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Robust Digital Watermarking for High-Definition Video using Steerable Pyramid Transform and Fast Fourier transformation

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Abstract. In this paper, we propose a robust blind watermarking algorithm for high-definition video contents. For the security of watermark information, a matrix of random numbers is generated using a secret key. We perform inverse steerable pyramid transformation (SPT) to the matrix to produce a transformed matrix. The 2-dimensional fast Fourier transformation (2D FFT) is performed to the luminant component of each frame. The watermark is embedded into the low frequencies of 2D FFT coefficients using the transformed matrix. In the procedure of extraction, forward SPT is applied to the transformed matrix and the 2D FFT coefficients to produce oriented sub-bands, respectively. The watermark of each frame is extracted by correlation between the two oriented sub-bands. The experimental results show that the proposed watermarking algorithm is imperceptible and moreover is robust against variety of attacks.

Keywords: Video Watermarking, Steerable Pyramid Transform, Fast Fourier Transformation

1 Introduction

In recent years, the development of the Internet and multimedia transmission technology has led to the explosive growth of the digital video distribution services. The distribution of digital video contents is getting easier as increasing the network speed and the computing capacity. However, the increase of video distribution has led to an issue of illegal distribution. Copyright infringement has become a serious problem [1]-[4].

In this paper, we propose a robust blind watermarking algorithm for high-definition videos. For the security of watermark information, a secret key is used to generate a matrix of random numbers for later embedding. Two transformation methods are used to increase robustness against common image processing distortions such as compression and noise. One is 2-dimensional fast Fourier transformation (2D FFT), which is used to transform the video frames to the frequency domain. The other one is steerable pyramid transformation (SPT) [5], [6]. Inverse SPT is performed to the matrix before embedding it into the 2D FFT coefficients, whereas in the extraction procedure, forward SPT is performed to the 2D FFT coefficients and the transformed matrix to produce oriented sub-bands, respectively. The watermark of each frame is

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extracted based on the correlation between the two oriented sub-bands. The watermarks contains some errors by the distortion of the video. To decrease the bit error rate (BER) between the extracted watermark and the original watermark, an ensemble position-based error correcting (EPbEC) algorithm is proposed to estimate the errors and automatically correct them. The experimental results demonstrate resiliency and imperceptibility of the proposed watermarking algorithm.

2 Steerable Pyramid Transformation

The SPT is a discrete extension of the curvelet transform which captures curves instead of points. It is a method of linear multi-resolution image transformation like contourlet transform. The construction of the contourlet transform is based on the directional filter banks. The SPT divides an image into a set of sub-bands which is localized at different orientations and scales [5]. It is computed using decimation and convolution operations. A high-pass and a low-pass filters are applied to the target image to produce high-pass and low-pass sub-bands. The low-pass sub-band is further divided into a low-pass and oriented sub-bands. The inverse transformation reconstructs the original image with the high-pass, low-pass, and the oriented sub-bands.

3 Proposed Watermarking Scheme

Each frame of a video is converted to the NTSC color space to obtain grayscale signal, the luminance component. The luminance component is then transformed to the frequency domain using 2D FFT. A secret key is used to generate a $n/2 \times n/2$ matrix of random numbers. It is expanded to two $n \times n$ matrices for high-pass and oriented sub-bands. Each element of the $n/2 \times n/2$ matrix is expanded to 2×2 elements of the $n \times n$ matrix. The inverse SPT transforms the three matrices using one orientation and produces a $n \times n$ transformed matrix TM. Fig. 1 shows the embedding process.

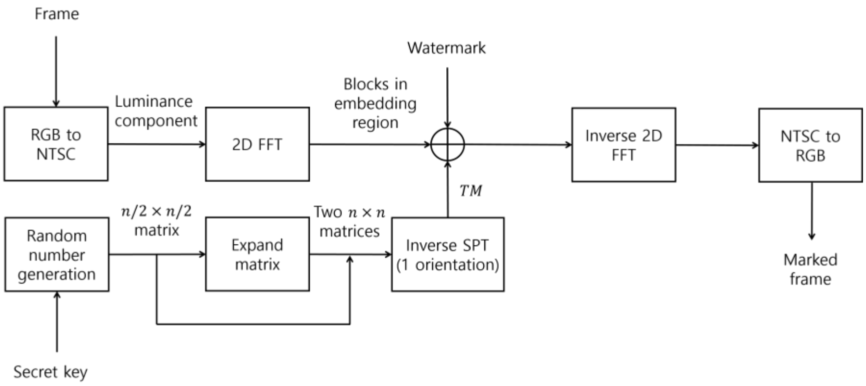


Fig. 1. Watermark embedding process

The transformed matrix is embedded into the low frequencies of 2D FFT coefficients based on the watermark w as (1). The embedding region is divided into N blocks. The size of each block B is $n \times n$.

$$B' = \begin{cases} B_{i,j} + \alpha \times TM, & if\ w_{i,j} = +1 \\ B_{i,j} - \alpha \times TM, & otherwise \end{cases} \quad (1)$$

where α denotes the embedding strength, B' denotes the marked coefficient block.

In the procedure of watermark extraction, the TM is generated in the same way as in the embedding procedure. Each block of the embedding region of the 2D FFT coefficients and the TM are transformed by forward SPT with one orientation. Fig. 2 shows the extraction process. The cross-correlation coefficients CC between the two oriented sub-bands of 2D FFT coefficient block and the TM are computed. The watermark of each frame is extracted based on the maximum and the minimum correlation peaks as follows:

$$w_{i,j}' = \begin{cases} +1, & \left|\max\{CC_{i,j}\}\right| > \left|\min\{CC_{i,j}\}\right| \\ -1, & \text{otherwise} \end{cases} \quad (2)$$

where $w_{i,j}'$ is the extracted watermark of a frame.

The EPbEC algorithm uses binary positions of data to correct errors. It is inspired by error correcting output codes (ECOC), which is a powerful framework to deal with multi-label categorization problems [7], [8]. The EPbEC combines the watermarks of several frames and corrects the errors to produce final watermark.

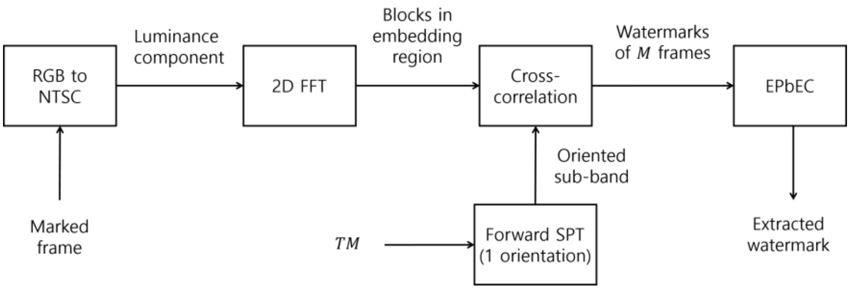
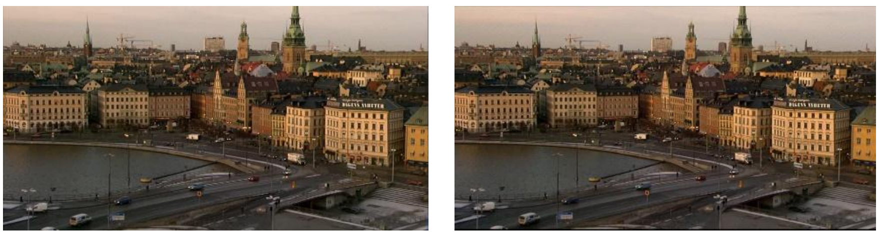


Fig. 2. Watermark extracting process

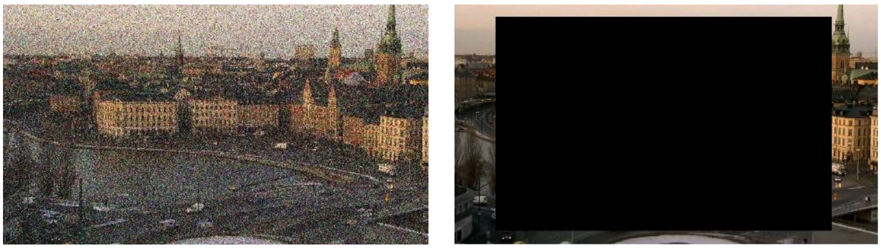
4 Performance Evaluations

We evaluated the proposed watermarking scheme using 720×1280 high-definition videos 'stockholm' (sample 1), 'shields' (sample 2) and 'mobcal' (sample 3). The framerate of the three samples are 59, 50 and 50 fps. Their bitrates are 15698, 15795 and 17529 kbps. The length of the watermark, N was 64 and the size of the transformed matrix, n was 32. We performed experiments on a computer with an i7 3.6 GHz CPU, a 16 GB RAM and Windows 8 64 bit OS. The average watermark embedding and extraction time were 0.12 and 0.16s. The quality of marked frame was measured with peak signal-to-noise ratio (PSNR). The embedding strength α was set to be 20. Fig. 3 (a) shows the original frame and Fig. 3 (b) shows the marked frame of sample 1. The PSNR between the two frames is 45.73. They show the proposed watermarking algorithm is imperceptible. Fig. 4 (a) shows attacked frame by adding Gaussian noises of mean 0 and variance 0.1. Fig. 4 (b) shows the cropped frame with only 30% of frame is remained. The BERs are 1.56% and 0%, respectively.



(a) Original frame (b) Marked frame

Fig. 3. Original and marked frame



(a) Attacked frame by adding Gaussian noises (b) Cropped frame

Fig. 4. Attacked frames

Table 1 shows the BERs according to variety of attacks. The mean of the Gaussian noise was set to be 0 and the variance was 0.1. The noise density of salt & pepper noise was 0.2. After adding the two types of noises, the BERs of the three samples were less than 10%, which means the proposed algorithm is robust against noise attack. If the frame size of videos for watermark extraction is not equal to 720×1280, the video will be resized to 720×1280 before extraction. After scaling half size of the frame, the BERs of three samples maintained between 10 and 15%. Framerate and bitrate were used to manipulate the compression rate. The BER of sample 2 was greater than 10%, when it was compressed with bitrate of 3000 kbps, whereas those of the other two samples were less than 2%. The cropping attack removed the areas located at the center of the frame. Even if we removed 90% of the frame area, the BERs were less than 10%, showing good performance.

Table 1. BERs according to attacks

Attacks	Sample 1	Sample 2	Sample 3
Gaussian noise (0.1)	1.56	6.25	3.13
Salt & pepper noise (0.2)	1.56	7.81	3.13
Scaling (0.5)	10.94	14.06	12.5
Compression (15, 3000)	0	12.5	1.56
Cropping (90%)	6.25	9.38	9.38

5 Conclusion

In this paper, we proposed a digital video watermarking scheme using 2D FFT and SPT. The proposed method extracts luminance component from each frame and transforms it to the frequency domain using 2D FFT. A matrix of random numbers is transformed by inverse SPT and is embedded into the low frequencies of 2D FFT coefficients based on watermark information. In the process of watermark extraction, forward SPT is applied to the transformed matrix and the 2D FFT coefficients to produce oriented sub-bands, respectively. The watermark of each frame is extracted based on the cross-correlation coefficients of the two oriented sub-bands. The EPbEC algorithm is used to estimate the errors of watermarks of several frames and automatically correct them. The experimental results show the PSNR is greater than

40. The BER of watermark is less than 10% after adding strong noises. Even if 90% of the frame area is removed, the BER is still less than 10%.

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