Video Watermarking Scheme Based on Principal Component Analysis and Wavelet Transform

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Summary
This paper presents a novel technique for embedding a binary logo watermark into video frames. The proposed scheme is an imperceptible and a robust hybrid video watermarking scheme. PCA is applied to each block of the two bands (LL – HH) which result from Discrete Wavelet transform of every video frame. The watermark is embedded into the principal components of the LL blocks and HH blocks in different ways. Combining the two transforms improved the performance of the watermark algorithm. The scheme is tested by applying various attacks. Experimental results show no visible difference between the watermarked frames and the original frames and show the robustness against a wide range of attacks such as MPEG coding, JPEG coding, Gaussian noise addition, histogram equalization, gamma correction, contrast adjustment, sharpen filter, cropping, resizing, and rotation.

Key words:
Video watermarking, Principal Component Analysis, Discrete Wavelet Transform, binary logo watermark.

1. Introduction

Recently, the users of networks , especially the world wide web are increasing rapidly. The reproduction, manipulation and the distribution of digital multimedia (images, audio and video) via networks become faster and easier. Hence, the owners and creators of the digital products are concerned about illegal copying of their products. As a result, security and copyright protection are becoming important issues in multimedia applications and services. Watermarking techniques have been proposed for these purposes in which the copyright information is embedded into multimedia data in order to protect the ownership.

In the literature, different digital video watermarking algorithms have been proposed. Some techniques embed watermark in the spatial domain by modifying the pixel values in each frame but these methods are not robust to attacks and common signal distortions. In contrast, other techniques are more robust to distortions when they add the watermark in the frequency domain. In these types of schemes, the watermark is embedded by modifying the transform coefficients of the frames of the video sequence. The most commonly used transforms are the Discrete Fourier Transform (DFT), the Discrete Cosine Transform (DCT), and the Discrete Wavelet Transform (DWT). Several researches concentrated on using DWT because of its multiresolution characteristics, it provides both spatial and frequency domain characteristics so it is compatible with the Human Visual System (HVS).

The recent trend is to combine the DWT with other algorithms to increase robustness and invisibility. Serdean [1] has combined the advantages of both Fourier-Mellin Transform (FMT) image registration techniques and the watermarking in the DWT domain in order to undo geometric attacks. Elarbi [2] has proposed a digital video watermarking scheme based on multiresolution motion estimation and artificial neural network. In Gaobo [3], the watermark is scrambled and embedded into the mid frequency DWT coefficients of each frame of the video. The quality of the scheme is enhanced by using a genetic algorithm. Afterwards, Elarbi [4] has described a method to embed different parts of a single watermark into different shots of a video under the wavelet domain. A multiresolution motion estimation algorithm (MRME) has been adopted to allocate the watermark to coefficients containing motion.

Other transformations have also been explored for watermarking such as principal component analysis (PCA). PCA is a linear transformation that chooses a new coordinate system for the data set. It has the advantage of high energy concentration and complete decorrelation which it is suitable for data hiding. PCA has been used in different ways in image and video watermarking methods. Hien [5] has proposed a method for selecting a set of coefficients in each PCA subblock to cast the watermark. In Yavuz [6], PCA has been used to obtain a reference of the cover image. The watermark is embedded according to the difference of the original and its reference image. Kang [7] has presented a new approach that incorporates multi-band (M-band) wavelet transformation and PCA. While Sun [8], has proposed a video watermarking scheme to resist the temporal desynchronization by using shot segmentation and two-dimensional PCA.

In this paper, we propose a new video watermarking scheme which combines both the DWT and PCA to develop a new hybrid non-blind scheme that is resistant to a variety of attacks. It is well known that even after the orthogonal wavelet decomposition, there still exists some correlation between the wavelet coefficients. PCA

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removes this correlation and concentrates the energy of the wavelet coefficients and distributes the watermark energy over embedding subbands, resulting in enhanced watermarking visibility and robustness. The watermark is embedded in the luminance component of each frame of the uncoded video because the luminance component is less sensitive to human eye than chrominance components. The lowest (LL) and the highest (HH) frequency bands are selected to apply block based PCA to embed the watermark.
The rest of the paper is organized as follows: section 2 presents the proposed watermarking scheme. Section 3 introduces the experimental results and finally section 4 concludes the paper.

2. Proposed Watermarking Scheme

The proposed watermarking scheme is based on combining two transformations; the DWT and the PCA. The block diagrams of embedding and extraction algorithms are shown in Fig. 1 and Fig. 2. In our method, video frames are taken as the input, and watermark is embedded in each frame by altering the wavelet coefficients of selected DWT subbands, followed by performing the PCA transformation on the selected subbands.

2.1 Principal Component Analysis

PCA is an optimal unitary transformation that projects the data on a new coordinate system such that the greatest data variation data comes lies on the first principal component, the second greatest variation on the second principal component, and so on. This transformation orthogonalizes the components of the input data vectors so that they are completely decorrelated. The resulting orthogonal components called (principal components) are ordered such that most of the energy is concentrated into the first several principal components [9]. Due to the excellent energy compaction property, components that contribute the least variation in the data set are eliminated without much loss of information. Unlike other linear transformations, the PCA does not have a fixed set of basis functions but it has basis functions which depend on the data set.

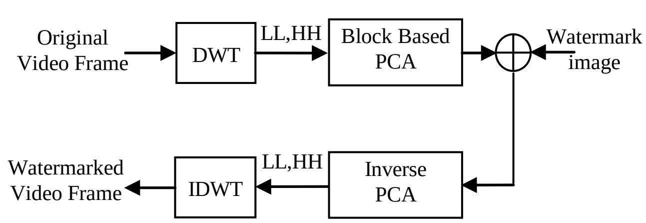


Fig.1 Watermark embedding algorithm

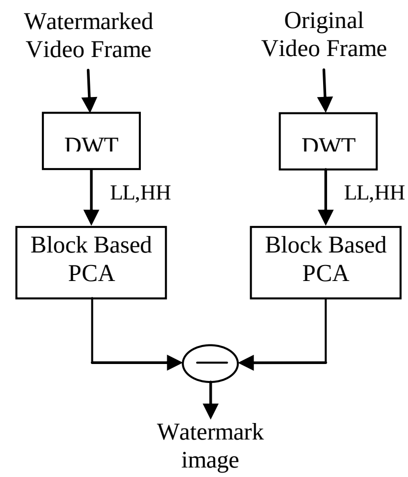


Fig.2 Watermark extraction algorithm

The PCA approach is applied to the transform coefficients of wavelet subband I_θ where θ represents (***LL*** or ***HH***) as shown in the following steps:

Step1: The wavelet subband I_θ with NxN dimension is subdivided into nxn non overlapping blocks (the block size should be appropriate to the subband size) where the number of blocks is given by $k = NxN/nxn$.

Step 2: Each block in ***LL*** band can be processed by *method1* and each block in HH band can be processed by *method2* as following:

<u>method 1:</u> Consider each block like a vector; data vectors can be expressed as: $I_\theta = (I_{\theta 1}, I_{\theta 2}, I_{\theta 3}, \ldots\ldots, I_{\theta k})^T$, where vector $I_{\theta i}$ represents block number i with n^2 dimension.

<u>method 2:</u> Each block can be considered as 2D array $B_\theta = (B_{\theta 1}, B_{\theta 2}, B_{\theta 3}, \ldots\ldots, B_{\theta k})^T$, where array $B_{\theta i}$ represents block number i with size nxn.

Step 3: For each block, the covariance matrix C_i of the zero mean block A is calculated as:

$$C_i = A_i A_i^T \qquad (1)$$

where T denotes the matrix transpose operation, and A is defined by :

<u>method 1:</u> for a vector block as $A_i=E(I_{\theta i} - m_i)$.

<u>method 2:</u> for 2D array block as $A_i=E(B_{\theta i} - m_i)$.

where m_i is the mean of block and E denotes expectation operation.

Step 4: Each block is transformed into PCA components by calculating the eigenvectors (basis function) corresponding to eigenvalues of the covariance matrix:

$$C_i \Phi = \lambda_i \Phi \quad (2)$$

where Φ is the matrix of eigenvectors and λ is the matrix of eigenvalues defined for:

method 1: for a vector block as $\Phi = (e_1, e_2, e_3, \ldots\ldots, e_{nxn})$ and $\lambda_i = (\lambda_1, \lambda_2, \lambda_3, \ldots\ldots\ldots \lambda_{nxn})$.

method 2: for 2D array block as $\Phi = (e_1, e_2, e_3, \ldots\ldots, e_n)$ and $\lambda_i = (\lambda_1, \lambda_2, \lambda_3, \ldots\ldots\ldots \lambda_n)$.

Φ vectors are sorted in descending order according to λ_i, where $(\lambda_1 \geq \lambda_2 \geq \lambda_3 \geq \ldots\ldots \geq \lambda_n$ or $(\lambda_{nxn}))$. The matrix Φ is an orthogonal matrix called basis function of PCA (PCA eigenimages)

Step 5: Calculate the PCA components of the block. The PCA transforms the correlated block into uncorrelated coefficients by taking the inner product of the block with the basis functions Φ:

$$Y_i = \Phi^T A_i \quad (3)$$

where Y_i is the PC block which represents the principle component of block i.

Step 6: Apply inverse PCA on the modified PCA components to obtain the modified wavelet coefficients. The inversion can be performed by the following equation:

$$A_i = \Phi Y_i \quad (4)$$

2.2 Watermark Embedding

The proposed watermarking process shown in Fig.1 is briefly described in the following steps:

Step 1: Divide video into frames and convert ***2Nx2N*** **RGB** frames into **YUV** components.

Step 2: For each frame, choose the luminance **Y** component and apply the DWT to decompose the Y frame into four multiresolution subbands ***NxN***: ***LL***, ***HL***, ***LH***, and ***HH***.

Step 3: Divide the two subbands ***LL*** and ***HH*** into ***n x n*** nonoverlapping blocks.

Step 4: Apply PCA to each block in the chosen subbands ***LL*** by using *method1* (see 2.1) and ***HH*** by using *method2* (see 2.1) .

Step 5: Convert the 32x32 binary watermark logo into a vector $W = \{ w_1, w_2, \ldots\ldots, w_{32x32} \}$ of '0's and '1's.

Step 6: Embed the logo into ***LL*** and ***HH*** bands by different ways. For ***LL*** band, the watermark bits are embedded with strength α_1 into the first principle component of each PC block Y_i. From equation (3) , for the PC block $Y_1, Y_2, Y_3, \ldots\ldots, Y_k$, we can define $Y_I = (Y_1(1), Y_2(1), Y_3(1), \ldots\ldots, Y_k(1))^T$ and the embedding equation:

$$Y_I' = Y_I + \alpha_1 W \quad (5)$$

Step 7: For ***HH*** band, use two pseudorandom sequences (PNS); p_0 and p_1 with different keys k_1 and k_2 to embed the watermark bit w '0' and '1' respectively [10,11]. So, we can represent W_m as follows:

$$W_m = \begin{cases} p_0 & if \quad w = 0 \\ p_1 & if \quad w = 1 \end{cases} \quad (6)$$

when bit $w=0$, embed p_0 with strength α_2 to the mid-band coefficient of PC block Y_i and when bit $w=1$, embed p_1 with strength α_2 to the mid-band coefficients of PC block Y_i.

If Y_B includes the mid-band coefficients then the embedding equation is :

$$Y_B' = Y_B + \alpha_2 W_m \quad (7)$$

Step 8: Apply inverse PCA on the modified PCA components of the two bands to obtain the modified wavelet coefficients.

Step 9: Apply the inverse DWT to produce the watermarked luminance component of the frame. Then reconstruct the watermarked frame.

2.3. Watermark Extraction

The watermark extraction process shown in Fig. 2 is the inverse procedure of the watermark embedding process. The proposed algorithm is a nonblind algorithm so the original video sequence and the user key are required. The watermark extraction procedure is as follows:

Step 1: Convert the watermarked (and may be attacked) video into frames and convert the ***2Nx2N*** **RGB** frames into **YUV** components.

Step 2: For each frame, choose the luminance **Y** component and apply the DWT to decompose the **Y** frame into four multiresolution subbands ***NxN***.

Step 3: Divide the subbands ***LL*** and ***HH*** into ***n x n*** nonoverlapping blocks .

Step 4: Apply PCA to each block in the chosen subbands ***LL*** by using *method1* (see 2.1) and ***HH*** by using *method2* (see 2.1) .

Step 5: Convert the 32x32 binary watermark logo into a vector $W = \{ w1, w2, \ldots\ldots, w32x32 \}$ of '0's and '1's.

Step 6: For the ***LL*** band, the watermark bits are extracted from the first components of each block by:

$$W' = (Y_I' - Y_I)/\alpha_1 \quad (8)$$

Step 7: For the ***HH*** band, re-generate the two (PNS) sequences p_0 and p_1 with the same keys k_1 and k_2 used in embedding. Afterwards, the (PNS) sequences are extracted from the mid-band coefficient of each PC block Y_B by:

$$W_m' = (Y_B' - Y_B)/\alpha_2 \quad (9)$$

The embedded bits are estimated depending on the correlation value ***Cor*** between p_0 and p_1 and extracted sequences W_m' and a predefined threshold ***Th*** as follows:

$$W' = \begin{cases} 0 & \text{if } Cor(p_0, Wm') > Cor(p_1, Wm') \text{ and } Cor(p_0, Wm') > Th \\ 1 & \text{if } Cor(p_1, Wm') > Cor(p_0, Wm') \text{ and } Cor(p_1, Wm') > Th \end{cases} \quad (10)$$

Step 8: After extracting the watermark from ***LL*** and ***HH*** bands, similarity measurements of the extracted watermark ***W'*** and the referenced watermark ***W*** are used for objective judgment of the extraction fidelity ***NC*** which is given by:

$$NC = \frac{\sum_i \sum_j W(i,j) * W'(i,j)}{\sqrt{\sum_i \sum_j W(i,j)^2}\sqrt{\sum_i \sum_j W'(i,j)^2}} \quad (11)$$

Where, **NC** is the normalized correlation whose peak value is one.

3. Experimental Result

The performance of the proposed approached has been tested on the Foreman video sequences [12].

The performance has been evaluated in terms of the imperceptibility and robustness against various attacks. The Peak-Signal-To-Noise Ratio (PSNR) is used to measure the visual quality of watermarked and attacked frames and is defined as:

$$PSNR = 10 \log \frac{255^2}{MSE} \quad (12)$$

where MSE (mean squared error) between the original and distorted frames and is defined as follows:

$$MSE = \frac{1}{mn} \sum_{i=1}^{m} \sum_{j=1}^{n} [I(i,j) - \hat{I}(i,j)]^2 \quad (13)$$

Where *m,n* give the size of the frame and $I(i,j), \hat{I}(i,j)$ are the pixel values at location *(i,j)* of the original and distorted frame. However, robustness is measured by ***NC*** as denoted by (11).

The first 100 frames of size 256x256 from the video sequence have been tested. Only the luminance components of the different frames are watermarked during the test procedures. The watermark is a binary logo image with size 32x32. We choose ***T***=0.7 and α_1 =12 for embedding into ***LL*** band and α_2 = 6 for embedding into ***HH*** band to balance the tradeoff between the robustness and imperceptibility. Different kinds of attacks have been simulated to test our DWT-PCA based watermarking scheme.

Fig. 2(a) shows the original sampled frame from Foreman video sequence and Fig. 2(b) shows the corresponding watermarked frame with PSNR 39.1084 db. In this case, the watermarked frame appears visually identical to the original. The original watermark and the extracted watermark from ***LL*** band and ***HH*** band are shown in Fig. 3 for the case of no attack. The **NC** value of the watermark in the two bands are 0.95 and 1 respectively, this indicate the exact extraction.

Fig. 2. (a) Original frame (b) Watermarked frame (PSNR = 39.1084 db)

Fig. 3. (a) Watermark (b) Extracted watermark (LL NC=0.95) (HH NC=1)

Table 1, illustrates the PSNR values of 100 watermarked frames of foreman Video and average PSNR for all the watermarked frames is 39.0693 dB.

To measure the robustness, several experiments had been done. The watermarked frame was subjected to different attacks. The chosen attacks were MPEG4, JPEG, scaling, adding noise, filtering, rotation, histogram equalization, contrast adjustment, gamma correction, cropping, frame averaging and the frame dropping.

Table 2, Illustrates the attacked frame by Gamma correction at different values 0.5, 2 and 4 and the extracted watermark from LL and HH with their NC values. The watermark can be easily recognized from HH subband with high correlation values equal NC=0.9823, NC=0.97415 and NC= 0.89502. So the scheme can resist this attack. In the same manner the proposed scheme is robust against histogram equalization with NC=0.97359 (HH) as shown in Table 3, and robust against contrast adjustment with factor = 10 and 30 with NC=0.9627 and NC=0.9123 as shown in Table 4.

Table 5, summarizes the results for the case of geometric transformations (frame resizing and frame rotating) and frame cropping, Since we are using a nonblind watermarking scheme, we are able to rotate/resize the frame back to its original position/size after the rotation/resize attack. The recovered watermark, however, has High NC = 0.98922 (LL) and NC = 1 (HH) in both subbands for the resize attack and has lower NC values for rotation attack: NC=0.1135 (LL) and NC=0.81191 (HH). By cropping 40% of the watermarked frames, the watermark was recovered with NC = 0.075214 (LL) and NC =0.86358 (HH).

Table 1. PSNR values of 100 watermarked frames of the Foreman Video

Frame	***PSNR***									
1 ~ 10	39.12	39.08	39.07	39.09	39.09	39.10	39.05	39.05	39.06	39.06
11~20	39.06	39.07	39.07	39.07	39.07	39.08	39.08	39.06	39.08	39.08
21~30	39.06	39.08	39.07	39.07	39.04	39.07	39.05	39.07	39.06	39.06
31~40	39.05	39.06	39.08	39.09	39.07	39.06	39.07	39.07	39.07	39.07
41~50	39.06	39.07	39.09	39.06	39.06	39.06	39.06	39.08	39.06	39.07
51~60	39.06	39.06	39.06	39.07	39.06	39.06	39.05	39.05	39.05	39.05
61~70	39.04	39.03	39.07	39.09	39.10	39.08	39.07	39.07	39.06	39.09
71~80	39.10	39.08	39.08	39.06	39.08	39.07	39.07	39.08	39.08	39.08
81~90	39.08	39.10	39.08	39.07	39.06	39.06	39.06	39.05	39.07	39.06
91~100	39.06	39.05	39.08	39.05	39.06	39.06	39.07	39.09	39.09	39.10
average	39.0693									

Table2. Gamma correction attack

Attack *(XnView)*	Gamma correction 0.5	Gamma correction 2	Gamma correction 4
Attacked Frame	 (PSNR=14.399 db)	 (PSNR=15.817 db)	 (PSNR=11.304 db)
Extracted Watermark	 (LL) NC=0.216  (HH) NC=0.982	 (LL) NC=0.153  (HH) NC=0.974	 (LL) NC=0.071  (HH) NC=0.895

Table 3. Automatic equalization attack

Attack *(XnView)*	Automatic equalization	
Attacked Frame	 (PSNR = 15.34 db)	
Extracted Watermark	 (LL) NC=0.338	 (HH) NC=0.974

Table 4. Contrast Adjustment attack

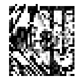
Attack *(XnView)*	Contrast (factor = 10)		Contrast (factor = 30)	
Attacked Frame	 (PSNR= 32.502 db)		 (PSNR = 23.365 db)	
Extracted Watermark	 (LL) NC=0.526	 (HH) NC=0.963	 (LL) NC = 0.191	 (HH) NC = 0.912

Table 5. Resize, Rotation and Cropping attack.

Attack	Resize 256→ 512 → 256 (XnView)		Rotate 5^{o} (matlab)		Cropping (matlab)	
Attacked Frame	 (PSNR = 41.217 db)		 (PSNR = 17.243 db)		 (PSNR = 6.2982 db)	
Extracted Watermark	 (LL) NC =0.989	 (HH) NC= 1.0	 (LL) NC = 0.113	 (HH) NC=0.812	 (LL) NC=0.258	 (HH) NC= 0.864

The Foreman sequence has been filtered by a sharpening filter with parameter values 0.2 and 0.6. The watermark was reconstructed from the HH band with a high NC value which exceeds 0.9 as in Table 6.

To test the robustness of the proposed algorithm against noise attack, we added Gaussian noise to the watermarked video at mean =0 and variance =0.001 and extracted the watermark data from corrupted watermarked frame with high NC=0.86743 (LL) and lower NC = 0.76568 (HH) values but the watermark was still recognizable with human eyes. Table 7, shows the attacked watermark frame by Gaussian noise and recovered watermark.

JPEG is a widely used compression format and the watermark should be resistant to this distortion.

As shown in Table 8, with the decreasing quality of the JPEG from 80% to 40% , the response of the watermark detector also decreased from NC =0.983 (LL) to NC =0.845 (LL). We have found that the proposed watermark can survive even when the quality factor is lower than 40% , although the frame is visibly distorted.

Finally, the system performance for MPEG4 compression attack has been investigated. The Foreman sequence has been compressed at different bit rates of 6 Mbps, 4 Mbps and 1.5 Mbps (25 fps color video) and the watermark has been recovered from the LL and HH. When the compression bit rate has decreased, the watermark detector response has decreased at two subbands and the watermark has survived at LL than HH under MPEG4 compression. This happens because the lossy compression removes the details (i.e. the high Frequency components) of the image. The results of this test are shown in Table 9.

Table 7. Gaussian noise attack.

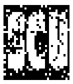
Attack (matlab)	Gaussian noise 0.001	
Attacked Frame	 (PSNR = 29.647 db)	
Extracted Watermark	 (LL) NC=0.867	 (HH) NC=0.766

Table 8. JPEG attack.

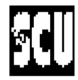
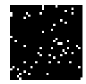
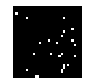
Attack (XnView)	JPEG 80%		JPEG 40%	
Attacked Frame	 (PSNR = 37.715 db)		 (PSNR = 34.3 db)	
Extracted Watermark	 (LL) NC =0.983	 (HH) NC=0.162	 (LL) NC =0.845	 (HH) NC=0.118

Table 9. MPEG attack.

Attack (XnView)	MPEG 6Mbps		MPEG 4Mbps		MPEG 1.5Mbps	
Attacked Frame	 (PSNR = 38.034 db)		 (PSNR = 37.775db)		 (PSNR = 36.823 db)	
Extracted Watermark	 (LL) NC =0.993	 (HH) NC=.99	 (LL) NC =0.986	 (HH) NC=0.976	 (LL) NC=0.856	 (HH) NC= 0.750

The watermark extracted by the proposed algorithm has produced an NC value that is higher than those produced using the conventional methods. As shown by the results, the proposed algorithm is robust against all these attacks.

In comparison with the method proposed by Wang in [13] under many kinds of attacks, the average PSNR value for the proposed method is equal to 39.0693 db and is greater than the PSNR value reported by Wang, which is almost equal to 32 db. In Table 10, the BER values are measured with both Wang's method and the proposed method. Our method outperforms Wang's method.

4. Conclusions

In this paper, a video watermarking scheme which combines PCA with DWT has been implemented. Applying PCA on DWT coefficients increases the robustness of the algorithm. So, the proposed scheme satisfies the requirement of imperceptibility and robustness for a feasible watermarking scheme. Furthermore, the advantage of the proposed scheme is that we can embed the watermark in LL band without the high degradation of the other DWT watermarking schemes. Experimental results show that the proposed scheme is robust against common video processing attacks. While, the method used in watermarking the lowest frequencies (LL) is robust against one group of attacks (adding Gaussian noise, JPEG compression and MPEG4 compression), the method used in watermarking the highest frequencies (HH) is more robust against another group of attacks (gamma correction, histogram equalization, contrast adjustment, resizing, cropping, rotation and sharpening).

In the future research, the most suitable wavelet for a given video sequence will be first detected to enhance the imperceptibility and robustness of our technique.

Table 10. BER at different attack of Wang's and the proposed method

Attack	Wang' method	Proposed method
Salt & pepper noise(0.05)	5%	46%
Guassian noise (0.005)	5%	42%
Sharpening	17%	2%
Rotate 0.3^o	25%	20%
Smoothing	25%	3%

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