other attacks like projections and cropping have to be studied with more detail.

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