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Imperceptible Improvement using Edge Area Selection for Robust Video Watermarking Using Tchebichef - Singular Value Decomposition

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Abstract: Watermarking is a technology to protect the copyright of multimedia data. Video is one of the most complex media compared to image or audio. In invisible watermarking, imperceptible aspects are important besides robustness. This research proposes a frame selection method based on the edge area. The frame with the most edge area is selected and used for watermark embedding with Tchebichef transformation and singular value decomposition. A dual-stage Arnold transform was carried out to spread the edge area, and the watermark was embedded more evenly to improve the imperceptibility quality. Based on the test results, this method can improve the peak signal to noise ratio (PSNR) quality by around 1dB to 2dB while still maintaining the robustness of the watermark compared to the previous method without edge area selection, and dual-stage Arnold transform.

Keywords: Edge detection, Dual-stage Arnold transform, Singular value decomposition, Tchebichef transform, Video watermarking.

1. Introduction

Digital watermarking is one of the popular methods used to authenticate data, especially multimedia data. In general, it works by embedding a watermark on the media cover. Many cover media are used, such as images, audio, and video. Watermarking on images is currently the most studied, but video media has greater complexity than images, making it a challenge and opportunity to develop watermarking methods on video. The video consists of a collection of images (frames) and audio so that the size becomes larger [1]. Watermarks can also be embedded in all video components, but this of course, has its own advantages and disadvantages. The more watermarked elements, the more robustness, but otherwise, the video quality will decrease drastically due to the large payload, so a wiser method is needed to determine the embedding of the watermark.

In video watermarking research, most of the embedding is done on the video frame [1–3]. Because a video has many frames, not all frames are watermarked. Frame selection can be made with various algorithms, such as in research [1], frame selection is based on the linear congruential generator (LCG) method, while study [2] uses the shuffle method based on the fisher-yates concept. Another technique uses the fibonacci sequence to determine the frame selection key [3]. The selection of frames based on the LCG, fisher-yates concept, and fibonacci methods is only used to authenticate but the frames are chosen randomly so they cannot take advantage of the most optimal frame features to increase imperceptibility.

Inspired by the many steganographic methods that propose embedding the edge area [4, 5]. The edge area was chosen because it has a greater tolerance for changes in pixel values due to distortion that occurs in the embedding process. Watermarking and steganography have similarities, where both are derivatives of hiding data. The difference is that watermarking protects the copyright of cover images, while steganography protects secret messages [6]. From this similarity, it can be hypothesized that using the edge area wisely, it can logically improve the quality of the watermarked image.

For the watermarking method to be more effective, many studies are designed to make more adaptive methods based on learning and optimization, such as research [7] using optimization techniques in determining the alpha value to embed the watermark. Next on research [8], developing embedding methods on the alpha value and two other parameters to determine the embedding radius, there is also an optimization technique by identifying the most optimal embedding region [9]. However, this method requires computational costs that are not cheap in the process.

Therefore, this research proposes a watermarking method for video by selecting frames based on the edge area. Then to optimize the embedding, scrambling media cover is carried out so that the edge area can be spread out and the watermark can be embedded more evenly so that the imperceptibility quality can be increased. The scrambling method used is the arnold transform which is carried out in two stages.

This paper is organized into five sections, the first of which is an introduction to this section. The second section is preliminaries that explain the methods and theories that inspired the methods proposed in this research. The third section describes the proposed method. The fourth section discusses the results and discussion, and finally, the fifth section describes the conclusions of the proposed method.

2. Preliminaries

2.1 Edge areas

Video is a collection of frames (images) combined with audio. Discussing frames in a video is closely related to the image area based on its edges. The image area consists of the edge area and the non-edge area. The edge area consists of image pixels with relatively more significant differences than the neighbouring pixel values. The edge area of the image is detected using various methods such as Canny, Sobel, Prewitt, Robert, etc. [10]. But the Canny method is a detection method that is widely used because it has high accuracy and precision and has one response at the edge [5]. In data science, the edge hiding area is often used as a larger message storage area than the non-edge area. This area was chosen because it has a greater tolerance for pixel value distortion [4].

Several studies have also utilized this area in their methods in image watermarking, such as in research [11, 12]. In research [11], edge detection is applied to the HH subband on the wavelet transform to improve the imperceptibility and robustness of the watermark. While in research [12], The insertion is based on the human visual system (HVS) by measuring entropy and edge entropy. Although both of them do not directly embed the edge area, logically, these two studies inspire to take advantage of edge detection to have the best video frame for embedding the watermark.

2.2 Discrete Tchebichef transform (DTT)

Discrete Tchebichef transform is an alternative transformation that has similarities to the discrete cosine transform (DCT), this transformation has advantages in computational speed because it can reduce the complexity of calculations [13], especially when compared to DCT. This transformation is an orthonormal tchebichef polynomial, which uses a recursive polynomial $r_p(x)$ to transform the image, where x defined $\in$ $0,1,\dots N-1$ [14]. DTT has been widely implemented in watermarking methods, such as in research [15, 16] for image and research [1], [17] for video. In implementing it, DTT is mostly done on image blocks, where the image is generally divided into smaller sizes such as 8×8 or 4×4, even 2×2. To get robustness, watermarks are usually embedded in each block's low coefficient. DTT can be calculated by Eq. (1).

$$T_{pq} = \sum_{x=0}^{N-1}\sum_{y=0}^{N-1} r_p(x) r_q(y) f(x,y) \quad (1)$$

Where p,q is the order of DTT; x,y are spatial pixel coordinates; $f(x,y)$ is the pixel value based on the x,y coordinates; and $p,q,x,y = 0 \dots N-1$. Next $r_0(x), r_1(x)$, and $r_\mathrm{p}(x)$ can be calculated by:

$$r_0(x) = \frac{1}{\sqrt{\mathrm{N}}} \quad (2)$$

$$r_1(x) = 2x + 1 - \mathrm{N}) \sqrt{\frac{3}{\mathrm{N}(N^2-1)}} \quad (3)$$

$$r_p(x) = (\mathrm{A}_1 \mathrm{x} + (\mathrm{A}_2) r_{\mathrm{p}-1}(x) + A_3 r_{\mathrm{p}-2}(\mathrm{x}) \quad (4)$$

$$A_1 = \frac{2}{p}\sqrt{\frac{4p^2-1}{N^2-p^2}} \quad (5)$$

$$A_2 = \frac{1-\mathrm{N}}{p}\sqrt{\frac{4p^2-1}{N^2-p^2}} \quad (6)$$

$$A_3 = \frac{p-1}{p}\sqrt{\frac{2p+1}{2p-3}}\sqrt{\frac{N^2-(\mathrm{N}-1)^2}{N^2-p^2}} \quad (7)$$

To do the inverse DTT can be done with Eq. (8).

$$f_{(xy)} = \sum_{p=0}^{N-1} \sum_{q=0}^{N-1} T_{pq} r_p(x)\, r_q(y) \quad (8)$$

2.3 Singular value decomposition (SVD)

SVD is a numerical analysis method that is widely used for various image processing applications [18], which can also be implemented in video watermarking [1, 19, 20]. This method performs a numerical analysis by decomposing the original matrix (Z) with size ($M \times N$) of rank r (the rank of a complex matrix Z that represents a specific value of a non-zero singular value) into three matrices of the same size. These three matrices are U, V and S. The U and V matrices are orthogonal matrices, while the S matrix is a "pseudo-diagonal" matrix or more commonly referred to as singular matrices. [21, 22]. SVD can be calculated by Eq. (9).

$$Z = U \times S \times V^T = \sum_{i=1}^{n} \sigma_i \times u_i \times v_i$$
$$S = \begin{Bmatrix} \sigma_i & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \sigma_n \end{Bmatrix} \quad (9)$$

Where S is a matrix where the r diagonal of the first matrix terms is positive, all the others being null. The r non-zero terms i are called singular values of Z.

3. Proposed method

This section describes the process of the proposed method inspired by research [1]. The proposed method combines DTT and SVD to produce a watermarked video that is resistant to various attacks, where DTT is strong against compression attacks and added noise. At the same time, SVD is resistant to geometry and cropping attacks. To improve imperceptibility, edge detection is used to get the best frame to optimize imperceptibility. In general, watermarking has two main processes, namely embedding and extraction, the explanations are explained in sub-chapters 3.1 and 3.2.

3.1 Embedding steps

At this stage, two primary inputs are needed: video as a cover media and a watermark in the form of a binary image. In detail, the embedding stage is carried out as follows:

1. At the initial stage, all frames from the video will be extracted and then carried out the edge detection process.
2. Count the number of border areas in each frame, then select the frame that has the highest number of border areas. Save the chosen data frame for the watermark extraction process.
3. Convert the color space of the selected frame from RGB to YCbCr, using Eq. 10. The purpose of this color space conversion is to be able to use the Y channel as an embedding to increase robustness.

$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.1687 & -0.3313 & 0.5 \\ 0.5 & -0.4187 & -0.0813 \end{bmatrix} . \begin{bmatrix} R \\ G \\ B \end{bmatrix} + \begin{bmatrix} 0 \\ 128 \\ 128 \end{bmatrix} \quad (10)$$

4. Perform scrambling on the selected Y channel using Arnold transform so that the edge area is not centred on one part but spread to the whole channel, using Eq. (11).

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} 1 & a \\ b & ab+1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} mod\ M \quad (11)$$

Where x, y are the coordinates of the original pixels, x', y' coordinates after scrambling, a, b are positive integers, and the image size is $M \times M$, then it is done with n iterations. Since the image does not have a size of $M \times M$, perform a two-stage Arnold transformation with a size of 288×288 on the left and 288×288 on the right, so that in the center the image will be transformed twice.

5. Next, do the DTT using Eq. (1) on channel Y, which has been randomized based on a sub-block with a size of 8×8. Then collect the coefficients of 0.0 into a new matrix (YD), see Fig. 2.
6. Do SVD on the YD matrix, then take the singular matrix (S_{YD}), use Eq. 12.

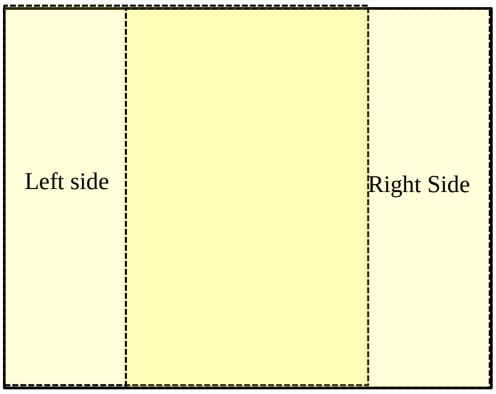

Figure. 1 Illustration of two-stage arnold transform

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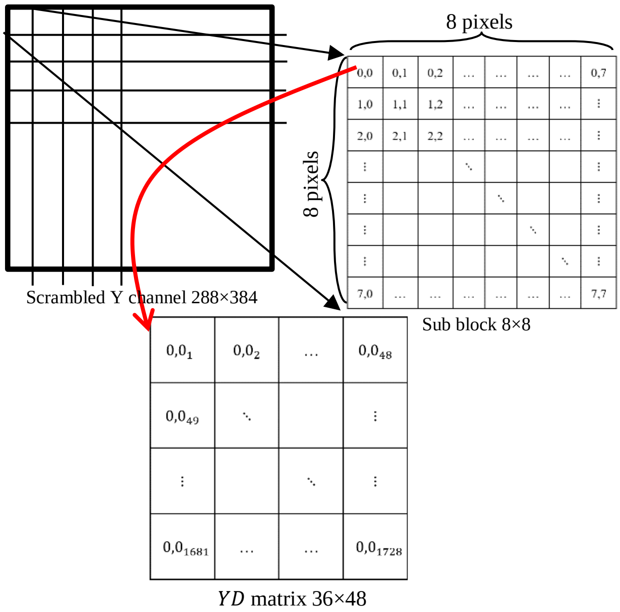

Figure. 2 Illustration of generation YD matrix

$$SVD(YD) = [U_{YD}, S_{YD}, V_{YD}] \quad (12)$$

7. Read the watermark image, then do SVD to get the singular watermark (S_w) matrix, use Eq. (13).

$$SVD(w) = [U_w, S_w, V_w] \quad (13)$$

8. Embed the S_w multiplied by the α parameter to the S_{YD} so that the new singular matrix (S_N) is obtained, using Eq. (14). Where the parameter must be the same for the embedding and extraction process, this parameter is also related to the imperceptibility and robustness qualities.

$$S_N = S_{YD} + (S_w \times \alpha) \quad (14)$$

9. Perform inverse SVD on the YD matrix by replacing S_{YD} with the S_N, so that we get a modified Y (YD'), use Eq. (15).

$$YD' = U_{YD} \times S_N \times {V_{YD}}^T \quad (15)$$

10. Return the modified coefficient 0.0 of the YD' matrix to the corresponding sub-block of 8×8, then inverse DTT using Eq. (8), then arrange each subblock into a modified channel Y (Y').
11. Descrambling the Y' with Eq. (16), use the same values of a, b and iteration when scrambling.

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 1 & a \\ b & ab+1 \end{bmatrix}^{-1} \begin{bmatrix} x' \\ y' \end{bmatrix} mod\ M \quad (16)$$

12. Convert frames from the YCbCr channel to RGB channel with Eq. (17), then use it to replace the selected frame, and get a watermarked video.

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1.402 \\ 1 & -0.34414 & -0.7414 \\ 1 & 1.772 & 0 \end{bmatrix} \cdot \begin{bmatrix} Y' \\ Cb \\ Cr \end{bmatrix} - \begin{bmatrix} 0 \\ 128 \\ 128 \end{bmatrix} \quad (17)$$

As a visual illustration of the embedding process, see Fig. 3. Then measure the quality of the watermarked video which is calculated by the peak signal to noise ratio (PSNR) which can be calculated by Eq. 18 and the mean square error (MSE) which can be calculated by Eq. (19).

$$MSE = \frac{1}{m \times n \times c \times f} \sum_{x=1}^{m} \sum_{y=1}^{n} \sum_{z=1}^{c} \sum_{h=1}^{f} \| V_W(x,y,z,h) - V_o(x,y,z,h) \|^2 \quad (18)$$

$$PSNR_{(dB)} = 10 \times Log\ 10 \left(\frac{255^2}{\sqrt{MSE}} \right) \quad (19)$$

Where m, n, c, and f are width, height, channel, and frame, respectively; x, y, z, and h represents the coordinates of the pixel values. While V_W is the watermarked video and V_o is the original video. This measurement aims to determine the imperceptibility quality of the watermarked video. MSE serves to determine the average value of the square of error, the larger the MSE value means the video quality is getting less good, and vice versa for a larger PSNR value indicates good video quality.

3.2 Extraction steps

The extraction method uses a non-blind technique, where at this stage, it takes several inputs such as watermarked video, original watermark, and selected data frame as the extraction key. In detail, the extraction steps are described as follows.

1. Read the watermarked video then select the frame based on the extracted key.
2. Perform steps 3 to 6 of the embedding process on the original frame and the watermarked frame, so that the So_{YD} matrix for the original frame and the Sw_{YD} watermarked frame matrix is obtained.
3. Perform substitution operations on the two matrices, to get the singular matrix from the extracted watermark image ($S_{w'}$), see Eq. (20).

$$S_{w'} = (Sw_{YD} - So_{YD}) / \alpha \quad (20)$$

4. Perform step 7 in the embedding process to get

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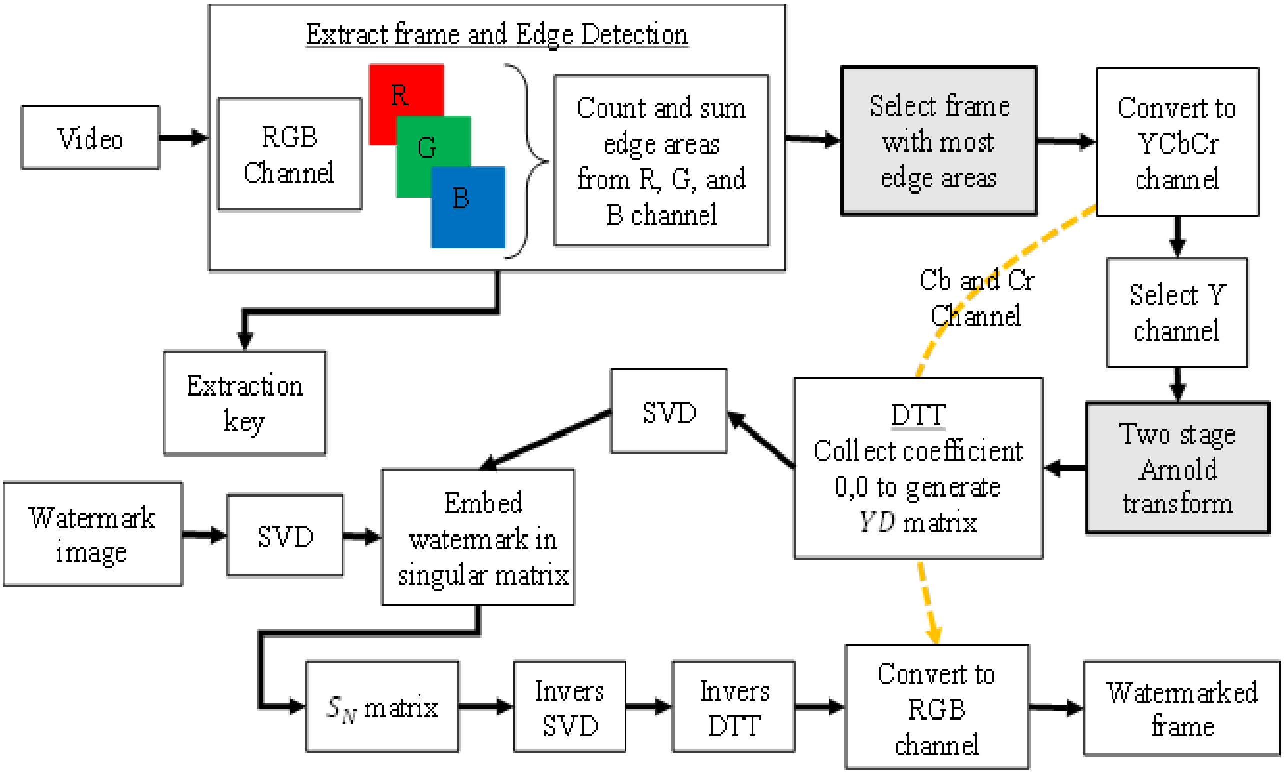


Figure. 3 Visualization of proposed watermark embedding

the U_w matrix and V_w matrix.

5. Get extracted watermark image (w') using Eq. (21).

$$w' = U_w \times S_{w'} \times V_w{}^T \tag{21}$$

6. Measure the quality of the extracted watermark image with a correlation coefficient (cc) that can be calculated with Eq. (22).

$$cc = \frac{\sum_x \sum_y (w_{xy} - \overline{w})(w'_{xy} - \overline{w'})}{\sqrt{(\sum_x \sum_y (w_{xy} - \overline{w})^2)(\sum_x \sum_y (w'_{xy} - \overline{w'})^2)}} \tag{22}$$

Where x, y is the watermark dimension in pixel (width and height), w' is extracted watermark, w is the original watermark, $\overline{w}$ is mean of w_{xy} and $\overline{w'}$ is mean of w.

Figure. 4 Dataset for testing

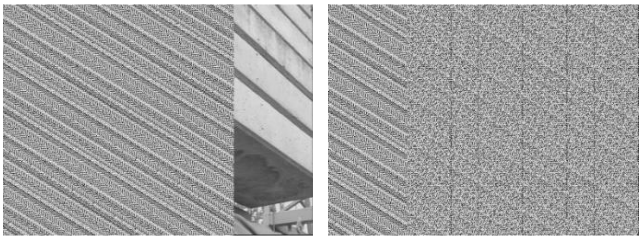
4. Implementation and analysis

This section tests the proposed method using Matlab software with the same public dataset as the research [1]. The dataset used can also be downloaded at the URL https://media.xiph.org/video/derf/. The video used has a 4:3 ratio, with dimensions of 288 × 384. If you download from that URL, all videos have the y4m extension, so they need to be converted to be processed with Matlab. All videos are converted to uncompressed AVI files using Total video audio converter 4. After conversion, all videos are 5 seconds long with a 30 frames /seconds frame rate. While the watermark used is a binary image with a size of 36×48 pixels. The dataset used in this research is presented in Fig. 4.

The most critical step in the proposed method is to find the frame with the most edge area from each video. The results are presented in Table 1. The second important step is to scramble the image on the

Table 1. Frame with the most edge area from each video

Video	Five frames with the most edge area				
	1st	2nd	3rd	4th	5th
akiyo	94	82	81	58	84
bus	2	1	4	50	3
foreman	86	84	140	129	83
hall	31	74	123	111	85



First stage Second stage

Figure. 5 Two-stage arnold transform for selected foreman frame

Table 2. PSNR and MSE results of watermarked video

Video	PSNR (dB)		MSE	
	Method [1]	Proposed	Method [1]	Proposed
akiyo	46.9510	47.8210	1.3121	1.1562
bus	54.4517	54.9873	0.2332	0.2097
foreman	51.1071	53.3593	0.5039	0.3629
hall	51.2981	52.5101	0.4822	0.4356

Y channel using two stages arnold transform. This step functions to randomize the pixels to aim that the edge area will be scrambled throughout the image. Both are the most critical stages to improve the imperceptibility aspect of the watermarked video. An illustration of this process is presented in Fig. 5.

After the entire embedding process is carried out, the imperceptibility quality measurement is carried out using PSNR and MSE. The results of these measurements are presented in table 2.

In Table 2, it appears that the results of this method are also compared with research [1]. This is done because the proposed method is a method development of the study and proves that the proposed method has succeeded in increasing the quality of imperceptibility. The problem that often arises in the development of the watermarking method is that increasing imperceptibility generally impacts decreasing robustness. Therefore, with the same dataset, we also tested the robustness aspect of the proposed method. This is done this by attacking the watermarked video, such as a) blurring with fspecial (disk, 3), b) cropping the image with a size of 128×128 pixels on the top left side, c) compression with 50 % quality, d) compression with 10 % quality, e) flip frame horizontally, f) flip frame vertically,

Table 3. CC results of extracted watermark

attack	akiyo	bus	foreman	hall
a	0.9364	0.9742	0.9298	0.8674
b	0.9171	0.9436	0.9219	0.8730
c	0.9392	0.9748	0.9308	0.8700
d	0.9392	0.9747	0.9306	0.8696
e	0.9385	0.9742	0.9305	0.8706
f	0.9390	0.9748	0.9308	0.8702
g	0.9327	0.9678	0.9256	0.8627
h	0.9397	0.9669	0.9538	0.9139
i	0.9390	0.9747	0.9306	0.8696
j	0.9385	0.9743	0.9305	0.8705
k	0.9324	0.9684	0.9250	0.8628
l	0.9402	0.9748	0.9306	0.8701
avg	**0.9360**	**0.9703**	**0.9309**	0.8725
method [1] avg	**0.9360**	0.9702	**0.9309**	**0.8726**

g) Gaussian noise 0.05, h) histogram equalization, i) 50 % rescaling, j) Rotate 180°, k) salt and pepper 0.1. Fig. 6 presents a sample frame after the attack.

After the attack is carried out, watermark extraction is carried out on the video. The watermark extraction results are measured by the correlation coefficient, which can be measured by Eq. (22). The measurement results are presented in table 3.

Table 3 presents the results of the cc measurement of each video for each type of attack. It appears that the results presented show that the resistance of the watermark to various attacks is very strong, this is evidenced by the cc value approaching the value inline l (no attack) and approaching the average value. But this method does have a few drawbacks, as unattended extraction cannot produce perfect cc values. This is due to several transformation processes and color space conversions. However, this is quite comparable to the strong robustness produced. The average robustness value is also similar to the method [1], which means it can be concluded that this method has succeeded in increasing imperceptibility by maintaining robustness.

Furthermore, we also did some comparisons with other methods that use the same video cover with the same type of watermark, namely research [2] and [23]. Method [2] has the same technique, namely using frame selection, while method [23] has similarities in using a combination of two different transformations.

From the results presented in Table 4, it appears that in terms of imperceptibility quality, the proposed method has advantages compared to the two methods. This is because the frame selection is based on the

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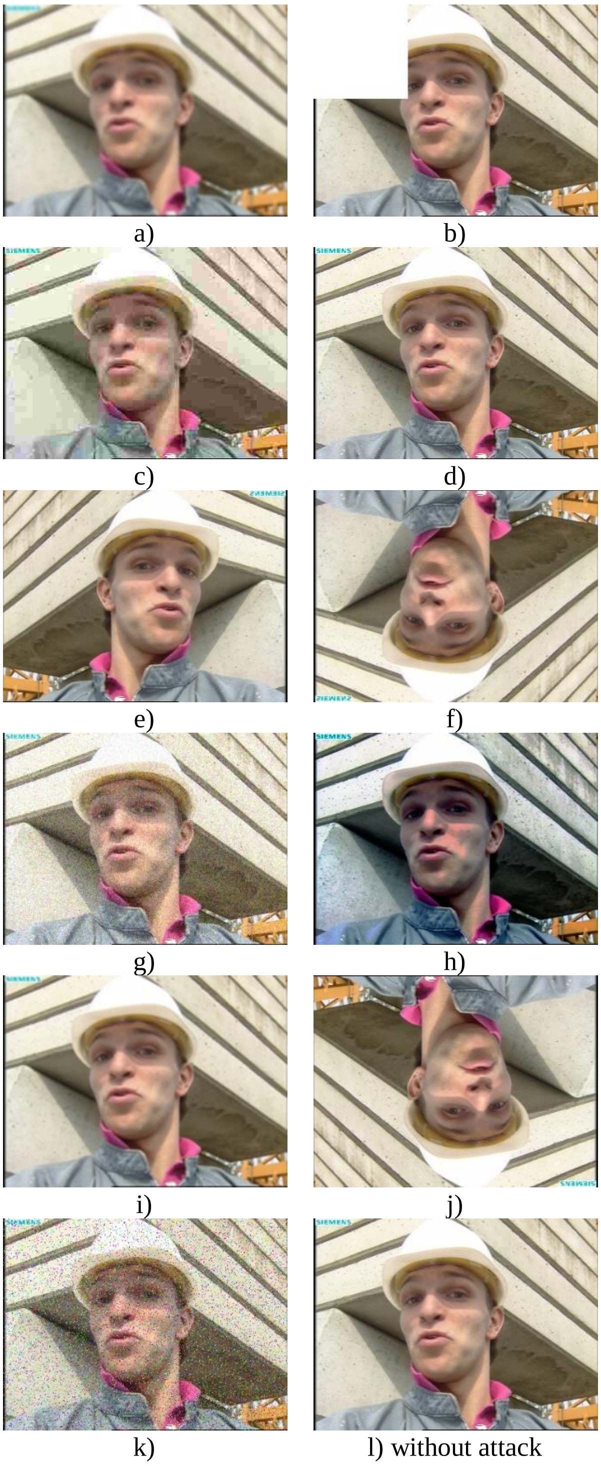

Figure. 3 Sample frame of foreman with the attack(a-k) and without attack (l)

edge features of the image. This feature has a significant effect on improving the imperceptibility aspect. While the two methods above do not use a feature-based frame selection technique and only rely on domain transformations for watermark embedding. Theoretically, our proposed method relies more on improving imperceptibility. But we managed to maintain the robustness level of the watermark by using a combination of the applied tchebichef and SVD transformations. Proven in Table 5 robustness, the proposed method excels at cropping attacks, adding noise and histogram equalization. Meanwhile, based on the observations from Table 5, it appears that the method [2] is able to perform the extraction perfectly, while the method [23] and the proposed method cannot perform watermark extraction perfectly even without attacks. However, the average robustness value of the proposed method is superior to the other two methods. This means that this method has a significant contribution both in terms of imperceptibility and robustness.

Table 4. PSNR (dB) results of watermarked video

Video	**Method**		
	Method [2]	**Method** [23]	**This Method**
akiyo	41.50	-	47.8210
foreman	41.51	45.4147	53.3593
hall	41.72	-	52.5101

Table 5. Correlation results of extracted watermark from foreman video

Attack	**Method**		
	Method [2]	**Method** [23]	**This Method**
Without attack	**1.000**	0.994	0.9306
Cropping	0.900	0.785	**0.9219**
Gaussian Noise	0.810	0.562	**0.9256**
Rescaling	**0.990**	0.756	0.9306
Histogram Equalization	0.8867	-	**0.9538**
Salt and pepper	**0.939**	-	0.9250
Average	0.9210	0.7743	**0.9313**

5. Conclusions

The main contribution of this research is to improve the imperceptibility quality of watermarked video with frame selection technique and two-stage Arnold transform. With this method, an average quality improvement of about 1 dB PSNR on watermarked video is produced compared to the same method without the frame selection technique. The embedding technique is performed using a combination of tchebichef and SVD transformations. To maintain the robustness, the coefficient of 0.0 on tchebichef and the singular matrix on SVD were chosen, both performed on the luminance channel. Based on the test results, this method is proven to be able to maintain the robustness performance of the

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watermark, with an average correlation coefficient value of 0.93. However, shortcomings still need to be corrected in the next research, namely in the extraction process on watermarked videos without attacks that have not produced a perfect correlation coefficient.

Conflicts of interest

We wish to confirm no known conflicts of interest associated with this publication. There has been no significant financial support for this work that could have influenced its outcome. We also confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed.

Author Contributions

Conceptualization, Nova Rijati; Methodology, Nova Rijati; Software, De Rosal Ignatius Moses Setiadi; Validation, Pulung Nurtantio Andono, and Nova Rijati; Formal analysis, Nova Rijati; Investigation, Nova Rijati, and Pulung Nurtantio Andono; resources, Pulung Nurtantio Andono; data curation, Nova Rijati; writing—original draft preparation, Nova Rijati; writing—review and editing, Pulung Nurtantio Andono and De Rosal Ignatius Moses Setiadi; visualization, Nova Rijati and De Rosal Ignatius Moses Setiadi; supervision, Nova Rijati; project administration, Nova Rijati.

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Appendix

Table 6. Notation list

Notation	Definition
a, b	Integer parameter of Arnold transform
B	Blue channel of RGB colour space
cc	Correlation coefficient
Cb	Chrominance blue channel of YCbCr colour space
Cr	Chrominance red channel of YCbCr colour space
$f(x, y)$	pixel value based on the x, y coordinates (spatial domain)
G	Green channel of RGB colour space
h	Number of frames
M, N	Size of image or matrix
MSE	Mean square error
p, q	Order of Tchebichef transform
$PSNR$	Peak signal to noise ratio
r_p and r_q	Recursive polynomial
R	The red channel of RGB colour space
S	Singular matrix of SVD
S_N	Modified singular matrix (after embedding)
So_{YD}	Singular Matrix of the original video
S_w	Singular matrix of SVD results of the watermark image
Sw_{YD}	Singular matrix of watermarked video
$S_{w'}$	Singular matrix of the extracted watermark
S_{YD}	Singular matrix of SVD results of YD matrix
T_{pq}	Tchebichef transform result
U and V	Orthogonal matrices of SVD
U_w *and* V_w	Orthogonal matrices of SVD results of the watermark image
U_{YD} *and* V_{YD}	Orthogonal matrices of SVD results of YD matrix
V_o	Original video
V_W	Watermarked video
w'	Extracted Watermark
Y	Luminance channel of YCbCr color space
YD	a matrix containing a coefficient of 0,0 of Tchebichef transform
Z	Original matrix before SVD
α	Parameters for setting the embedding level