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Robust non-blind color video watermarking using QR decomposition and entropy analysis ☆

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Issues such as content identification, document and image security, audience measurement, ownership and copyright among others can be settled by the use of digital watermarking. Many recent video watermarking methods show drops in visual quality of the sequences. The present work addresses the aforementioned issue by introducing a robust and imperceptible non-blind color video frame watermarking algorithm. The method divides frames into moving and non-moving parts. The non-moving part of each color channel is processed separately using a block-based watermarking scheme. Blocks with an entropy lower than the average entropy of all blocks are subject to a further process for embedding the watermark image. Finally a watermarked frame is generated by adding moving parts to it. Several signal processing attacks are applied to each watermarked frame in order to perform experiments and are compared with some recent algorithms. Experimental results show that the proposed scheme is imperceptible and robust against common signal processing attacks.

1. Introduction

These days, online video piracy has become a significant concern for film industries. Camcorder theft is the biggest problem that studio and movie producers are facing, being the largest source of video piracy [25]. According to statistics in Koch et al. [25] and Lee et al. [31], about 90% of illegal distributed versions of new release films are captured in a large screen movie theatre by a digital camcorder device and then distributed via the Internet without any copyright protection.

One of the techniques to protect the video files against piracy by any unauthorized person is digital video watermarking. Video watermarking is a method to embed data into the host frame by slightly modifying its content. In general, there are three different algorithms for watermarking, namely blind, semi-blind and non-blind. In blind algorithms, a secret key is needed to extract the watermark from the watermark signal [11]. In semi-blind algorithms, a secret key plus the original watermark are required to extract the watermark from watermark systems [34]. And finally, to extract the watermark from the watermark signal in a non-blind method, a secret key, the original signal and watermark sequence are needed [41,30].

There are several techniques for embedding data in the video. One straightforward approach for data embedding in video is considering the video as a sequence of images and using image watermarking algorithms on each frame independently. A lack of some metrics such as robustness, blind detection and imperceptibility are present in some basic watermarking methods which consist of an encoder and decoder [28,10]. Some methods tend to be less robust against certain compression attacks and temporal attacks [18]. Bringing temporal dimensions into the watermarking framework gives rise to another class of methods, examples of which include embedding in various 3D transform domains, such as Discrete Wavelet Transform (DWT) [7], Discrete Fourier Transform (DFT) [32], Ridgelet Transform [24], and Discrete Cosine Transform (DCT) [38] or frame-by-frame embedding according to the temporal characteristics of the video [17]. Other methods in this area are Deguillaume et al. [8], Huang et al. [19], Hartung and Girod [16], Huang et al. [19], Khalilian and Bajic [22], Koz and Alatan [26], Asikuzzaman et al. [6], Koz and Alatan [23], Tabassum and Islam [42], and Zhu et al. [49]. Pseudo 3D DCT in conjunction with Quantization Index Modulation (QIM) is employed in Huang et al. [19]. The authors applied the 2D DCT on non-overlapping blocks of each frame and then they temporally applied the 1D DCT on the

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spatially transformed coefficients. Finally QIM is used to watermark the summation of the resulting coefficients. Spread spectrum modulation is employed by utilizing the temporal human visual system (HVS) model in Koz and Alatan [26].

Khalilian and Bajic [23] proposed embedding a watermark in the low frequency subband of wavelet coefficients in an adaptive manner based on the energy of high frequency subbands and visual saliency, and decoding was performed based on the comparison among the elements of the first principal component resulting from empirical principal component analysis (PCA). The locations for data embedding were selected such that they offer the most robust PCA-based decoding. In Stutz et al. [41], a non-blind H.264/CAVLC structure-preserving substitution watermarking scheme was proposed. In the aforementioned scheme the watermark embedding was enabled by simple bit substitutions. The bit-substitutions change the motion vector differences of non-reference frames.

Tabassum and Islam [42] proposed a digital video watermarking technique based on identical frame extraction in 3-Level DWT. First, they divided the host video into video shots. Then, one video frame of each video shot was selected for watermark embedding. After that a 3-level DWT was used in order to decompose the frame. Finally the watermark was embedded into higher subband coefficients. In Zhu et al. [49] a quantization watermarking method is proposed. They obtained a feature signal by computing the normalized correlation (NC) between a random signal and the host signal. Information modulation was carried out on the generated NC by selecting a codeword from the codebook associated with the embedded information. Finally, the watermarked signal was produced to provide the modulated NC in the sense of minimizing the embedding distortion.

Independently if watermark algorithms are blind, semi-blind or non-blind, they can also be categorized into frequency domain or spacial domain. A watermark is directly embedded into a pixel value of the host image in spatial domain methods. In this case the resolution of the image does not considerably change, but is not robust against attacks [29]. Methods in the frequency domain embed watermarks into transform coefficients [35].

In this work, a novel watermarking scheme for video sequences by using QR decomposition [36], Chirp Z-transform (CZT) [2], Singular value decomposition (SVD) [12], DWT and entropy [48] is proposed. A watermark is embedded into low entropy parts of all three RGB color channels of each frame of the video sequences. The developed technique shows good robustness characteristics and satisfies imperceptibility requirements. Also a Correlation coefficient (CC) metric is used to evaluate the robustness of the proposed watermarking technique. It is used to measure linear association [47]. There are many alternatives, like the sum of absolute difference and sum of squared differences, to correlation coefficient, but they are not invariant to contrast and brightness [33]. The higher the correlation coefficient absolute value, the stronger the relationship is between original and extracted watermarks [44]. In relation to state-of-the-art approaches, our proposed watermarking scheme brings novelty by using QR decomposition, which improves many decompositions such as LUD and SVD [37]. The video sequences are also divided into moving and non-moving parts in order to enhance the visual quality of the watermarked sequence. The quantitative and qualitative experimental results are showing the superiority of our proposed technique over the state-of-the-art techniques proposed in Hamad et al. [14], Lai and Tsai [27] and Agoyi et al. [2].

The remainder of this paper is organized as follows. Section 2 contains a review of stages which are used in the proposed method. A detailed overview of the proposed method is presented in Section 3. Section 4 contains the outcome of the experimental results. Finally, Section 5 concludes the paper.

2. Background review

2.1. Discrete Wavelet Transform

The Discrete Wavelet Transform (DWT) produces a sparse time–frequency representation of a signal, which can be obtained by computing a successive high and low pass filter of a discrete time-domain signal [13]. DWT decomposes an input signal into four bands of data consisting of the low frequency band (LL), low–high (LH), high–low (HL), and high–high (HH) bands. While most information contained in the signal is concentrated in the LL band the LH band contains mostly the vertical detailed information, the HL band contains the horizontal edges information and the HH band contains the vertical edges information [4].

The major advantages of using the DWT to decompose a signal are due to its multi resolution and excellent localization characteristics similar to that of the theoretical models of the human visual system (HVS). The multi resolution characteristics of DWT allow for a watermark to be inserted into any of the bands, but generally watermarks embedded in the high frequency band have a high imperceptibility value, though robustness can be compromised. Though a watermark embedded in the LL band is generally robust against attacks, there can be degradation in the quality of the watermarked signal [9].

2.2. Lower and Upper decomposition (LU)

LU decomposition is a procedure of decomposing a matrix A of $n \times n$ into a lower triangular matrix L with 1's in its diagonal and an upper triangular matrix U as given in (1)

$$A = L \times U = \begin{bmatrix} 1 & 0 & 0 \\ l_{21} & 1 & 0 \\ l_{31} & l_{32} & 0 \end{bmatrix} \times \begin{bmatrix} d_1 & u_{12} & u_{13} \\ 0 & d_2 & u_{23} \\ 0 & 0 & d_3 \end{bmatrix} \tag{1}$$

The matrix U can be further decomposed into two matrices D and $U1$ by dividing out the diagonal of matrix U. The A matrix can then be decomposed into three matrices as given in Eq. (2) [20,46,15].

$$A = L \times U \times U_1 = \begin{bmatrix} 1 & 0 & 0 \\ l_{21} & 1 & 0 \\ l_{31} & l_{32} & 0 \end{bmatrix} \times \begin{bmatrix} d_1 & u_{12} & u_{13} \\ 0 & d_2 & u_{23} \\ 0 & 0 & d_3 \end{bmatrix} \times \begin{bmatrix} 1 & \frac{u_{12}}{d_1} & \frac{u_{13}}{d_1} \\ 0 & 1 & \frac{u_{23}}{d_2} \\ 0 & 0 & 1 \end{bmatrix} \tag{2}$$

2.3. Singular value decomposition

Singular value decomposition (SVD) is a well-known linear algebra technique for its many applications. SVD is an orthogonal transform which diagonalizes a given matrix and decomposes it into three matrices. A signal of $n \times n$ can be decomposed into U, S and V as given in Eq. (3)

$$[U \quad S \quad V] = svd(A) \tag{3}$$

where U and V are the orthogonal matrices and S is a diagonal matrix with the larger singular value entries of the image [3].

The three main properties of the SVD in digital image processing scheme are that: the change of a singular value due to addition of a small perturbation to an image is negligible because of the stability property of the singular value. The geometry of the image is specified by pairs of singular vectors and the singular value specifies the luminance of image layer. The intrinsic algebraic image properties are represented by the singular values [13].

The main advantage of using SVD is that the energy content of the matrix is located in the singular value, so when a small perturbation is added to a signal, its singular values do not change significantly due to the stability property of the singular value resulting in its being invariant to some signal processing operations [21].

2.4. Chirp-Z transform

Chirp-Z transform (CZT) is an algorithm for computing the Z transform of a sequence of samples. The transform helps to effectively evaluate the Z transform at points on the Z-plane which lie on a circular or spiral contour beginning at any arbitrary point on the Z-plane. Z-domain transfer functions can be factored into polynomials with poles and zeros as its roots. Describing a system in terms of its poles and zeros is an effective tool for analyzing the behavior of that system, where the poles represent the roots of the feedback part of the transfer function and the zeros represent the roots of the feed forward part of the transfer function. The CZT helps to investigate systems by precisely locating the poles and zeros of its transfer function.

The major advantages of using the CZT is that the sharpness of the resonance peak can be enhanced by computing the Z-transform along a contour that lies closer to the pole(s). Since CZT has the ability of evaluating the Z transform at points both inside and outside the unit circle, by evaluating the transform off the unit circle, the contour can be adjusted to pass closer to the poles of the signal, causing the spectrum to sharpen. Chirp-Z can also help to zoom the analyzed frequency spectrum with a very high resolution leading to its frequency resolution being greatly improved [43,45,39,40]. Its usage in watermarking will help to achieve a highly imperceptible and a robust watermarked signal, since the spectrum is sharpened and the frequency resolution is appreciably improved.

3. Proposed method

In this work a watermark is embedded in the non-moving part of each color frame in all three RGB channels. First some frames are chosen as a basis. Then moving parts and non-moving parts of each frame are separated by comparing the frame with the basis frames. Frame blocks with low complexity of non-moving parts of each frame are found by entropy estimation, and the watermark is embedded and extracted by combining characteristics of DWT, CZT, QR decomposition and SVD. The different steps of the proposed watermarking algorithm are described in the next subsections.

3.1. Watermark embedding

Algorithm 1 shows the algorithm for watermark embedding. Watermark embedding starts detecting the non-moving part of the color frame and dividing it into RGB color channels. Each $m \times n$ color channel is divided into blocks of the size $\alpha \times \beta$. An optimal value as the number of the blocks is determined based on a set of prior tests, where four is opted for, since higher ones proved not to lead to significant improvements, but would rather increase the computational complexity. Let $M = m/\alpha$ and $N = n/\beta$. Then each block can be described as in Eq. (4), where $z = \{R, G, B\}$.

$$B_{ij}^{z} \qquad i \in \{1 \ldots M\}, \quad j \in \{1 \ldots N\} \tag{4}$$

Entropy value for each block was calculated, where the entropy value is designated as e.

The average of all entropy values from all blocks is computed as shown in Eq. (5) and defined as T_z, being $E(.)$ the entropy estimation function.

$$T_z = \frac{1}{M \times N} \sum_{i=1}^{M} \sum_{j=1}^{N} E\left(B_{ij}^{z}\right) \tag{5}$$

Afterwards, two-level DWT is applied on each block with entropy value e less than calculated threshold T_z to decompose it into four subbands.

$$LL_{ij}^{z} LH_{ij}^{z} HL_{ij}^{z} HH_{ij}^{z} = DWT\left(B_{ij}^{z}\right), \quad \forall B_{ij}^{z} \in \left\{B_{ij}^{z} : E(B_{ij}^{z}) < T_z\right\} \tag{6}$$

CZT of high-frequency subband HH_{ij}^{z} is calculated for all decomposed blocks as given in Eq. (7).

$$C_{ij}^{z} = CZT\left(HH_{ij}^{z}\right) \tag{7}$$

Algorithm 1. Proposed Watermark Embedding Algorithm

```
Input: Original Frames, Watermark Image
Output: Watermarked Frames
READ Original Frame
Separate moving part and non-moving part of each frame
READ non-moving part of frame as a Frame'
READ Watermark
FOR j = 1:3
  Color = Get color matrix (Frame', j)
  FOR i = 1:4
    Blocks(i) = Get image block (Color, i)
    Entropy(i) = Find entropy (Blocks(i))
  END FOR
  AverageEntropy = SUM (Entropy)/4
  FOR i = 1:4
    IF Entropy(i) < AverageEntropy
      DWT = Discrete wavelet transform (Blocks(i))
      HH = Find high-frequency subband (Dwt)
      CZT = Chirp Z transform (HH^z)
      LU^z = LU^z decomposition (CZT^z)
      D^z = Find diagonal matrix (LU^z)
      AΣB^z = Singular value decomposition (D^z)
      (AΣB^z)_watermark = Singular value decomposition
                          (Watermark)
      Σ^z_watermark = Σ^z + Σ^z_watermark * ScalingFactor
      D^z = Inverse Singular value decomposition
            (SVD^z, SVD^z_watermark)
      LU^z = Inverse LU^z decomposition (LU^z, D^z)
      HH = Inverse Chirp Z transform (CZT^z, LU^z)
      Blocks(i) = Inverse discrete wavelet transform
                  (DWT^z, HH^z)
    END IF
  END FOR
  WatermarkedFrame'(j) = Add blocks together (Blocks)
END FOR
WatermarkedFrame' = Add colors together
                    (WatermarkedImages)
WatermarkedFrame = WatermarkedFrame' + Moving part of
                   frame
```

QR decomposition is defined to matrix C_{ij}^{z} from Eq. (7) to calculate the diagonal matrix as given in Eq. (8).

$$\begin{aligned} \left[Q_{ij}^{z} R_{ij}^{z}\right] &= QR\left(C_{ij}^{z}\right) \\ D_{1_j}^{z} &= diag(R_{ij}^{z}) \\ D_{ij}^{z} &= Zeros\left(R_{ij}^{z}\right) \\ D_{jj}^{z} &= D_{1_j}^{z} \end{aligned} \tag{8}$$

SVD is applied to diagonal matrix D_{ij}^{z} from Eq. (8) to further decompose it as shown in Eq. (9).

$$\left[U_{ij}^{z}S_{ij}^{z}V_{ij}^{z}\right] = SVD\left(D_{ij}^{z}\right) \tag{9}$$

SVD is also applied to watermark image W and decomposes it as shown in Eq. (10).

$$\left[U_{1}^{z}S_{1}^{z}V_{1}^{z}\right] = SVD(W^{z}) \tag{10}$$

New singular values are estimated by adding original frame decomposed singular values to watermark image singular values multiplied by scaling factor k, where k controls the strength of the added watermark, as shown in Eq. (11).

$$S_{2_{ij}}^{z} = S_{ij}^{z} + k \times S_{1}^{z} \tag{11}$$

Unitary matrices U_{ij}^{z} and V_{ij}^{z} are combined from the decomposed original image with new singular values calculated in Eq. (11), as shown in Eq. (12).

$$D_{2_{ij}}^{z} = U_{ij}^{z} \times S_{2_{ij}}^{z} \times \left(V_{ij}^{z}\right)^{T} \tag{12}$$

Upper-triangular matrix R_{ij}^{z} diagonal values are replaced with modified diagonal matrix D_{ij}^{z} as shown in Eq. (13) and unitary matrix Q_{ij}^{z} is combined with modified upper-triangular matrix R_{ij}^{z} as shown in Eq. (14).

$$R_{ij}^{z} = D_{2_{ij}}^{z} \tag{13}$$

$$C_{2_{ij}}^{z} = Q_{ij}^{z} \times R_{ij}^{z} \tag{14}$$

Then, inverse CZT of $C_{2_{ij}}^{z}$ is calculated in order to get a watermarked high-frequency subband as shown in Eq. (15) and inverse DWT is used to get a watermarked frame block. Instead of HH_{ij}^{z} modified $HH_{2_{ij}}^{z}$ was used as shown in Eq. (16).

$$HH_{2_{ij}}^{z} = ICZT\left(C_{2_{ij}}^{z}\right) \tag{15}$$

$$I_{ij}^{z} = IDWT\left(LL_{2_{ij}}^{z}LH_{ij}^{z}HL_{ij}^{z}HH_{ij}^{z}\right) \tag{16}$$

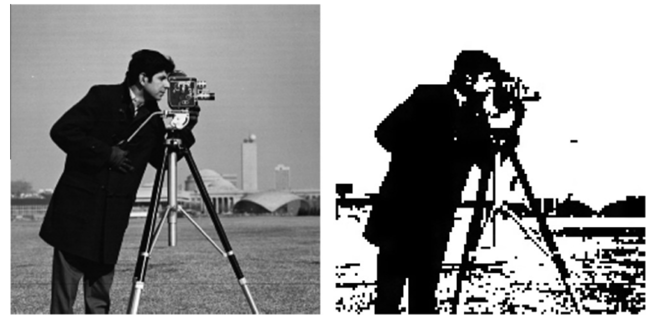

Fig. 2. Original and black and white cameraman watermark image.

Fig. 3. Original and black and white iCV watermark image.

Finally, modified low entropy blocks with high entropy blocks and all three color channels plus the moving part of the frame are added together in order to generate the watermarked color frame. Fig. 1 shows the flowchart of the proposed scheme.

3.2. Watermark extraction

The watermark extraction algorithm is presented in Algorithm 2. The same procedure for that watermark embedding is performed on the color frame for the first stages of watermark extraction. For

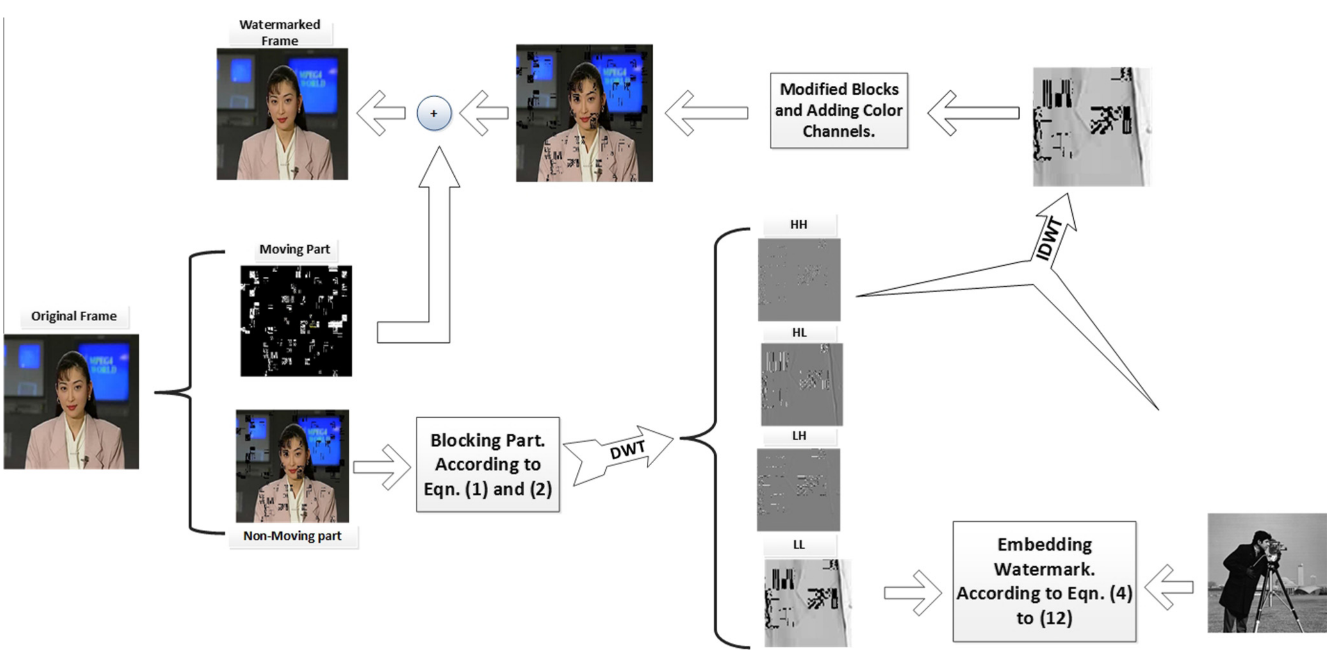

Fig. 1. The flowchart of the proposed system.

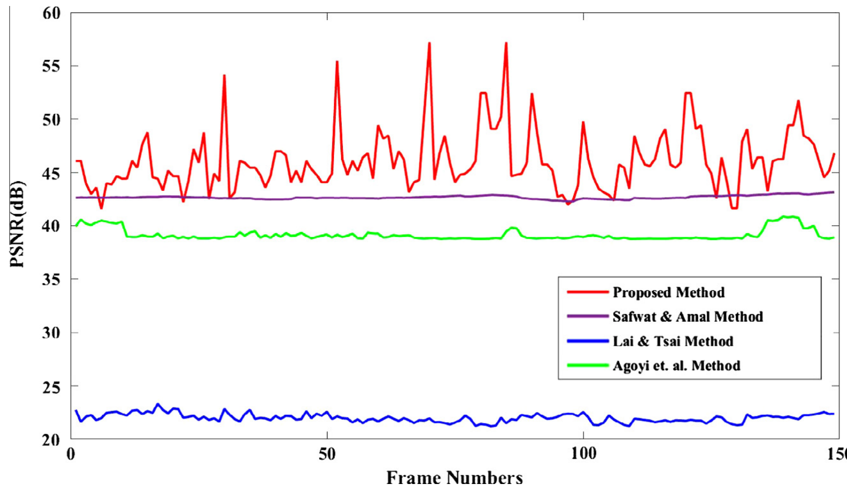

Fig. 4. PSNR results of watermarked Bus video sequences with the cameraman image.

the original color frame the methodology from Eqs. (4)–(10) are also applied. Singular values of original frame blocks are subtracted from the singular values of watermarked frame block and the outcome is divided by scaling factor k in order to generate the singular values of the extracted watermark image, as shown in Eq. (17).

$$S_{1'_{ij}} = \left(S'_{ij} - S_{ij}\right) \Big/ k \tag{17}$$

Unitary matrices U_1 and V_1 from the watermark image are combined with extracted singular values calculated in Eq. (17) to get the extracted watermark for each block as shown in Eq. (18).

$$W_{1_{ij}} = U_1 \times S_{1'_{ij}} \times V_1^T \tag{18}$$

The extracted watermark image is converted into black and white image by using an average of the image as the threshold.

Algorithm 2. Proposed Watermark Extraction Algorithm

Input: Watermarked Frames, Original Frame, Watermark Image
Output: Watermark image
READ Original Frame
READ Watermarked Frame
READ Watermark
FOR j = 1:3
  Color = Get color matrix (OriginalFrame, j)
  FOR i = 1:4
    Blocks(i) = Get image block (Color, i)
    Entropy(i) = Find entropy (Blocks(i))
    $W_{Blocks}(i)$ = Get image block (WatermarkedFrame, i)
  END FOR
  AverageEntropy = SUM (Entropy)/4
  FOR i = 1:4
    IF Entropy(i) < AverageEntropy
      DWT = Discrete wavelet transform (Blocks(i))
      HH^z = Find high-frequency subband (DWT)
      W^z_{DWT} = Discrete wavelet transform ($W_{Blocks}(i)$)
      W^z_{HH} = Find high-frequency subband ($W_D WT^z$)
      W^z_{CZT} = Chirp Z transform (W^z_{HH})
      LU^z = LU^z decomposition (hh^j)
      D^z = Find diagonal matrix (LU)
      W^z_{LU} = LU decomposition (W^z_{CZT})
      W^z_D = Find diagonal matrix (W^z_{LU})
      $A\Sigma B$ = Singular value decomposition (D^z)
      $W_{A\Sigma B}$ = Singular value decomposition (W^z_D)
      $A\Sigma B_{watermark}$ = Singular value decomposition (Watermark)
      $\Sigma_{Extracted}$ = $(W^z_\Sigma - \Sigma)$/ScalingFactor
      ExtractedWatermark = $U^z * \Sigma_{Extracted} *$ Transpose(V)
      ExtractedWatermark = Convert into black-and-white (ExtractedWatermark)
    END IF
  END FOR
END FOR

4. Experimental results

For the experiments several visual data from well known benchmarks like “Akiyo”, “Bus”, “Carphone” and video sequences in [5] are used. Watermark images were 128 × 128 gray scale images. Figs. 2 and 3 show watermark images “iCV group Logo” and “Cameraman”, used for experimental results. The watermark images of size 128 × 128 are embedded in all 300 frames of size 1024 × 1024 from Akyio video sequences as well as in 150 frames of size 1024 × 1024 from Bus video sequences.

Peak signal to noise ratio (PSNR) is used in order to evaluate imperceptibility characteristics quality measurement. It measures frame quality in decibels, and a frame with over 40 dB is considered to have high quality [1]. PSNR values of the proposed method are compared with three state-of-the-art methods, namely Lai and Tsai [27], Agoyi et al. [2], and Safwat and Amal [14]. The results of these comparisons are shown Figs. 4 and 5. These figures illustrate that PSNR results of the proposed method outperform PSNR results of Lai and Tsai [27], Agoyi et al. [2], and Hamad et al. [14].

Various attacks like additive contrast enhancement, cropping, gamma correction, blurring, flipping, histogram equalization, salt and pepper noise, Additive White Gaussian Noise (AWGN), scaling, JPEG compression, and sharpening were used on the watermarked frame in order to evaluate the robustness properties of our

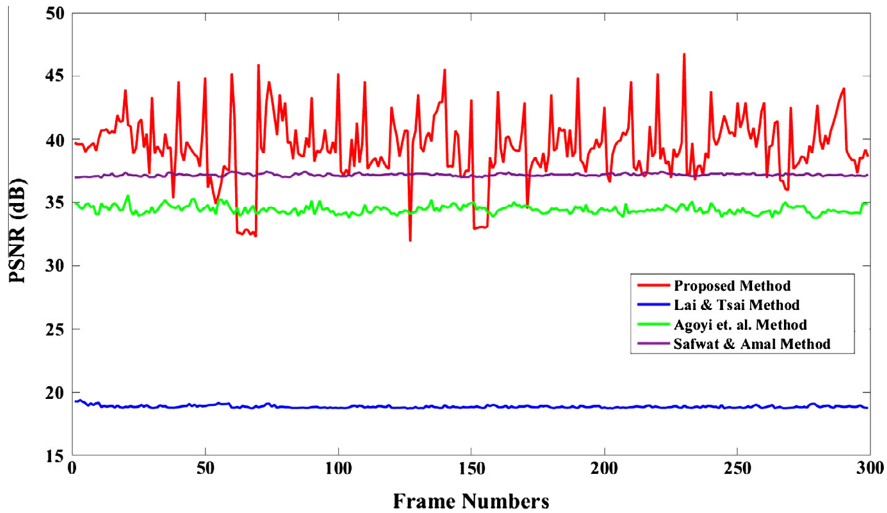

Fig. 5. PSNR results of watermarked Akiyo video sequences with the iCV logo.

Fig. 6. (a) Original frame No. 34, (b) watermarked frame with iCV logo, (c-n) watermarked frame with blurring, contrast enhancement, cropping, flipping, gamma correction, histogram equalization, JPEG, salt and pepper noise, AWGN, scaling and sharpening attacks.

Table 1
Correlation coefficient result of the bus video sequences with the host frame watermarked with the Cameraman image.

	Proposed method	Lai & Tsai method	Agoyi et al. method	Safwat & Amal method
Frame number	34	34	34	34
Flipping	**1**	0.9641	0.0422	0.7954
Histogram equalization	**0.9979**	0.8658	0.6808	0.8337
Cropping	**0.9854**	0.8552	0.2961	0.8432
JPEG	**0.9396**	0.9194	0.0612	0.9828
Blurring	**0.9336**	0.1880	−0.7051	−0.6145
Contrast enhancement	**0.9671**	0.9149	0.1394	0.8174
Salt and pepper noise	**0.9979**	0.9103	0.5300	0.5028
Gaussian noise	**0.9454**	0.7777	0.5199	0.4763
Sharpening	**0.9979**	0.7570	0.8561	0.8675
Gamma correction	**0.9854**	0.9476	0.0998	0.7613
Scaling	**0.8732**	0.2414	−0.7047	−0.5965
AWGN	**0.9474**	0.7137	0.5273	0.4778

The bold numbers show the best performance.

Table 2
Correlation coefficient result of Akiyo with the host frame watermarked with the Cameraman image.

	Proposed method	Lai & Tsai method	Agoyi et al. method	Safwat & Amal method
Frame number	34	34	34	34
Flipping	**0.9875**	0.9363	0.8855	0.6420
Histogram equalization	**0.9572**	0.9470	0.8324	0.9539
Cropping	0.9096	**0.9470**	0.5490	0.7711
JPEG	**0.9937**	0.9587	0.9644	0.8169
Blurring	**0.9301**	0.3148	−0.6975	−0.6127
Contrast enhancement	0.8372	0.9506	**0.9604**	0.7433
Salt and pepper noise	**0.9452**	0.8676	0.6050	0.5290
Gaussian noise	**0.8229**	0.6761	0.5506	0.4919
Sharpening	**1**	0.8610	0.9567	0.8396
Gamma correction	**0.9471**	0.9469	0.7574	0.7593
Scaling	**1**	0.3250	−0.6942	−0.6163
AWGN	**0.7934**	0.6227	0.5549	0.4870

The bold numbers show the best performance.

Table 3
Correlation coefficient result of the bus video sequences as the host frame watermarked with the iCV logo.

	Proposed method	Lai & Tsai method	Agoyi et al. method	Safwat & Amal method
Frame number	34	34	34	34
Flipping	**0.9848**	0.9171	0.0354	0.8293
Histogram equalization	**0.9978**	0.9083	0.8368	0.8664
Cropping	**0.9978**	0.8226	0.4060	0.9124
JPEG	**0.9220**	0.8816	0.3756	0.9868
Blurring	**0.9827**	0.2205	0.8744	−0.7660
Contrast enhancement	**0.9254**	0.8774	0.1746	0.8453
Salt and pepper noise	**1**	0.9141	0.6956	0.6202
Gaussian noise	**0.9827**	0.8849	0.6902	0.604
Sharpening	**0.9891**	0.8430	0.9366	0.9278
Gamma correction	**0.9978**	0.9200	0.0235	0.8308
Scaling	**0.9153**	0.2759	−0.8729	−0.7452
AWGN	**0.9764**	0.8323	0.7101	0.6084

The bold numbers show the best performance.

Table 4
Correlation coefficient result of Akiyo with the host frame watermarked with the iCV logo.

	Proposed method	Lai & Tsai method	Agoyi et al. method	Safwat & Amal method
Frame number	34	34	34	34
Flipping	**0.9618**	0.9258	0.9302	0.7625
Histogram equalization	0.9356	**0.9718**	0.9269	0.9335
Cropping	0.9144	**0.9499**	0.5713	0.7943
JPEG	0.9220	0.9627	**0.9689**	0.8560
Blurring	**0.8937**	0.3762	0.8814	−0.7859
Contrast enhancement	0.6932	0.9587	**0.9795**	0.8648
Salt and pepper noise	**0.9616**	0.9069	0.7503	0.6432
Gaussian noise	**0.8940**	0.7998	0.7306	0.6165
Sharpening	0.9806	0.8212	**0.9890**	0.9280
Gamma correction	0.8411	**0.9696**	0.8517	0.8562
Scaling	**1**	0.4048	0.8788	−0.7795
AWGN	**0.8149**	0.7398	0.7328	0.6163

The bold numbers show the best performance.

Fig. 7. Extracted black and white watermarks from frame 34 of Akiyo video sequences watermarked with the iCV logo.

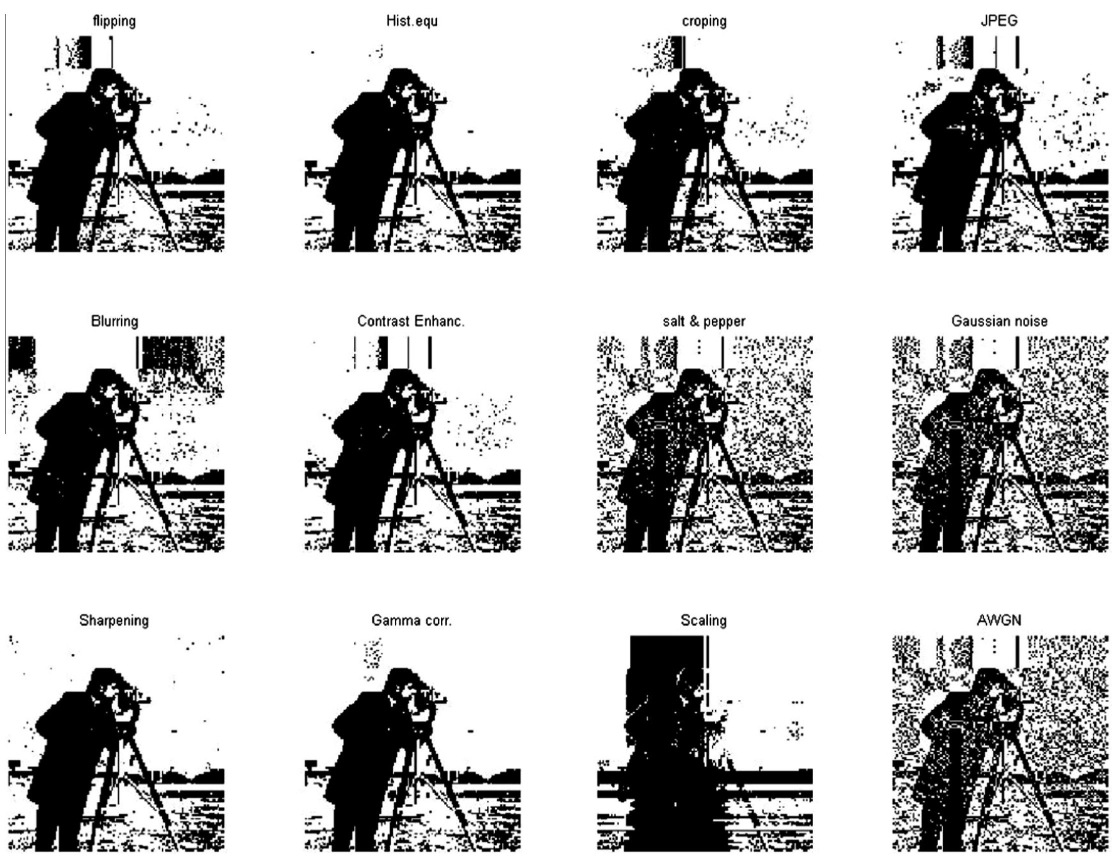

Fig. 8. Extracted black and white watermarks from frame 34 of bus video sequences watermarked with the Cameraman image.

proposed method. Fig. 6 shows a random host frame, a watermarked host frame and a watermarked frame with different attack.

A correlation coefficient metric is used to evaluate the extracted watermark frame. It evaluates similarity between the extracted watermark and the original watermark frame. From conducted tests it can be concluded that the presented watermarking scheme outperforms state of the art compared methods.

Tables 1 and 2 show comparisons between the proposed method and three state-of-the-art algorithms when a random frame of the Akiyo and the Bus video sequences are used as the host frames and the Cameraman image as watermark image. Table 1 shows that the proposed method has significantly better results in all attacks compared with the other methods. Table 2 points out that the proposed method has significantly better CC results with flipping, JPEG compression, blurring, AWGN, salt and pepper noise, sharpening and scaling attacks. CC results are slightly better with histogram equalization, gamma correction attack. The proposed algorithm shows slightly worse CC results than other compared methods with cropping and contrast enhancement attacks.

Tables 3 and 4 show comparisons when host frame "bus" and "Akiyo" are watermarked with the iCV logo. Table 3 shows that the proposed algorithm performs significantly better when flipping, histogram equalization, cropping, JPEG compression, blurring, contrast enhancement, salt and pepper noise, Gaussian noise, gamma correction, scaling and AWGN attacks are used.

Table 4 shows that the proposed method has significantly better CC results with flipping, blurring, salt and pepper noise, Gaussian noise, scaling and AWGN attacks. The proposed algorithm illustrates slightly worse CC results than other compared methods with histogram equalization, cropping, JPEG compression, contrast enhancement, sharpening and gamma correction attacks. Figs. 7 and 8 show visual results of the extracted watermark in black and white with Akiyo and bus video sequences as host.

The conducted experimental results indicate the robustness of the proposed method over many of the signal processing attacks in which the watermark is preserved and retrievable. The results show that the proposed method performs better than the state-of-the-art methods.

5. Conclusion

This paper presented a novel and robust watermarking scheme for colored video sequences. The method embeds a watermark into all three color channel singular values of the host frame. First, it divides the frame into moving and non-moving parts, then the non-moving part is used as the input to the system. Input is divided into three RGB color channels which are divided into blocks. Blocks with low entropy value are found and are used for watermark embedding. Each low entropy block is decomposed into frequency channels and further decomposed using CZT. Afterwards orthogonal–triangular decomposition is used to obtain an upper-triangular matrix and unitary matrix. Then, the diagonal matrix is estimated and singular values are calculated. Watermark image singular values are added with decomposed singular values from the input frame and a watermark is embedded. Finally the moving part was added in order to generate a watermark frame. Experimental results performed on several well-known video frames showed that the proposed algorithm is robust, imperceptible and outperforms state-of-the-art watermarking methods on public image data sets.

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