VISAPP 2007

Proceedings of the
Second International Conference on
Computer Vision Theory and Applications

Volume IFP/IA

Barcelona, Spain

March 8 – 11, 2007

Co-organized by
INSTICC – Institute for Systems and Technologies of Information, Control and Communication
and
CVC – Computer Vision Center

Edited by AlpeshKumar Ranchordas, Helder Araújo and Jordi Vitrià

Printed in Portugal

ISBN: 978-972-8865-73-3

Depósito Legal: 254546/07

http://www.visapp.org

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3D VOLUME WATERMARKING USING 3D KRAWTCHOUK MOMENTS

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Keywords: Watermarking, Data Hiding, 3D volume, 3D Krawtchouk moments.

Abstract: In this paper a novel blind watermarking method of 3D volumes based on the Weighted 3D Krawtchouk Moments is proposed. The watermark is created by a pseudo-random number generator and is embedded on low order Weighted 3D Krawtchouk Moments. The watermark detection is blind, requiring only the user's key. The watermark bit sequence is created using the key and its cross correlation with the Weighted 3D Krawtchouk Moments of the possible watermarked volume. The proposed method is imperceivable to the user, robust to geometric transformations (translation, rotation) and to cropping attacks.

1 INTRODUCTION

In the recent past, with the rapid development of 3D computing application, huge amount of multimedia data have become publicly available (photographs, videos, paintings, music etc). Moreover, the rapid growth of Internet has increased the number of channels for digital data distribution. In this environment, the need for protection of copyrighted digital data is obvious. The most classic method to achieve the latter is the watermarking. Extra information (the watermark), is hidden with an appropriate algorithm in the digital data in a way that is imperceptible from the user, but it can be perceived by an appropriate detection algorithm.

A watermarking algorithm has to fulfil the following criteria:

- *Robustness against attacks*: The watermark has to be detectable if the digital data are intentionally or unintentionally modified.
- *Invisibility*: The user must not be able to perceive that the digital data are watermarked.

Concerning color and grayscale 3D volumes, only few methods have been presented so far. The majority of the methods hide the watermark in appropriate coefficients of an invertible transformation (e.g. DCT (Wu et al., 2001), Fourier (Solachidis and Pitas, 2005), wavelet (Wu et al., 2001)). The watermark affects the appropriate parameters in order to ensure both imperceptibility and robustness against various attacks. For example, in the secure Fourier-based watermarking technique presented in (Solachidis and Pitas, 2005), the watermark is embedded in the middle frequency coefficients, because the low frequency coefficients can alter the initial volume in a way that is visible to the user and the high frequency coefficients can be easily filtered. There are also other approaches, (e.g. (Tefas et al., 2002), (Louizis et al., 2002)) in which the 3D volume is modified in the spatial domain, using appropriate embedding functions.

In this paper, a novel blind 3D volume watermarking technique which utilizes the 3D Krawtchouk moments presented in (Mademlis et al., 2006) is proposed, in order to watermark 3D volumes. The projection of any 3D volume to the space of Weighted 3D Krawtchouk moments, which is fully reversible. Moreover, the Weighted 3D Krawtchouk Moments are defined in the discrete field, thus no discretization error is inserted during the Weighted 3D Krawtchouk moments analysis. Also, the proposed 3D Krawtchouk watermarking method is robust against the geometric transformations of rotation and translation and against cropping attacks.

The rest of the paper is organized as follows. In Section 2 a brief overview of the Weighted 3D Krawtchouk Moments is given. The watermark embedding approach is presented in Section 3, while the watermark detection algorithm is analyzed in Section 4. In Section 5 the experimental results are presented and finally the conclusions are drawn in Section 6.

2 3D KRAWTCHOUK MOMENTS

3D Krawtchouk Moments have been introduced in (Mademlis et al., 2006) and exploited for 3D object search and retrieval applications. In this paper, this theory is utilized for watermarking purposes. For the shake of completeness, the theory of 3D Krawtchouk Moments is briefly described in the sequel.

The n-order Krawtchouk classical polynomials (Koekoek and Swarttouw, 1998) are defined in terms of the hyper-geometric function as:

$$K_n(x;p,N) = \sum_{k=0}^{N} a_{k,n,p}x^k = {}_2F_1(-n,-x;-N;\frac{1}{p}) \quad (1)$$

where $x,n = 0,1,2\ldots N, N > 0, p \in (0,1)$ and the function ${}_2F_1$ is the hypergeometric function.

The set of Krawtchouk polynomials $S = \{ K_n(x;p,N), n = 0\ldots N \}$ has $N+1$ elements and forms a complete set of discrete basis functions with weight function:

$$w(x;p,N) = \binom{N}{x} p^x(1-p)^{N-x} \quad (2)$$

Krawtchouk Polynomials are orthogonal:

$$\sum_{x=0}^{N} w(x;p,N)K_n(x;p,N)K_m(x;p,N) = \quad (3)$$

$$= \rho(n;p,N)\delta_{nm} \quad (4)$$

where $n,m = 1,2,3\ldots N$,

$$\rho(n;p,N) = (-1)^n \left(\frac{1-p}{p}\right)^n \frac{n!}{(-N)_n} \quad (5)$$

and δ_{nm} is the Kronecker delta function.

Let $f(x,y,z)$ be a 3D function defined in a discrete field $A = \{(x,y,z) : x,y,z \in \mathbb{N}, x = [0\ldots N-1], y = [0\ldots M-1], z = [0\ldots L-1]\}$. The Weighted 3D Krawtchouk moments of order (n+m+l) of f, are defined as (Mademlis et al., 2006):

$$\begin{aligned} \bar{Q}_{nml} = & \sum_{x=0}^{N-1}\sum_{y=0}^{M-1}\sum_{z=0}^{L-1} \bar{K}_n(x;p_x,N-1) \times \\ & \times \bar{K}_m(y;p_y,M-1)\bar{K}_l(z;p_z,L-1) \times \\ & \times f(x,y,z) \end{aligned} \quad (6)$$

where $\bar{K}_n(x;p,N)$ is the family of weighted Krawtchouk polynomials defined as:

$$\bar{K}_n(x;p_x,N-1) = K_n(x;p,N)\sqrt{\frac{w(x;p,N)}{\rho(n;p,N)}} \quad (7)$$

Due to the orthonormality property of the Weighted 3D Krawtchouk Moments:

$$\begin{aligned} f(x,y,z) = & \sum_{x=0}^{N-1}\sum_{y=0}^{M-1}\sum_{z=0}^{L-1} \bar{K}_n(x;p_x,N-1) \times \\ & \times \bar{K}_m(y;p_y,M-1)\bar{K}_l(z;p_z,L-1) \times \\ & \times \bar{Q}_{nml} \end{aligned} \quad (8)$$

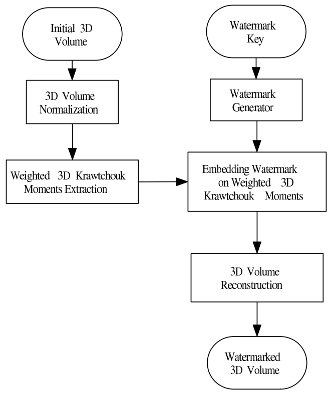

Figure 1: The watermark embedding procedure.

3 WATERMARK EMBEDDING

The watermark generation procedure aims at generating a two-valued watermark series $w_{nml} \in \{-1,1\}$, $n = 0\ldots N_1-1$, $m = 0\ldots M_1-1$, $l = 0\ldots L_1-1$, where $N_1 * M_1 * L_1$ is the watermark length, and $N_1 \leq N$, $M_1 \leq M$, $L_1 \leq L$. The watermark bits are produced by a method that relies on a seed, which completely defines it. In this paper a pseudo-random number generator is utilized. Alternatively, a chaotic sequence could be used.

Let O be the initial 3D volume, represented by the volumetric function $f_O(x,y,z)$. Firstly, O is normalized for rotation and translation and the computed normalization parameters are stored for the reconstruction process. For translation normalization, the 3D volume is translated so as the mass center of the object is placed on $[N/2, M/2, L/2]$. For achieving rotation normalization, the classical Principal Component Analysis (PCA) is followed. Finally, the

Weighted 3D Krawtchouk moments are extracted according to (6).

The watermark is embedded in the low order Weighted 3D Krawtchouk moments as follows:

$$\bar{Q}'_{nml} = (1 + \alpha w_{nml}) * \bar{Q}_{nml} \quad (9)$$

where α is the embedding strength of the watermark, $\bar{Q}_{nml}$ are the Weighted 3D Krawtchouk Moments of the initial object and $\bar{Q}'_{nml}$ are the Weighted 3D Krawtchouk Moments of the watermarked object.

Finally, the watermarked object is reconstructed from the Weighted 3D Krawtchouk Moments according to (8) and it is translated and oriented to initial position, according to the computed normalization parameters.

The embedding process is depicted in Figure 1.

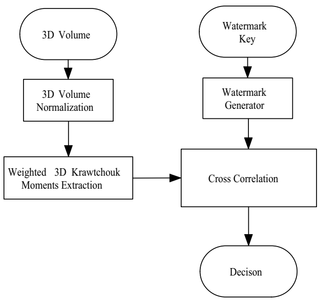

Figure 2: The watermark detection procedure.

4 WATERMARK DETECTION

Let O' be a possibly watermarked 3D volume and $f_{O'}(x,y,z)$ its volumetric function. The volume is normalized with respect to rotation and translation and the appropriate Weighted 3D Krawtchouk Moments $\bar{Q}'_{nml}$ are computed, according to (6).

The watermark detection is blind, thus only the key of the owner is needed, which is used for the watermark generation $\mathbf{W} = [w_{nml}]$.

In order to detect if a volume is watermarked with the watermark $\mathbf{W}$, the correlation γ between the possibly watermarked coefficients $\bar{Q}_{nml}$ and the watermark $\mathbf{W}$ can be used to detect the presence of the watermark, in a similar manner to the blind approach of (Solachidis and Pitas, 2005):

$$\gamma = \sum_{nml} \bar{Q}'_{nml} w_{nml} \quad (10)$$

If the volume is watermarked with the same watermark $\mathbf{W}$:

$$\gamma = \sum_{mnl} \bar{Q}_{nml} w_{nml} + \alpha \sum_{mnl} \bar{Q}_{nml} w^2_{nml} \quad (11)$$

If the volume is watermarked with a different watermark $\mathbf{W}'$:

$$\gamma = \sum_{mnl} \bar{Q}_{nml} w_{nml} + \alpha \sum_{mnl} \bar{Q}_{nml} w_{nml} w'_{nml} \quad (12)$$

Then, assuming that the two watermarks $\mathbf{W}$ and $\mathbf{W}'$ are two uncorrelated random variables which are also uncorrelated to the Weighted 3D Krawtchouk Moments of the initial model $\bar{Q}_{nml}$, then:

$$E\{\gamma\} = \begin{cases} 0 & \text{if } O' \text{ is not watermarked} \\ 0 & \text{if } O' \text{ is watermarked with } \mathbf{W}' \\ A & \text{if } O' \text{ is watermarked with } \mathbf{W} \end{cases} \quad (13)$$

where $A = \alpha N_1 M_1 L_1 E\{\bar{Q}_{nml}\}$.

Thus, using an appropriately selected threshold T, which can be computed for every object from the Weighted 3D Krawtchouk coefficient parameters and the watermark strength, a decision whether the O' is watermarked with $\mathbf{W}$ can be made. The watermark detection algorithm is schematically depicted in Figure 2.

5 EXPERIMENTAL RESULTS

The proposed algorithm has been tested for its performance using MRI 3D volumes with size $64 \times 64 \times 64$ and $128 \times 128 \times 32$. Each 3D volume was watermarked with a thousand different watermarks with a length of 216 bits. The watermark is embedded on Weighted 3D Krawtchouk Moments with $n = [0 \ldots 5]$, $m = [0 \ldots 5]$ and $l = [0 \ldots 5]$, watermark strength $\alpha = 0.1$, and $p_x = p_y = p_z = 0.5$.

- *Imperceptibility*: In order to measure the imperceptibility of the embedded watermark, the Peak Signal-to-Noise Ratio was calculated. The formula used is:

$$PSNR = 10 \log \left(\frac{\sum_{xyz} 255^2}{\sum_{xyz} (f_O(x,y,z) - f_{O'}(x,y,z))^2} \right) \quad (14)$$

where $f_O(x,y,z)$ and $f_{O'}(x,y,z)$ are the volumetric functions of the initial and the watermarked object respectively.

The PSNR value varies between 42 dB and 47 dB, thus it is expected that the watermark is imperceptible to the user. In Figure 3 a slice from the initial 3D volume and the corresponding slice from the watermarked 3D volume are depicted. Although the intensity of the voxels has been changed, it is not perceptible from the user.

- *Geometric attacks*: The geometric attacks considered are the rotation and translation. The normalization step which was initially utilized ensures invariance under this kind of attacks and the percentage of correct watermark detections was 100%.
- *Cropping*: The low level Krawtchouk moments capture information mainly for a neighborhood of the 3D volume located around the point $(p_x N, p_y M, p_z L)$. The higher the order of the polynomials the greater the area. The watermark has been embedded in the center of the volume, thus, any cropping attempt that does not affect the watermarked area, does not affect the watermark detection. If the center area of the 3D volume is removed, the object is not useful.

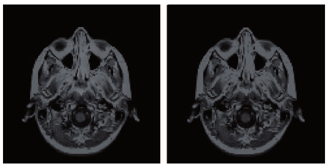

Figure 3: Slice of the initial 3D volume (top) and the corresponding watermarked slice (bottom).

The proposed algorithm was also tested for its performance for different lengths of the watermark and was compared to with a similar watermarking approach based on the Fourier Transform. The same watermark is embedded both on the Euclidean norm of middle frequency Fourier coefficients and the low order Weighted 3D Krawtchouk moments. Figure 4 depicts the performance of the two methods in terms of PSNR versus watermark length. The experimental results prove that the proposed Krawtchouk watermarking scheme can achieve more imperceptible results than the Fourier Transform for the same watermark bit length.

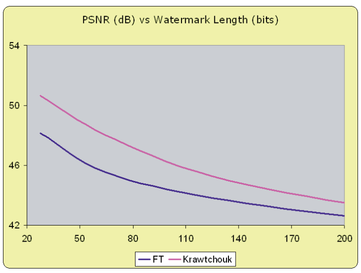

Figure 4: PSNR values for different watermark length.

6 CONCLUSIONS

In this paper, a novel blind method for 3D volume watermarking was presented. The 3D volume is normalized in terms of rotation and translation in order to achieve robustness against these geometric transformations. Then, the Weighted 3D Krawtchouk moments of the 3D volume are extracted and the watermark, which is created by a random number generator having as seed the user's private key, is embedded on low order coefficients which capture local information around the 3D volume's mass center of the volume. For watermark detection, only the owner's key is needed, and a decision is made. The experimental results proved that the method is imperceptible to the final user and robust against geometric transformations and cropping.

ACKNOWLEDGEMENTS

This work was supported by the VICTORY and CATER EC IST projects and by the PENED Greek project.

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