Digital Video Watermarking Robust Against Camcorder Recording Based on DWT-SVD

Chandaravuth Chhang
Department of Computer Science and Technology
Tsinghua University
Beijing, China
zhangyuf16@mails.tsinghua.edu.cn

Daoshun Wang
Department of Computer Science and Technology
Tsinghua University
Beijing, China
daoshun@mail.tsinghua.edu.cn

Shundong Li
School of Computer Science
Shanxi Normal University
Shanxi, China
shundong@snnu.edu.cn

Xianghui Zhao
China Information Technology Security Evaluation Center
Beijing, China
zhaoxianghui@mail.itsec.gov.cn

***Abstract*—**In order to reduce the block effects in the dark regions and improve the flicker in the bright regions of the existing video watermark algorithms, we propose an improved video watermarking algorithm against camcorder recording based on DWT-SVD. In proposed algorithm, 3th level Discrete Wavelet Transform (DWT) is applied to Y luminance of every single frame, and Singular Value Decomposition (SVD) is used on sub-band of DWT. Watermark sequence is embedded by fine-tuning the singular value of consecutive frames. Experimental results show that the proposed algorithm is robust against many different attacks such as geometric attack, signal processing and camcorder recording. Moreover, the proposed scheme can reduce the blocks effect and improve the flicker by embedding watermark into edge feature of video frame. Although, the method can provide high video quality than the existing schemes, however, it is not robust to strong compression such as MPEG.

Keywords-*video watermarking; discrete wavelet transform; singular value decompositon; camcorder recording; temporal modulation*

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I. Introduction

In the last decade, with the development of mobile phones and digital cameras, HD (High Definition) video can be easily recoded and illegally copied, distributed or uploaded to the video distribution sites such as Youtube, Nexflix, Aiqiyi, Tudou, Youku etc. To prevent digital multimedia from piracy and protect its intellectual property rights, many researchers had proposed several watermarking methods against video camcorder recording. In order to prevent the digital cinema, Lesst et al. [1] proposed a video watermark algorithm to embed watermark bit by modifying the mean luminance value of consecutive frames. Watermark strength is generated by using the motion and texture of the video. The algorithm is robust to geometric distortion and also camcorder recording, but it has the flicker during changing the luminance of consecutive frame. Delannay et al. [2] proposed an idea to restore the geometric distortion by using different transformations from camcorder recorded video before watermark extraction. The scheme is robust to geometrical attack, but it is non-blind which is required original video during watermark extraction and has a high computational complexity. Lee et al. [3] used the LACF (Local Auto-Correlation Function) to find the peak of watermark after projective distortion. Watermark sequence is extracted by applying inverse projective transform on camcorder recorded video. The method has low robustness when the peaks are not clear after meet different signal processing attacks. Sibaji et al. [4] proposed a watermark scheme based on SIFT (Scale Invariant Feature Transform) and 3D-DWT (3 Dimension Discrete Wavelet Transform). By matching SIFT feature points of neighboring frames, segment the video frames into different segments and each segment is divided into several groups. 2th level 3D-DWT is applied to all frames in each group, then using SIFT to extract the key points from the low frequency sub-band. The watermark information is embedded by altering the DC coefficient value of the 3×3 block in DCT domain around the key points. The algorithm can resist to camcorder recording, compression, frame blending and projective attack, but due to the unstable of SIFT feature points, it can decrease the watermark extraction correction rate. The algorithm not only has high complexity, but also has the block effect after reconstruct video frame from 3D-DWT.

Hoseok Do et al. [5] proposed a video watermarking method by using histogram features and temporal modulation. The scheme generates watermark pattern by using histogram of video frame and one bit of watermark sequence is embedded in to consecutive frames by using temporal modulation. Although the algorithm is robust to geometric attack and cam-corded video, but since the scheme uses texture and motion of video to construct the watermark intensity, then the watermark cannot be effectively extracted in the smooth region and stationary background. Choi D et al. [6] proposed a blind watermarking algorithm based on compressed domain. Watermark sequence is embedded in B frame of MEPG-2 domain by using temporal modulation method. The scheme has a good robustness, however, altering the DCT coefficient values (except DC coefficients) of video frame can cause flicker and impact the video quality. LiLi et al. [7] proposed a method which dividing the video frame into block and using the Watson visual model of DCT to generate watermark pattern. Watermark sequence is embedded into five consecutive frames by fine-tuning Y luminance using temporal modulation. The algorithm can solve the problem in [5] and has the low complexity, but it can cause the block effect in dark or smooth regions. Pei Liu et al [8] solved the problem in [7] by proposed a video watermarking algorithm based on DT-CWT and temporal modulation. The scheme uses Watson visual model for Antonini9-7 wavelet [9] to generate a watermark pattern in the DT-CWT domain. 4th levels DT-CWT is applied to whole frame of Y luminance and watermark sequence is embedded by fine-tuning the 5 consecutive frames in low frequency sub-band using temporal modulation. The algorithm has a high robustness against geometric attack, signal processing and camcorder attack, but since altering the low frequency sub-band of consecutive frames can easily cause flicker in the bright regions, then the algorithm has the low invisibility.

In this paper, in order to solve the problems in [7] and [8], we proposed a video watermark algorithm against camcorder recording based on DWT-SVD. In watermark embedding process, 3th level DWT is applied consecutive frame and to get the singular value, SVD is applied to HL3 sub-band of the frame. Watermark pattern is constructed by computing the NVF (Noise Visibility Function) [10] on HL3 and apply the SVD on NVF matrix. Watermark bit is embedded in 5 consecutive frames by fine-tuning the singular value using temporal modulation method which proposed in [5]. Watermark Sequence is extracted by computing the trend luminance of 5 consecutive frames.

The rest of paper is organized as follows. In section 2, paper [7] and paper [8] are introduced and its existing problems are discussed. In section 3, the watermark pattern generation is described and the watermark embedding and extracting process are explained. Experimental results included video quality and watermark robustness of paper [7], paper [8] and proposed method are presented in section 4. The paper is concluded in section 5.

II. Temporal Modulation Watermarking Algorithms and Its Problems

A. Temporal Modulation Watermark Video Based on Block

Paper [7], in order to generate the watermark pattern, first Y luminance of each frame is divided into non-overlapping 32×32 blocks and each block is divided into 16 non-overlapping 8×8 blocks. Then, Calculate DC (Direct Current) coefficients and its mean value by using the relation between DC and pixel value [11] on each 8×8 block. After that, computes the JND (Just Noticeable Difference) value of 8×8 block by using DC and mean value of DC coefficients. Every 8×8 block is divided into non-overlapping 4×4 blocks and select the block which has the largest average luminance value as modification region. Repeat the above step to form the watermark pattern of one frame. The watermark sequence is embedded by altering Y luminance value with watermark pattern. For resistant to temporal attack, time synchronization sequence is added before watermark sequence. Embedding process is shown in the following steps:

Input: Original video V

Time synchronization sequence I_{time}

Watermark sequence $I_{watermark}$

Output: Watermarked video V_w

Step1: Decode video V to YUV420P sequence.

Step2: Video frames are grouped in 5 consecutive frame

Step3: Embed one watermark bit into each group by using temporal modulation method.

1) If the watermark bit equal to 1, then increase the Y luminance value in the first two frames of the group by adding watermark pattern W and decrease the Y luminance value in the last two frames by subtracting watermark pattern W
2) If the watermark bit equal to 0, then decrease the Y luminance value in the first two frames of the group by subtracting watermark pattern W and increase the Y luminance value in the last two frames by adding watermark pattern W

Step4: Repeat steps 2 and 3 till the watermark sequence is embedded

Step5: Encode the YUV420 into watermarked video

In watermark extraction process, paper [7] first segment watermarked video into different single shots by using DEMD (Directional Empirical Mode Decomposition). Then, time synchronization and watermark sequence are extracted in every single shot by comparing the luminance trend of consecutive frames. Extracting process is shown in the following steps:

Input: Watermarked video V_w

Time synchronization sequence I_{time}

Output: Watermark sequence I'

Step1: Segment the watermarked video into single shots

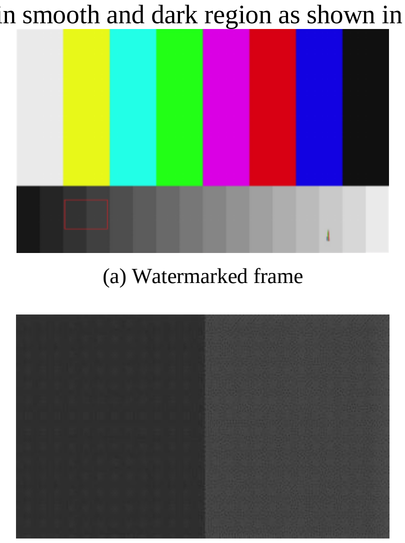
Step2: Choose the single shots which has length longer than $5 \times Length_{tw} / 25$ s

Step3: Extract time synchronization I'_{time} by comparing the luminance trend of 5 consecutive frames. If the hamming distance between I'_{time} and I_{time} are less than 1, then the time synchronization is extracted

Step4: Extract the watermark sequence $I'_{watermark}$ till the next time synchronization is extracted

Step5: Repeat step2, step3 and step4 till every selected single shots were extracted

Paper [7] can resist to geometric attack, signal processing and camcorder recording. The scheme solves the problems in paper [5] which has the low robustness in smooth and stationary background. Although, this method has good robustness, but according to the detail analysis in paper [8], paper [7] has the block effect in smooth and dark region as shown in Fig.1.



(a) Watermarked frame

(b) Block effects in the red window of (a)

Figure 1. Block effects in dark and smooth regions.

B. Temporal Modulation Watermark Based on CT-DWT

To solve problems of smooth and dark regions in paper [7], paper [8] proposed an idea by altering the luminance in whole frame of the consecutive frames. In order to generate to watermark pattern, first 4th level of DT-CWT (Dual Tree Complex Wavelet Transform) is applied to Y luminance of each frame. Then computes amplitude modulation value of each point in DT-CWT low frequency component. After that, watermark pattern in one frame is formed by calculates the watermark strength using amplitude modulation value and embedding intensity coefficient. In paper [8], watermark sequence is divided to several sub watermark sequences called small group watermark which each group contains number of watermark bits. To resist against temporal attack during recording video, the corresponding time synchronization sequence is added before each group of sub watermark sequence. Embedding process is shown in the following steps:

Input: Original video V , Time synchronization sequence I_{time} , Watermark sequence $I_{watermark}$

Output: Watermarked video V_w

Step1: Decode video V to YUV420P sequence.

Step2: Video frames are grouped in 5 consecutive frame

Step3: Apply 4th level DT-CWT on every single frame

Step4: Embed one watermark bit into each group by using temporal modulation method.

1) If the watermark bit equal to 1, then increase low frequency value in the first two frames of the group by adding watermark pattern W and decrease low frequency value in the last two frames by subtracting watermark pattern W

2) If the watermark bit equal to 0, then decrease low frequency value in the first two frames of the group by subtracting watermark pattern W and increase low frequency value in the last two frames by adding watermark pattern W

Step4: Repeat steps 3 and 4 till all video frames are embedded
Step5: Encode the YUV420 into watermarked video V_w

In watermark extraction process, paper [8] first segment watermarked video into different single shots by using SURF (Speeded-Up Robust Features). Then, time synchronization and watermark sequence are extracted in every single shot by comparing the luminance trend in every 5 consecutive frames. Extracting process is shown in the following steps:

Input: Watermarked video V_w
Time synchronization sequence I_{time}

Output: Watermark sequence I'

Step1: Segment the watermarked video into single shots

Step2: Choose the single shots which has length longer than length of a small group watermark

Step3: Extract time synchronization I'_{time} by comparing the luminance trend of 5 consecutive frames. If the hamming distance between I'_{time} and I_{time} are less than 1, then the time synchronization is extracted

Step4: Extract the sub watermark sequence $I'_{watermark}$ till the next time synchronization is extracted

Step5: Repeat step2, step3 and step4 till every selected single shots were extracted

According to the experimental results, paper [8] has the strong robustness in many different attacks such as geometric attack, camcorder recording etc. Moreover, due to the watermark sequence is embedded by modifying the low frequency value in whole frame, then the scheme does not have blocks effect as result in paper [7]. However, human eyes are every sensitive to the smooth region as mention in HVS (Human Visual System) when luminance is changed, then paper [8] altering low frequency value of 4th level of DT-CWT in consecutive frames cause the flicker, human eyes can easily see the luminance change at the bright regions of frame. The flicker of 5 consecutive frames is shown in Fig. 2.

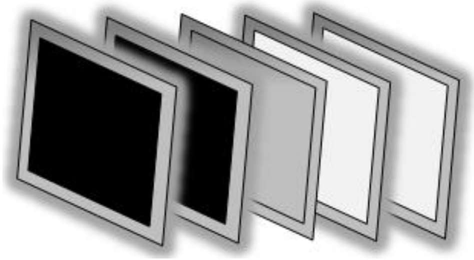


Figure 2. Luminance change in 5 consecutive frames.

III. THE PROPOSED ALGORITHM

In section 2, we explained the schemes which are proposed by paper [7] and [8] and also mentioned its existing problems. These two schemes are robustness but it is very sensitive to human eyes. In order to solve the block effect in paper [7] and improve the flicker in paper [8], we proposed a method to embed watermark in edge feature of video frames based on DWT-SVD and temporal modulation. The video frame is grouped into 5 consecutive frames using temporal modulation method in paper [5]. To embed watermark bit, we first apply 3th level of DWT on every single frame in each group, then applies SVD on HL3 sub-band. One bit of watermark is embedded into 5 consecutive frames by altering the singular value.

A. Watermark Embedding Pattern

Watermark embedding pattern is constructed by compute the NVF (Noise Visibility Function) matrix on HL3 sub-band of the 3th level DWT and apply the SVD on NVF matrix. We first give a brief introduction about DWT, SVD and NVF, and then describes the step of generating watermark pattern.

1) Discrete wavelet transform

Wavelet transform [12] is common tool use in watermark and image processing, DWT can decompose the image or video frame into multi-resolution sub-bands. 1th level of DWT divides the image into four different non-overlapping sub-bands which are LL_1 , LH_1 , HL_1 and HH_1 . LL_1 is called approximation component and the other three components are called detail components. This transform can be repeated by decompose sub-bands into other four different sub-bands. When we apply 3th level DWT on the image, then we can decompose image into 10 non-overlapping sub-bands which the last four sub-bands are LL_3 , LH_3 , HL_3 and HH_3 .Fig 3 gives an example of 3th level DWT of an image.

ISSN: 2454-4248
32 – 39

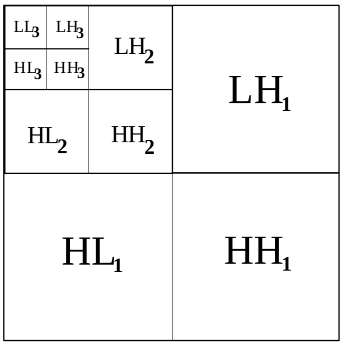


Figure 3. 3th level DWT of image

2) Singular value decomposition (SVD)

Singular value decomposition is a linear transform which is used for factorization of a real or complex matrix [13]. Suppose an image I which has width M and height N is the 2 dimensional $M \times N$ matrix, then the SVD of image I can be written as following:

$$\mathrm{SVD}(I) = U \cdot S \cdot V^T \quad (1)$$

Where U and V are orthogonal matrices and S is called singular matrix which is a diagonal matrix with non-negative singular values of image I. S is written in the form as:

$$S = \begin{bmatrix} \Sigma_r & 0 \\ 0 & 0 \end{bmatrix}, \quad \text{where } \Sigma_r = \begin{bmatrix} \delta_1 & & & 0 \\ & \delta_2 & & \\ & & \ddots & \\ 0 & & & \delta_r \end{bmatrix} \quad (2)$$

Where $\sigma_1 \geq \sigma_2 \geq ...... \geq \sigma_r \geq 0$ are singular value.

3) Noise visibility function (NVF)

Suppose $NVF(i,j)$ is the noise visibility function matrix of image I, then $NVF(i,j)$ can be computed by:

$$NVF(i,j) = \frac{1}{1 + \theta \cdot \sigma_x^2(i,j)} \quad (3)$$

Where $\theta = \frac{D}{\sigma_{x_{\max}}^2}$ denotes tuning parameter, $D \in [50,100]$ is experimentally determined parameter, $\sigma_x^2(i,j)$ represents local variance of the image in a window centered on the pixel with coordinates (i,j), $\sigma_{x_{\max}}^2$ is the maximum local variance for a given image. $\sigma_x^2(i,j)$ can be computed as following:

$$\sigma_x^2(i,j) = \frac{1}{(2L+1)^2} \sum_{k=-L}^{L} \sum_{k=-L}^{L} \left(x(i+k, j+l) - \bar{x}(i,j) \right)^2 \quad (4)$$

$$\bar{x}(i,j) = \frac{1}{(2L+1)^2} \sum_{k=-L}^{L} \sum_{k=-L}^{L} x(i+k, j+l) \quad (5)$$

4) Watermark pattern generation

Watermark pattern (WP) is generated by following steps:

- Decode the video into YUV420P sequence
- Apply 3th level DWT on Y luminance of video frame to obtain LL_3, LH_3, HL_3 and HH_3
- Compute the NVF matrix on LH_3
- Apply singular value decomposition on noise visibility function (NVF) matrix, $SVD(NVF) = \mathrm{U}_w \cdot S_w \cdot V_w$ and the form of S_w is:

$$S_w = \begin{bmatrix} s_{w1} & 0 & \cdots & 0 \\ 0 & s_{w2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & s_{wM} \end{bmatrix} \quad (6)$$

- Watermark pattern is generated by applying the following formula on singular value of matrix S_w:

$$WP(i,i) = \alpha \left(\frac{1}{1 + \mathrm{e}^{S_W(i,i)}} + 1 \right) \quad (7)$$

$$WP(i,i) = \begin{bmatrix} \alpha\left(\frac{1}{1+e^{s_{w1}}}+1\right) & 0 & \cdots & 0 \\ 0 & \alpha\left(\frac{1}{1+e^{s_{w2}}}+1\right) & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \alpha\left(\frac{1}{1+e^{s_{wM}}}+1\right) \end{bmatrix} \quad (8)$$

Where α is the experimental parameter. The value of α will be discussed later.

B. Embedding process and extracting process

As mentioned above, watermark sequence is embedded into every 5 consecutive frames by altering singular value. Moreover, there are time variations when starting to record the video and switching on the display. This may cause de-synchronization between the source frame and the cam-corded frame. In order to solve the time de-synchronization problem, we add time synchronization sequence before the watermark sequence as shown in Fig. 4.

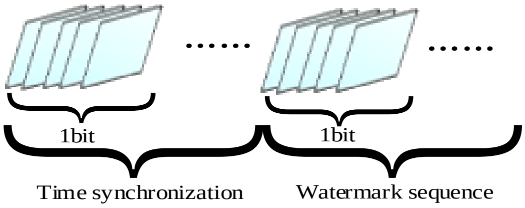


Figure 4. Time synchronization sequence and watermark sequence

Input: Original video V
Time synchronization sequence I_{time}
Watermark sequence $I_{watermark}$

Output: Watermarked video V_w

Step1: Decode video V to YUV420P sequence.

Step2: Video frames are grouped in 5 consecutive frame

Step3: Apply 3th level DWT on every single frame in each group, then apply SVD on LH_3 which $LH_3 = USV^T$, where S is diagonal matrix

Step4: Watermark sequence is embedded video frame by using temporal modulation method as follow:

1) If the watermark bit is 1, then increase the singular value in the first two frames of the group by adding watermark pattern WP and decrease the singular value in last two frames by subtracting watermark pattern WP

ISSN: 2454-4248
32 – 39

2) If the watermark bit is 0, then decrease the singular value in the first two frames of the group by subtracting watermark pattern *WP* and increase the singular value in the last two frames by adding watermark pattern *WP*

Step5: Apply inverse SVD and DWT on video frame
Step6: Repeat steps2, step3 and step4 to embed the watermark cyclically until the whole video frame is embedded
Step7: Encode the YUV420P into watermarked video

During watermark embedding process, watermark strength is computed by given experimental value α . Different α value is given to different background and texture of original video. According to experiences, we set the value of α from 110 to 160 for video which has the smooth background and for video that has more textures and colorful, the value of α is set to 20 to 60. On the other hand, during subtracting singular value by watermark pattern *WP*, if the singular value in matrix *S* is smaller than α ,then the singular value is set to 0. The same case when adding WP on singular value, if the singular value smaller than α , then we add this singular value with constant number *C*, where $C \in [20,50]$.

In watermark extraction process, watermark video is segmented into single shots by using SURF algorithm as mentioned in paper [8]. In each single shot, we first extract the time synchronization sequence by comparing the trend singular value in LH_3 of every 5 consecutive frames. If the time synchronization sequence is successfully extracted, then we start to extract to watermark sequence. Watermark extracting processing is shown in the following steps:

Input: Watermarked video V_w
Time synchronization sequence I_{time}
Watermark length WL
Output: Watermark sequence $I_{watermark}$

Step1: Segment the watermarked video into single shots

Step2: Choose the single shots which has length longer than $5 \times Length_{tw} / 25\,\text{s}$

Step3: Apply 3th level DWT on every single frame , then apply SVD on LH_3 which $LH_3 = USV^T$ to get the diagonal matrix S

Step4: Extract time synchronization I'_{time} by comparing the trend of total singular value of 5 consecutive frames.

1) If the sum of total singular value between first two frames are greater than the sum of total singular value between last two frames, then the watermark bit is 1

2) If the sum of total singular value between the last two frames are greater than the sum of total singular value between first two frames, then the watermark bit is 0

Step5: compute the hamming distance between I'_{time} and I_{time}. If the result is less than 1, then the time synchronization is successfully extracted, otherwise move to the next frame and repeat Step3 and Step 4 till the time synchronization sequence is extracted

Step6: If the time synchronization is successfully extracted, then compare the rest of frame number with $5 \times watermark\ length$. If the rest of frame numbers is greater than or equal to $5 \times WL$, then we extract the watermark sequence $I'_{watermark}$ by comparing trend total singular value trend as Step4, otherwise discard it
Step7: Repeat step2, step3, step4, step5 and step6 till every selected single shot is extracted
Step8: return the watermark sequence

IV. EXPERIMENTAL RESULTS AND ANALYSIS

A. *Experimental set up*

In section 2 and section 3 we explained paper [7], paper [8] and our proposed algorithm in detail. In this section, we will give the experimental results of our proposed algorithm and compare the results with paper [7] and paper [8].

Our experiment is tested on different types of High Digital H.264/AVC videos. The resolution of these video sequences is 1920×1080 with the frame rate 25fps and 10Mbps bit rate. To compare the performance of our algorithm with paper [7] and [8], we first segment the long length of video sequences into single-shot by SURF and select only the four different types of video as shown in Fig.5. The length of these single shot videos is around 30s. video 1 has colorful with small motion, video 2 contains smooth region with stationary background, video 3 and video 4 are colorful which contain more motion and little scene change. In order to test the robustness of the algorithm, we use VirtualDub program to simulate the several image processing attacks such as rotation, scaling, noise addition, blurring and cropping. Then, we use Matlab to randomly drop the small amount of frames in videos. After that, FFmpeg is used for changing the frame rate, recoding and transcoding video. For video camcorder recording, we use a camera which is JVC-GY-HM200EC model to record video from 28inch PHILLIPS-288P6L monitor. Moreover, watermark sequence number is set to 40 bits and we use 10 bits of time synchronization number adding before watermark sequence.

B. *Video qualit and watermark correction rate*

In order to compare the watermark correction rate and video quality between our proposed method with paper [7] and paper [8], we divide our experiment in two parts. First, we choose 2 videos, video 1 which is colorful with small motion and contains a lot of textures, video 2 which has smooth region and steady background to test on camcorder recording. Then, we choose 2 more videos, video 3 and video 4 which are colorful, different background and contain slow movement to test on collusion of image processing which combine rotation, cropping and upscaling. Moreover, we compute the average of PSNR (Peak Signal to Noise Ratio) between the original video and watermarked video to measure the video quality after applying the watermark embedding algorithm.

1) *Experimental on video 1 and video 2*

In the experiment on video 1 and video 2 of our proposed method, we set up parameters as shown in TABLE I.

TABLE I. THE EXPERIMENTAL PARAMETERS ON VIDEO 1 AND VIDEO 2

Video	Wavelet	*D*	α	*C*
Video 1	Sym5	100	35	20
Video 2	Sym5	100	135	20

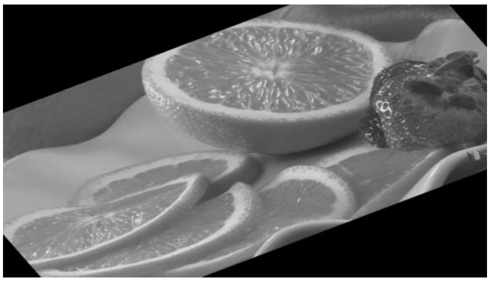
(a) Video 1

(b) Video 2

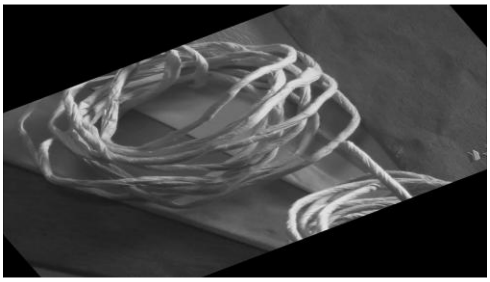
(c) Video 3

(d) Video 4

Figure 5. Four different HD video sequences



(a) Y luminance of video 3 after image processing



(b) Y luminance of video 4 after image processing

Figure 6. Video 3 and Video 4 after rotating 30 degrees, cropping and upscaling

(a) Video 1 is normally recorded

(b) Video 1 is recorded by rotation

(c) Video 1 is recorded by rotation and scaling

Figure 7. Video 1 is camcorder recorded in different angles

The robustness of three algorithms are tested by many different attacks such as geometric attacks (rotation, scaling, cropping), signal processing and camcorder recording. We record the video in three different angles as shown in Fig.7.

 ISSN: 2454-4248
32 – 39

Fig.7 (a) is normally recorded (Recording 1), (b) is recorded by rotation (Recording 2) and (c) is recorded by rotation and up scaling (Recording 3). TABLE II shows the average PSNR of video 1 and video 2 after watermark embedding.

TABLE II. THE AVERAGE PSNR OF VIDEO 1 AND VIDEO 2

Video	Paper [7]	Paper [8]	Proposed method
Video 1	53.3623dB	54.8878dB	57.3044dB
Video 2	53.8859dB	53.7333dB	57.2868dB

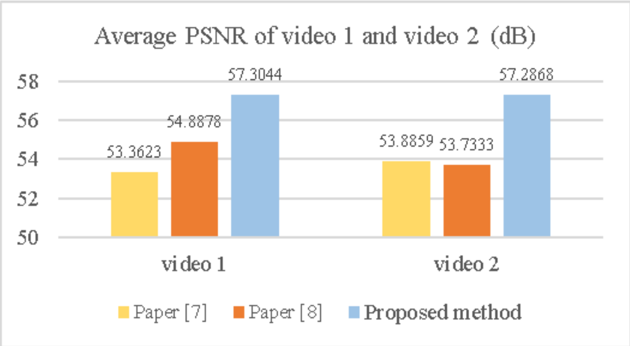


Figure 8. Average PSNR of video 1 and video 2

In the following, TABLE III shows the performance of the proposed method, paper [7] and [8] on video 1 and video 2.

TABLE III. THE ROBUSTNESS OF ALGORITHMS WITH DIFFERENT ATTACKS

Attacks	Paper [7]		Paper [8]		Proposed method	
	Video1	*Video2*	*Video1*	*Video2*	*Video1*	*Video2*
Rotate 5°	100%	100%	100%	100%	100%	100%
Rotate 10°	100%	100%	100%	100%	100%	100%
Down scaling (1280×720)	100%	100%	100%	100%	100%	100%
Crop 5%	100%	100%	100%	100%	100%	100%
Crop 10%	100%	100%	100%	100%	100%	100%
Frame rate change(29.97)	100%	100%	100%	100%	100%	100%
Transcode (6 Mbps)	100%	100%	100%	100%	100%	100%
Recording 1	93.7%	98.7%	95%	100%	98.7%	100%
Recording 2	91.2%	98.7%	93.7%	98.7%	97.5%	100%
Recording 3	91.2%	96.2%	92.5%	98.7%	97.5%	98.7%

The results in TABLE III shows that paper [7], paper [8] and our proposed algorithm have a strong robustness to different attacks, but for camcorder recording attack, our scheme performs better. Moreover, from Table 2 and Fig.8 we can see that our proposed algorithm has higher PSNR value that means our method can provide high video quality than the other two methods.

2) Experimental on video 3 and video 4

During the experiment on video 3 and video 4 of our proposed method, parameters were set up as shown in TABLE IV. In addition, to measure the quality after embedding watermark sequence, we compute the average PSNR of video 3 and video 4 as shown in TABLE V.

TABLE IV. THE EXPERIMENTAL PARAMETERS ON VIDEO 3 AND VIDEO 4

Video	Wavelet	*D*	α	*C*
Video 3	Sym5	100	30	20
Video 4	Sym5	100	30	20

TABLE V. THE AVERAGE PSNR OF VIDEO 3 AND VIDEO 4

Video	Paper [7]	Paper [8]	Proposed method
Video 3	48.3112dB	52.0451dB	58.0275dB
Video 4	53.0583dB	55.0972dB	58.3885dB

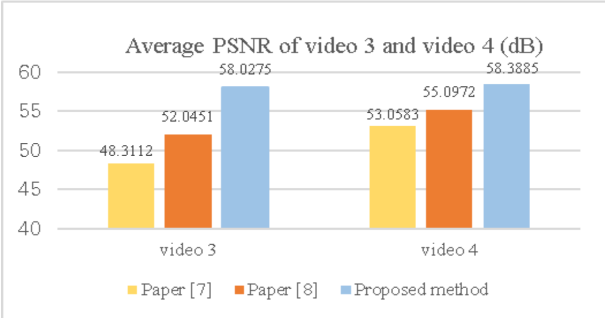


Figure 9. Average PSNR of video 3 and video 4

For video 3 and video 4, we test the robustness of methods with different attacks as mentioned above, but the attacks do not include camcorder recording. Instead of camcorder recording, we test video 3 and video 4 by collusion attacks which combine geometric attack with signal processing as shown in Fig.6. In the following, TABLE VI shows the performance of the proposed method, paper [7] and [8] on video 3 and video 4.

TABLE VI. THE ROBUSTNESS OF ALGORITHMS WITH DIFFERENT ATTACKS

Attacks	Paper [7]		Paper [8]		Proposed method	
	Video3	Video4	Video3	Video4	Vdieo3	Video4
Rotate 10°	95%	88.7%	96.6%	95%	98.7%	100%
Rotate 20°	95%	90%	96.6%	95%	97.5%	100%
Crop 5%	95%	90%	96.6%	95%	98.7%	100%
Down scaling (1280×720)	90%	93.7%	95%	95%	98.7%	98.7%
Median filter	87.5%	91.2%	96.6%	96.6%	98.7%	100%
Gaussian noise	90%	95%	96.6%	96.6 %	98.7%	100%
Collusion	95%	91.2%	95%	95%	97.5%	98.7%

From the results in Table 6, we can see that our proposed method has a strong robustness to many attacks than other two schemes. In paper [7] and paper [8], we increase embedding strength in order to make the algorithms robust against different attacks. However, paper [7] extracts watermark by using the middle area of video frame, so it causes the correction rate decrease when video has a slow movement such as video 3 and 4. Paper [8] performs better than paper [7], but there still have correction rate errors during luminance changes in consecutive frames when video contains some slow movement. For our method, we embed watermark in edge feature of video frame which is robust to little movement of consecutive frames and also it is not sensitive to human eyes, so we can provide high quality and strong robustness on slow movement video such video 3 and video 4.

V. Conclusions

In order to solve the blocks effect in the dark region and improve the flicker in bright region of existing methods, we proposed a method to embed the watermark sequence in the DWT and SVD domain. Watermark bit is embedded by altering the singular value of consecutive frames in DWT domain. Experimental results show that our proposed method is robust to many different attacks, such as rotation, scaling, cropping, signal processing and video camcorder recording. Moreover, our method not only solve the blocks effect in paper [7] and improve the flicker of paper [8], but also provide higher video quality than the two existing schemes. However, since we embed the watermark sequence into edge region of video frame, then our proposed algorithm is not robust to strong compression such as MPEG.

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