Video Watermarking Scheme with High Payload and Robustness against Geometric Distortion

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Abstract. Besides copyright protection, digital video watermarking is also applied in non-security applications like second screen annotation, where high robustness against geometric distortions and high watermark payload are required. Robustness against geometric distortions, however, is still one of the major challenging issues in video watermarking, in particular for the schemes in compressed domain. In this paper, we propose a video watermarking scheme that can resist geometric attacks. The watermark embedding is performed in Fourier domain using patchwork method which is able to handle high embedding payload. Fast transform between block DCT and DFT enables the proposed scheme to be applicable directly in the compressed domain, significantly reducing the computation cost. Perceptual masking is applied in both DFT and DCT domains to ensure high visual quality. Experimental results demonstrate that the proposed scheme achieves satisfactory robustness against all kinds of attacks, including geometric distortions and frame dropping and swapping.

Keywords: video watermarking, annotation application, geometric distortion, temporal attack

1 Introduction

Digital video watermarking is commonly used as an effective technique for copyright protection of video content [1]. With the increasing employment in practice, non-security applications based on watermarking technology also attract great interest. For instance, in the recent emerging second screen application, digital watermark can serve as an invisible annotation of the video content, which can be captured by a smartphone to retrieve related information of the ongoing scenes.

Depending on particular applications, video watermarking has to comply with corresponding requirements, such as transparency, payload, robustness and security. For copyright protection, security against removal attacks and robustness to common video processing are of high concern. In contrast, in non-security applications like second screen, the most significant requirements are high robustness against affine transforms and high payload while security becomes subordinate. This is because geometric distortions are inevitable during the capture of video content using a smartphone camera and a high payload of watermark information is needed to provide reasonable annotations.

In the past decades, many video watermarking algorithms have been proposed targeted for copyright protection applications [1-3]. While many video watermarking algorithms can survive common video processing, they lacks robustness against geometric and temporal attacks, such as cropping, scaling, rotation, frame dropping, swapping, insertion, averaging and so forth [2-3]. For high efficiency, conventional video watermarking schemes tend to embed information in the compressed domain so as to avoid the complete decoding and encoding. Since almost all the video data are compressed as block DCT coefficients and motion vectors, such as MPEG-2, MPEG-4 and H.264, any geometric attack will regroup the blocks and entirely change the bitstream structure, which leads to de-synchronization of the embedded watermark. In addition, temporal attacks can also compromise the watermark detection by disabling the watermark synchronization across frames. Therefore, how to tackle the geometric attacks and temporal attacks in compressed video domain is still a challenging topic.

The existing watermarking algorithms, which aim at achieving good robustness against geometric attacks, can be roughly categorized into three classes: template based scheme, feature based scheme and invariant domain based scheme [4].

Template based schemes embed a structured template in addition to the informative watermark to register the undergone geometric distortion and rectify the host data before performing watermark detection. Template based methods are reported to have good robustness against geometric attacks [4]. Its main drawback lies in the vulnerability to removal attacks. Because all copies share the same template, it can be discerned by collusion attack using multiple copies and be removed afterwards.

Feature based schemes use local or global features, which are invariant to affine transformation, to synchronize the watermark. In [5-6] Harris corners are used as local feature points in the watermarking. While the local feature points are fairly robust against scaling and rotation, they are vulnerable to cropping and require high computational complexity. In addition, some of local features suffer from most signal processing attacks like low-pass filtering. In contrast, in [7] the global feature of the histogram of a frame sequence is used for watermarking. Since the global feature is independent of the pixel position in a frame, it is robust to geometric attacks and slight cropping. However, histogram based schemes provide rather low watermark payload, which makes them of limited use in practical applications. The scheme in [7] embeds the watermark by modifying selected consecutive bins of the histogram of the average DC energy of frames. Averagely it can embed only 1 bit per 400 frames, which makes it not suitable for annotation applications like second screen. In addition, such histogram based scheme is not applicable in all types of videos. According to our experiments, when the video contains few motions between frames, the average DC energy of each frame will converge on a few bins in the histogram while the number of samples on other bins is close to zero. Thus, the embedding will fail due to the lack of sufficient bins to modify.

Invariant domain based schemes embed the watermark in a geometric transform invariant domain. The most popularly used invariant domain is Fourier-Mellin transform [8-9]. However, since log-polar mapping is involved, it is very difficult to implement watermarking in Fourier-Mellin domain without causing severe quality loss [8]. In [10] and [11], the full DCT is used as a scaling invariant domain for watermarking, because the scaling of one frame has roughly equivalent effect to the truncation of high-frequency band in its full DCT domain. Thus, the watermark embedded in the low-frequency area will not be impacted by downscaling. Nevertheless, these schemes are not robust against other geometric distortions, like cropping and rotation. Therefore in [11] the authors have to propose another solution for cropping attack. Furthermore, embedding in low-frequency band may lead to more visual quality loss.

As previously mentioned temporal attacks like frame dropping and swapping may also destroy the watermark synchronization in video data [12]. The histogram based scheme in [7] is claimed to be robust against frame dropping, but according to our experiments, if the varying frames (scene changing) in a video clip are dropped, the distribution of the histogram of the average DC energy will be greatly changed so that the watermark cannot be detected. In [11], an additional strategy was proposed to resist frame dropping attack, which divides the video sequence into scenes and accordingly partitions the watermark into groups of bit strings. For each scene, the corresponding group of bit is redundantly embedded into all frames within the scene. However, this method can only ensure the watermark integrity in case of frame dropping inside a scene. If the whole scene is dropped or the video is truncated, the extracted watermark will become incomplete.

In this paper, we proposed a video watermarking scheme targeted for annotation applications like second screen. As security is not much concerned, the template based method is adopted to achieve the robustness against geometric distortions because of its good performance. Besides the informative watermark message, a structured template is embedded in the Fourier domain to register the undergone geometric transformations. The watermark embedding is done using an effective patchwork method in the same Fourier domain, which is able to handle a high watermark payload. As well known, high payload will cause more quality degradation. Hence, a perceptual masking is applied to reshape the embedded energy to ensure good visual quality. In addition, in order to tackle the problem of temporal attacks, each watermark segment in separate frames is indexed with a unique ID to be self-synchronizable. Furthermore, to lower the computation cost and achieve high efficiency, the embedding process is done directly in the compressed domain by applying a fast transform between block DCT and 2D-DFT. To demonstrate the performance of the proposed scheme, the experimental results are compared with other schemes which use feature based and invariant domain based methods resisting geometric distortions.

The rest of the paper is organized as follows. In section 2, we introduce the fast transform between block DCT and 2D-DFT. The proposed video watermark scheme is presented in Section 3. Experimental results are given in Section 4 and we conclude the paper in Section 5.

2 Fast Transform between Block 2D-DCT and 2D-DFT

Nearly all video data are stored and transmitted in compressed format and most commonly used video compression methods, such as MPEG-2, MPEG-4 and H.264, apply block DCT for spatial redundancy reduction. Thus, if another transform domain, e.g. DFT and DWT, is applied in the watermark embedding, the video data has to be first decoded to its uncompressed format and then transformed to the watermarking domain. When the embedding is finished, the watermarked data must be again inversely transformed to the spatial domain and then transformed into block DCT. The whole process involves four mathematical transforms and is usually computationally complex and time consuming.

To avoid the complete decoding and encoding, a direct embedding using block DCT is highly desired. As both DCT and DFT are linear and invertible transforms, a linear relationship exists between block DCT coefficients and DFT coefficients of the full frame [13]. Therefore, we can directly attain a frame's DFT coefficient without first decoding it into its uncompressed format.

Given a frame Y of size LN×LM, where L is the DCT block size, the relationship between its block 2D-DCT and 2D-DFT can be denoted by

$$\mathrm{F} = \mathrm{P}\hat{\mathrm{C}}\mathrm{Q}^{\mathrm{T}},\ \hat{\mathrm{C}} = \mathrm{P}^{-1}\mathrm{F}(\mathrm{Q}^{-1})^{\mathrm{T}} \tag{1}$$

where F is the 2D-DFT of Y and $\hat{\mathrm{C}}$ is the stacked block DCT of Y. $\mathrm{P} = \mathrm{A_c}\hat{\mathrm{B}}_{\mathrm{LN}}^{-1}$ and $\mathrm{Q} = \mathrm{A_r}\hat{\mathrm{B}}_{\mathrm{LM}}^{-1}$, where $\mathrm{A_c}$ and $\mathrm{A_r}$ are the DFT transform matrices for column and row, $\hat{\mathrm{B}}_{\mathrm{LN}}$ and $\hat{\mathrm{B}}_{\mathrm{LM}}$ are the stacked block DCT transform matrices.

Note that the transform matrix P and Q are determined by M, N and L, i.e. the frame size and block size, being independent of the frame content. Since the frame size in a video is constant, these transform matrices can be calculated in advance. This will significantly reduce the computation cost at embedding.

3 Proposed Video Watermarking Scheme

As shown in Figure 1, the proposed video watermarking scheme consists of the following four parts: frame grouping, watermark encoding, template and watermark embedding, and watermark reshaping.

3.1 Frame grouping

In contrast to image, video data normally contains a large number of frames. Effective utilization of this feature could help improve the watermarking performance in terms of payload, robustness and video quality.

In our scheme we apply a frame grouping strategy to separate the template and watermark embedding into different frames. The structured template can not only rectify the geometric distortion but also be used as a temporal synchronization signal.

Assuming a video clip that contains K frames, we divide all the frames into G groups, resulting in *n* frames in each group. Then the first *t* frames will be used for template embedding, denoted as template frame, and the rest *n-t* frames for watermark embedding, denoted as watermark frame.

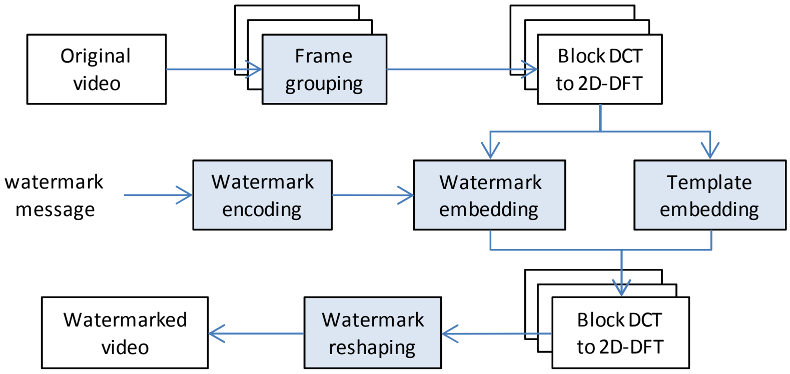

Fig. 1. Diagram of proposed watermarking scheme

3.2 Watermark encoding

In the proposed scheme, we desire to embed a watermark payload which can meet the common requirement for reasonable annotation while preserving the video perceptual quality. In order to effectively utilize the watermark capacity of all frames, when necessary, the watermark message is segmented and spreads over the *n-t* frames in each group. However, as mentioned in Section 1, watermarks embedded across frames will suffer from temporal attacks, which will disable the synchronization between the watermark segments in different frames. Hence, in order to be resynchronizable after distortions like frame missing, the watermark message is encoded as follows.

To ensure the integrity of extracted watermark, the original watermark message is first encoded using cyclic redundancy check (CRC) code. The encoded message m_i, $i=1,2,\ldots,N_w$, is then divided into *n-t* segments. For each segment, an indexing ID is attached to the watermark bits before embedding. Thus every single watermark segment becomes self-synchronizable. The bit length of the indexing ID is determined by the number of watermark segment. Furthermore, the resulting watermark bits in each segment are further encoded using BCH code, generating the final encoded watermark, w_k, $k=1,2,\ldots,N_c$.

3.3 Watermark and template embedding

In every frame group, each watermark frame is used to embed one watermark segment w_k. The encoded watermark segment is embedded in the DFT domain of the corresponding frame using the patchwork algorithm in [14]. The DFT magnitude coefficients in the middle-frequency band are used for embedding in order to achieve better robustness against low-pass filtering attacks and lossy compression. In this work, the used frequency band ranges from 0.15 to 0.35 in the normalized frequency. The embedding payload in each frame is limited to N_c. The patchwork algorithm in [14] yields good robustness against a large number of attacks and the ability to resist cropping attack. Moreover, the patchwork technique enables blind detection which means that no original video data has to be supplied during the detection process.

In each template frame of every frame group, a structured template is embedded in the same DFT domain using the same approach as in [14], which can register the undergone geometric transformations. The template contains 14 points uniformly distributed along two lines in the first and second quadrants of the magnitude spectrum. The angles of the lines and the radii of points can be randomly chosen, controlled by a secret key. Nevertheless, they should avoid extremely low or high frequency band, because the energy embedded in high frequency can be easily reduced by lossy compression and the energy embedded in low frequency will cause noticeable artifacts. In this work, the template points reside in a normalized mid-frequency band of [0.25, 0.35]. In order to ensure a good fidelity on average, the same embedding strength is used for the template embedding in all frames.

In case that the watermarked video is geometrically distorted, the detected transformation parameters out of the template shall be used to rectify the video before carrying out watermark detection. Moreover, the embedded template information also offers a means of identifying frame groups or synchronizing video temporally in case that the video is truncated or some frames are dropped.

3.4 Watermark reshaping

Although the embedding strength is adaptively controlled in the DFT domain based on the spectrum properties, like magnitude of the coefficients and their corresponding frequency bands, these properties doesn't cover all the characteristics of human visual system. For example, no local perceptual analysis of pixels can be done in Fourier domain, because Fourier transform only provide a global frequency analysis.

Since we obtain the DFT coefficients directly from block DCT coefficients out of compressed video stream, there is no access to the pixel values. After inversely transformed to block DCT, the embedded energy is distributed over the whole frame which will degrade the visual quality.

To tackle the perceptual error and conform the embedding to the visual content more precisely, we utilize Watson perceptual model in DCT domain [15] to reshape the embedded energy,

$$\Delta C(i,j,k)_m = \rho \cdot m'_{ijk} \cdot \Delta C(i,j,k) \tag{2}$$

where $\Delta C(i,j,k)$ is the original watermark energy for the DCT coefficient $C(i,j,k)$ in the *k*th block. m'_{ijk} is the normalized contrast masking threshold [15], ρ is a scaling factor to ensure the total embedding energy is conserved after reshaping.

$$\rho = \sqrt{\sum \Delta C(i,j,k)^2 / \sum \left(m'_{ijk} \cdot \Delta C(i,j,k)\right)^2} \tag{3}$$

3.5 Watermark detection

Since the watermarked video may have suffered from both geometric and temporal attacks, the number of frames may have changed and the position of frames may also be different from the original video. Hence, in the detection process, we first scan the frames to detect the template information. If a valid template is found, the detected scaling and rotation parameters are used to rectify the whole video sequence. Since there might exist many frames with template information detected, we choose the one with the minimal MSE_T, which is the template detector response, indicating the accuracy of template detection, as global optimum.

Following geometric rectification, the watermark detection is performed. The detected template frames are considered as synchronization points of frame groups and the following frames are examined as a group for watermark detection. When the watermark message is embedded across frames, the detected watermark segments will be decoded and united together by their attached indexing ID. Since some frames may be dropped or swapped and the watermark embedded in some frame may be impaired by possible attacks, it may be necessary to combine detected watermark segments from more than one frame group to obtain a complete watermark message. Then the integrity of the detected message will be double-checked by the CRC code.

4 Experimental Results

In our experiments the size of frame group is set to 22, in which 2 frames are used for template embedding and 20 frames for watermark embedding. The indexing ID is 5 bit long and the watermark payload is 12 bits per frame. The net payload is 48 bits and the total payload reaches 240 bits per frame group after BCH and CRC encoding.

Three video sets with different resolution and frame rate are used to evaluate the proposed scheme as listed in Table 1. Every data set contains some or all of the following standard test video clips: Mobile Calendar, Park Run, Shields and Stockholm[1].

Table 1. Standard test data set information

Test Data	Set 1	Set 2	Set 3
Resolution	1920x1080	1280x720	720x576
Frames	252	504	252
Frame rate	25 fps	50 fps	25 fps
Color subsampling	4:2:0	4:2:0	4:2:0

To demonstrate the performance, we compare the results of our scheme with two other video watermarking schemes which uses feature based and invariant domain based methods to resist geometric distortions. One is the histogram based algorithm proposed in [7], the other is the full DCT based algorithm proposed in [10]. In the following tables, the three schemes are denoted as Hist, Dct and Our, respectively.

Table 2 shows the average PSNR of the four watermark videos. As only 2 bits are embedded by the histogram based algorithm, it yields the highest PSNR values. The full DCT based algorithm has embedded 12 bits. Regardless of the low watermark

[1] The used video test sets can be downloaded via ftp://ftp.ldv.ei.tum.de/videolab/public/SVT_Test_Set/

payload, the watermarked video is of worst quality. This is due to the embedding in low frequency band of DCT. In contrast, our scheme shows a good tradeoff between watermark payload and visual quality. The average PSNR is above 53dB, which means the embedded watermark is totally invisible.

Table 2. Average PSNR (dB) of watermarked videos

Schemes	Hist	Dct	Our
Mobile Calendar	63	34	53
Park Run	62	34.5	57
Schields	61	34.9	54
Stockholm	63	35	53

In the evaluation of robustness, the following types of attacks are considered:

- Geometric attacks: rotation, scaling, cropping,
- Removal attack: lossy compression,
- Signal processing attack: blur, sharp,
- Temporal attack: temporal smoothing, frame dropping, frame swapping.

The test results regarding robustness against video processing and geometric attacks are shown in Table 3. All the values are the average testing results on all the three test sets in Table 1. A "-" means that the watermark detection fails. As can be observed, the histogram based scheme yields very high robustness on Mobile Calendar and Schields, but completely fails on Park Run and Stockholm. This result proves our discussion in the previous section. The video Park run and Stockholm don't have enough varieties between frames, so the histogram of the average DC energy contains only limited number of bins which makes robust embedding unfeasible.

The full DCT based algorithm shows overall low robustness. It is robust to scaling attack but fragile to rotation and cropping. Our scheme demonstrates in general high robustness against all the attacks. Moreover, it is independent of video types, so our scheme outperforms the other two schemes in terms of tradeoff between payload, robustness and adaptability.

The test results on frame dropping and frame swapping are listed in Table 4. Since in practical applications the frame dropping and swapping attacks are often combined with other attacks, the robustness against frame dropping and swapping is tested together with other seven attacks respectively, including geometric attacks and signal processing attacks. The listed values in Table 4 are the average testing values on all of the four videos in Test Data Set 3, i.e. with a resolution of 720x576.

As shown in Table 4, both our scheme and histogram based algorithm yield high robustness against any attack combination between frame dropping/swapping and other attacks. The bit error rate of the detected watermark using these two schemes is always kept to zero or very close to zero. The full DCT based algorithm loses the competition again with the much higher bit error rate values. These test results demonstrate that it is an effective mean to resist frame dropping/swapping by attaching an indexing ID to each watermark segment.

Table 3. Average detection BER after various attacks

Attacks	**Mobile Calendar**			**Park Run**			**Schields**			**Stockholm**		
Schemes	Hist	Dct	Our	Hist	Dct	Our	Hist	Dct	Our	Hist	Dct	Our
Rotation 1°	0	0.08	0.06	-	0.11	0	0	0.08	0.01	-	0.08	0
Rotation 2°	0	0.08	0	-	0.11	0	0	0.08	0	-	0.08	0
Rotation 3°	0	0.11	0.04	-	0.11	0	0	0.11	0.03	-	0.08	0
Scaling 0.5	0	0.08	0	-	0.05	0	0	0.05	0	-	0.08	0
Scaling 0.6	0	0.08	0	-	0.05	0	0	0.05	0	-	0.08	0
Scaling 0.7	0	0.08	0	-	0.05	0.03	0	0.05	0	-	0.08	0
Scaling 0.8	0	0.08	0	-	0.05	0	0	0.08	0	-	0.08	0
Cropping 12%	0	0.08	0	-	0.16	0	0	0.16	0	-	0.16	0
Cropping 22%	0	0.11	0	-	0.16	0	0	0.16	0	-	0.08	0
Cropping 32%	0	0.14	0	-	0.16	0	0	0.16	0	-	0.08	0
MPEG-2	0	0.11	0.04	-	0.11	0	0	0.11	0.01	-	0.08	0
MPEG-4	0	0.08	0	-	0.08	0	0	0.08	0	-	0.08	0
H.264	0	0.11	0.14	-	0.08	0	0	0.08	0	-	0.08	0
Blur	0	0.08	0	-	0.05	0	0	0.05	0	-	0.08	0
Sharpen	0	0.08	0	-	0.05	0	0	0.05	0	-	0.08	0
Temporal smoothing	0	0.08	0	-	0.05	0	0	0.05	0	-	0.08	0

Table 4. Average detection BER after frame dropping and swapping

Attacks	**Drop 40 frames**			**Drop 120 frames**			**Frame swapping**		
Schemes	Hist	Dct	Our	Hist	Dct	Our	Hist	Dct	Our
Rotation 2°	0	0.08	0	0	0.16	0	0	0.08	0
Scaling 0.8	0	0.08	0	0	0.08	0	0	0.08	0.04
Cropping 80x80	0	0.08	0.03	0	0.08	0.07	0	0.08	0
MPEG-4	0	0.08	0	0	0.16	0	0	0.08	0
Blur	0	0.08	0	0	0.08	0	0	0.08	0
Sharpen	0	0.08	0	0	0.08	0	0	0.08	0
Temporal smoothing	0	0.08	0	0	0.08	0	0	0.08	0

5 Conclusion

To be applicable in practical annotation applications, video watermarking has to be robust and efficient. Geometric and temporal attacks are more challenging than other attacks like lossy compression and transcoding, in particular for watermarking schemes in compressed domain. In this paper, a robust video watermarking scheme is proposed for annotation applications, which combines different strategies for fast embedding, high robustness and payload, and good visual quality. The watermark embedding is done in DFT domain using patchwork approach. Fast transform between block DCT and 2D-DFT enables the direct embedding in compressed domain. Structured template is embedded in selected frames to rectify possible geometric distortions. Each watermark segment embedded in separate frames is individually indexed so that it is able to be resynchronized in case of temporal attacks.

In addition, although the embedding position of template can be randomized by a secret key, its security against removal attack needs further investigation and improvement in the future work for the applications with high security requirement.

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