Block Based Video Watermarking Scheme Using Wavelet Transform and Principle Component Analysis

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Abstract

In this paper, a comprehensive approach for digital video watermarking is introduced, where a binary watermark image is embedded into the video frames. Each video frame is decomposed into sub-images using 2 level discrete wavelet transform then the Principle Component Analysis (PCA) transformation is applied for each block in the two bands LL and HH. The watermark is embedded into the maximum coefficient of the PCA block of the two bands. The proposed scheme is tested using a number of video sequences. Experimental results show high imperceptibility where there is no noticeable difference between the watermarked video frames and the original frames. The computed PSNR achieves high score which is 44.097 db. The proposed scheme shows high robustness against several attacks such as JPEG coding, Gaussian noise addition, histogram equalization, gamma correction, and contrast adjustment.

Keywords: *Digital video watermarking, Principal Component Analysis, Discrete Wavelet Transform, Binary watermark.*

1. Introduction

Digital watermarking is a new technology used for copyright protection of digital media. Digital watermarking was introduced at the end of the 20^{th} century to provide means of enforcing copyright protection of digital data. Where, ownership information data called watermark is embedded into the digital media (image, audio, and video) without affecting its perceptual quality. In case of any dispute, the watermark data can be detected or extracted from the media and used as a proof of ownership. Imperceptibility and robustness against attacks are the fundamental issues in digital watermarking techniques [1-2]. Recently, digital video watermarking has emerged as a significant field of interest and a very active area of research [3]. Many digital watermarking schemes have been proposed for video. Most these schemes are based on the techniques of image watermarking, but video watermarking has some issues not present in image watermarking. This is because video sequences have some distinguish characteristics such as the temporal and inter-frame characteristics, which require specific approaches for video watermarking [4-7]. Video watermarking schemes can be classified into two main categories based on the domain which used for hiding the watermark bits in the host video. The first one is the spatial domain watermarking where embedding and detection of watermark is performed by directly manipulating the pixel intensity values of the video frame [8-9]. The second category is the transform domain techniques [10-12] in which the watermark is embedded by changing the frequency components. The commonly used transform domain techniques are Discrete Fourier Transform (DFT), the Discrete Cosine Transform (DCT), the Discrete Wavelet Transform (DWT), and Principle Component Analysis transform. The frequency domain watermarking schemes are relatively more robust than the spatial domain watermarking schemes, particularly in lossy compression, noise addition, pixel removal, rescaling, rotation and cropping.

Swanson [13] has proposed a scene-based video watermarking procedure in which the watermark is generated from a temporal wavelet transform of the video scenes. In Inoue [14] the watermark was embedded in the lowest frequency components of each frame in the uncoded video using a controlled quantization process. Chan *et al.* [15] propose a hybrid digital video watermarking scheme based on the scene change analysis and error correction code. He has used the Discrete Wavelet Transform by embedding in frequency coefficients of video frames. Hussein [16] embeds the watermark data to the HL and LH bands of the wavelet domain using motion estimation approach. The motion in these bands does not affect the quality of the frame.

The PCA domain was first introduced to gray-scale image watermarking by Thai D. Hien *et al.* [17]. In [18] the PCA transform is used to embed the watermark in each RGB color channel of each frame of the video, where the same or multi-watermark can be embedded into the three color channels of the image in order to increase the robustness of the watermark. The main advantage of using PCA transform is to choose the suitable significant components into which to embed the watermark. In Yavuz [19], a reference image is generated from the cover image using PCA and the watermark is embedded according to the difference between the image and its reference. Kang [20] has proposed a new algorithm where advantage of the strength of both multi-band wavelet transform (MWT) and PCA is used. The watermark energy is distributed to wavelet coefficients of every detail sub-band efficiently to achieve better robustness and perceptual transparency. A hybrid scheme combining both DWT and PCA has been proposed by Mostafa *et al.* in [21]. The watermark was embedded into the first principle components and the mid-band coefficient of the PCA wavelet frame. In Sinha [22] a binary watermark is embedded into each of the video frames by the decomposition of the frames into DWT sub bands followed by block based PCA on the sub-blocks of the low frequency sub-band. The watermark is embedded into the principal components of the sub-blocks.

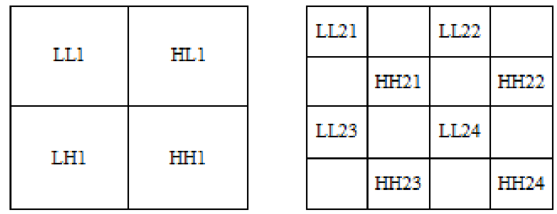
In this paper, we propose an imperceptible and robust video watermarking algorithm based on DWT and PCA. DWT is more computationally efficient than other transform methods because of its excellent localization properties which provide the compatibility with the Human Visual System (HVS). This paper is organized as follows: section 2 presents the proposed watermarking scheme. Section 3 introduces the experimental results and the conclusion is given in section 4.

2. Proposed Watermarking Scheme

The proposed hybrid watermarking scheme is based on the combination of DWT and PCA.

2.1 Discrete Wavelet Transform

The DWT is used in a wide variety of signal processing applications [23]. 2-D discrete wavelet transform (DWT) decomposes an image or a video frame into sub-images, 3 details and 1 approximation. The approximation sub image is lower resolution approximation image (LL) however the details sub images are horizontal (HL), vertical (LH) and diagonal (HH) detail components. The process can then be repeated to compute multiple "scale" wavelet decomposition. The main advantage of the wavelet transform is its compatibility with a model aspect of the HVS as compared to the FFT or DCT. This allows us to use higher energy watermarks in regions that the HVS is known to be less sensitive, such as the high resolution detail bands. Embedding watermarks in these regions allow us to increase the robustness of our watermark without any visible impact on the image quality. In the proposed algorithm, sub-bands LL and HH from resolution level 2 of the wavelet transform of the frame are chosen for the embedding process. The following figure shows the selected DWT bands which used in our proposed algorithm.



(a) (b)

Fig.1 DWT sub-bands in (a) level 1, (b) level 2.

Embedding the watermark in low frequencies obtained by wavelet decomposition increases the robustness against attacks like filtering, lossy compression and geometric distortions while making the scheme more sensitive to contrast adjustment, gamma correction, and histogram equalization. Embedding the watermark in high frequency sub-bands makes the watermark more imperceptible while embedding in low frequencies makes it more robust against a variety of attacks.

2.2 Principal Component Analysis

Principal component analysis (PCA) is a mathematical procedure that uses an orthogonal transformation to convert a set of observations of correlated variables into a set of values of uncorrelated variables called principal components. PCA plots the data into a new coordinate system where the data with maximum covariance are plotted together and is known as the first principal component. Similarly, there are the second and third principal components and so on. The first principal component has the maximum energy concentration [24].

The diagram in Fig. 2 shows the embedding and extraction process of the watermark. In the proposed scheme, a binary image is embedded in the LL DWT sub-bands of level 2 of each decomposed frame in the video. Also, the same binary image is embedded in the HH DWT sub-band of level 2 of each decomposed frame. Embedding the watermark in both LL and HH makes the scheme robust to a variety of low and high frequency characteristic attacks. The extraction procedure of the watermark is similar to the embedding one.

2.3 Embedding Procedure

Step 1: Divide video into frames (2Nx2N), then convert RGB frames to YUV frames.
Step 2: Choose the luminance component Y of each frame and apply DWT on it. This result in four multi-resolution sub-bands (NxN): LL1, HL1, LH1, and HH1. For each band apply DWT again to get 16 sub-bands (N/2xN/2). From these sub-bands, select (LL21, LL22, LL23, LL24, HH21, HH22, HH23, and HH24).

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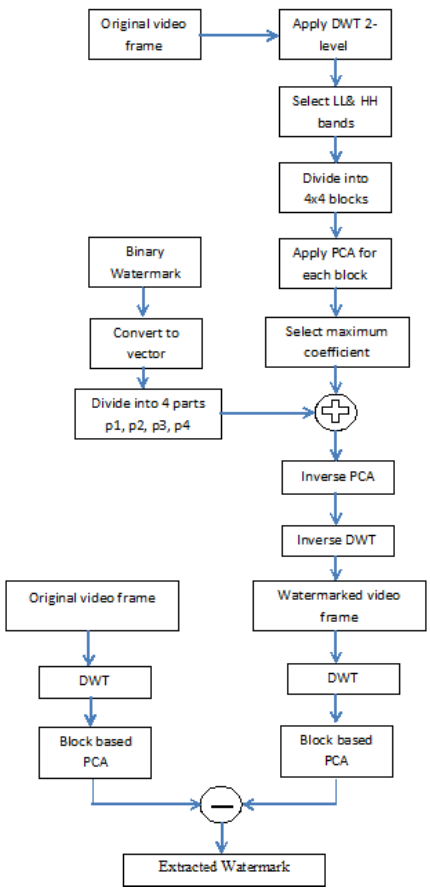


Fig. 2 Watermark embedding and extraction algorithm.

Step 3: Divide each selected sub-bands I_s with N/2xN/2 dimension into nxn non-overlapping blocks where the number of blocks is k = (N/2xN/2)/(nxn). Then, apply PCA to each block as described.

1. For each block B_{si} (nxn) compute the mean of the block m_i , where B_{si} represent block number i in the selected sub-band I_s. Then get the block zero mean A_i as follows:

$$A_i = E(B_{si} - m_i) \tag{1}$$

2. For each block, calculate the covariance matrix C_i of the zero mean block A_i as:

$$C_i = A_i \times A_i^T \tag{2}$$

Where T denotes the matrix transpose operation.

3. Transform each block into PCA components by calculating the eigenvectors corresponding to eigenvalues of the covariance matrix:

$$C_i \phi = \lambda_i \phi \tag{3}$$

Where ϕ is the matrix of eigenvectors and λ is the matrix of eigenvalues.

4. Compute the PCA transformation of each block to get a block of uncorrelated coefficients by:

$$Y_i = \phi^T A_i \tag{4}$$

Where Y_i is the principle component of the i^{th} block.

Step 4: Convert the RGB 32x32 watermark image to binary image. Convert the binary image into a vector W = $\{w_1, w_2, \ldots\ldots, w_{32x32}\}$ of zeros and ones.

Step 5: Divide the vector W into four parts p1, p2, p3, and p4. Then p1 is embedded into each of the corresponding LL21 and HH21, p2 is embedded into each LL22 and HH22, p3 is embedded into each LL23 and HH23, and p4 is embedded into each LL24 and HH24. The watermark bits are embedded with strength α into the maximum coefficient M_i of each PC block Y_i. The embedding equation is:

$$M_i' = M_i \pm \alpha W \tag{5}$$

Where, α is the watermark embedding strength. The value of α in this algorithm is 9 for all selected wavelet bands. If the watermark bit is 1 then adding α to the maximum coefficient in the Y block but if it is zero, then α is subtracted from the same coefficient.

Step 6: Apply inverse PCA on the modified PC block Y_i' to obtain the modified wavelet block by using:

$$A_i = \phi Y_i' \tag{6}$$

Step 7: Apply the inverse DWT to obtain the watermarked luminance component of the frame. Finally reconstruct the RGB watermarked frame and obtain the watermarked video.

2.4 Watermark Extraction

The steps used for watermark extraction is the same as the steps in the embedding but in the reverse direction. The original video sequence is required for the extraction procedure so the algorithm is non-blind.

Step 1: Convert the watermarked video into frames. Each RGB frame is converted to YUV representation.

Step 2: For each Y component, apply DWT to decompose Y into 16 multi-resolution sub-bands. Choose LL and HH sub-bands and divide them into nxn non-overlapping blocks.

Step 3: For each block, apply PCA transformation as described in the embedding procedure.

Step 4: Extract the watermark by applying the following equation:

$$W' = \frac{M_i' - M_i}{\alpha} \tag{7}$$

Step 5: The extracted watermark is compared with the original watermark by computing the similarity measure between them as follows:

$$NC = \frac{\sum_i \sum_j W(i,j).W'(i,j)}{\sum_i \sum_j W(i,j)^2} \quad (8)$$

Where, NC is the normalized correlation.

NC value is 1 when the watermark and the extracted watermark are identical and zero if the two are different from each other.

3. Experimental Results

A number of video sequences are used for testing the proposed scheme for example the foreman video sequence [12]. For evaluating the performance of any watermarking system, Peak Signal to Noise Ratio (PSNR) is used as a common measure of the visual quality of the watermarking system. To calculate the PSNR, first the Mean Square Error (MSE) between the original and watermarked frame is computed as follows:

$$MSE = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}[I(i,j) - I'(i,j)]^2 \quad (9)$$

Where M, N are the size of the frame, and I(i, j), I'(i, j) are the pixel values at location (i, j) of the original and watermarked frames. Then, PSNR is defined as:

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

The luminance component of the first 100 frames of the foreman video sequence are watermarked. The frame size is 256x256. The watermark is a binary image with size 32x32.

The original sampled frame and its corresponding watermarked frame are shown in Fig. 3. The measured PSNR is 44.0975 db and the watermarked frame appears visually identical to the original. The value of PSNR is constant over all the tested frames which means that the error between the original and watermarked frames is very low so high visual quality is obtained. Fig. 4 shows the original watermark and the extracted watermark from LL band and HH band where no attacks were applied. The measured value of NC is 1 for both LL band and HH band, i.e. the extracted watermark is identical to the original and exact extraction is obtained.

(a) (b)

Fig. 3 (a) Original frame, (b) Watermarked frame (PSNR = 44.0975 db).

(a) (b) (c) (d)

Fig. 4 (a) Original watermark, (b) Binary watermark, (c) Extracted LL watermark (NC=1), (d) Extracted HH watermark (NC=1).

To measure the robustness of our proposed scheme, the watermarked frame was subjected to a variety of attacks such as gamma correction, contrast adjustment, histogram equalization, and jpeg compression.

Fig. 5, illustrates the attacked frame by Gamma correction at different values 0.5, 2, and 4. The extracted watermarks from LL and HH are also illustrated. It is shown that, by the proposed algorithm the watermark can be easily extracted and recognized from both LL band and HH band.

Robustness against histogram equalization and Gaussian noise attacks are shown in Fig. 6. When adding Gaussian noise with zero mean and variance = 0.001 to the watermarked frame, the extracted watermark for both LL and HH bands is shown in Fig. 6. These watermarks can be easy recognized by human eyes. While Fig. 7 illustrates the performance of the proposed scheme in case of contrast adjustment attacks at factors 10 and 30.

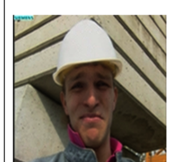
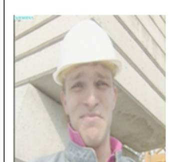
Attack	Gamma correction 0.5	Gamma correction 2	Gamma correction 4
Attacked Frame	 PSNR = 15.426 db	 PSNR = 16.481 db	 PSNR = 12.311 db
Extracted Watermark	 LL NC = 0.935 HH NC =0.980	 LL NC = 0.584 HH NC =0.820	 LL NC = 0.357 HH NC =0.507

Fig. 5 Gamma correction attack.

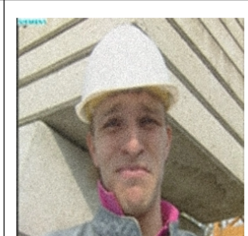
Attack	Automatic Equalization	Gaussian noise 0.001
Attacked Frame	 PSNR = 18.608 db	 PSNR = 29.807 db
Extracted Watermark	 LL NC = 0.990 HH NC = 0.996	 LL NC = 0.880 HH NC = 0.859

Fig. 6 Automatic equalization and adding Gaussian noise attack.

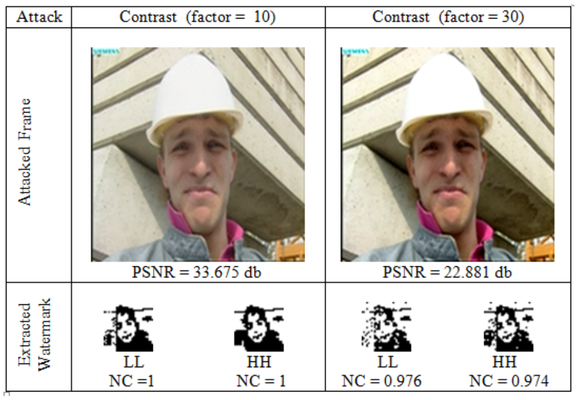


Fig. 7 Contrast adjustment attack.

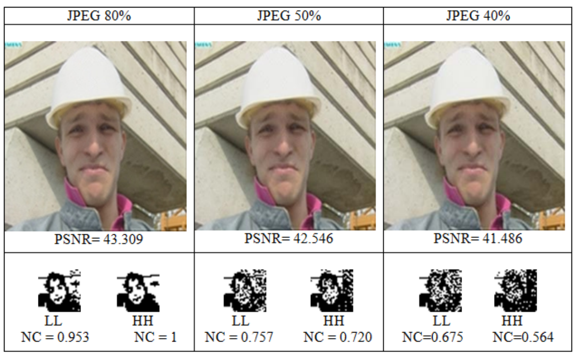


Fig. 8 JPEG attacks.

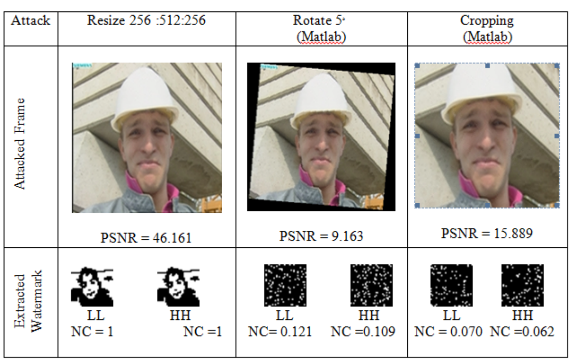


Fig. 9 Some geometric attacks.

The watermark must be robust against JPEG compression attack since it is the common compression technique used in image compression. Fig. 8 shows the performance of the proposed scheme when subjected to such attack. As shown in Fig. 8, the value of NC is decreasing as the quality factor of JPEG decrease. At QF = 80%, the NC for LL and HH are 0.953 and 1 respectively. Also, At QF = 40% the NC for LL and HH are 0.675 and 0.564 respectively. In case of jpeg compression, the watermark can survive under quality factor 40%.

In case of geometric attacks, we test the scheme against frame resizing, frame rotation, and frame cropping. The frame is resized from 256 x256 to 512x512 then back to its original size. The results show that the watermark is totally recovered as shown in Fig. 9. In same way rotate/resize and crop/resize of the frame gives the results shown in Fig. 9. From the results, the scheme is not robust against frame rotation and frame cropping which will be investigated in the future.

By comparing the proposed method with previous methods such as Mostafa [21] and Wang [25], we find that the proposed scheme registered a constant PSNR equal to 44.0975 db which is greater than the PSNR reported by both Mostafa and Wang as shown in table 1.

Table 1: PSNR Comparison

Algorithm	***PSNR (db)***
Mostafa [21]	39.0693
Wang [25]	32
Proposed	44.0975

Bit Error Rate (BER) is used as another performance metric to compare the performance of the proposed scheme. BER is the ratio of the number of bits recovered in error to the total number of received bits [26]. Table 2 contains some values of BER measured by Mostafa's method, Wand's method, and our proposed method.

Table 2: BER Comparison

Attack	***Mostafa [21]***	***Wang [25]***	***Proposed Method***
Salt & Pepper Noise (0.05)	46%	5%	37.7%
Guassian noise (0.005)	42%	5%	40.6%
Sharpening	2%	17%	1.5%
Rotate 0.3°	20%	25%	49%
Smoothing	3%	25%	22%

4. Conclusions

A video watermarking scheme has been proposed in this paper. The algorithm is implemented using 2-level DWT in conjunction with PCA transform. This scheme is imperceptible and robust against several attacks. A binary watermark has been embedded into LL and HH bands of level 2 of DWT block based PCA. The proposed scheme has a good performance compared with previous schemes. As a future work, embedding the watermark into higher levels of the wavelet transform will be investigated. Collecting other transformations together to enhancement the performance of the proposed scheme against geometric attacks will be studded.

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