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Digital Watermarking of Video using DWT, PCA and Arnold Scrambling Technique applied on a Binary Watermark

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Abstract: In this paper analysis have been performed for a good trade-off between the perceptual quality of the video after watermarking and the robustness of the video against various attacks by embedding the binary watermark into the video frame. The embedding and the extraction of watermark is done in the high frequency domain of Discrete Wavelet Transform since small modifications done in this domain are not perceived by human eye. Arnold Cat Map Scrambling technique is used in the algorithm, which is applied on the binary watermark before embedding to provide some level of security. In the paper four watermarking algorithms are presented to do a comparative study. The normalized correlation and bit error is used to compute the measure of the extracted watermark. The experimental results shows high imperceptibility and high robustness against several attacks especially noisy attacks and filtering attacks in all the cases. The comparison has been shown in the result section.

Keywords: Digital Video Watermarking, Discrete Wavelet Transform, Principal Component Analysis, Arnold Cat Map.

I. INTRODUCTION

In recent years, the advancement in the digital multimedia technologies has brought many facilities in reproduction, transmission and data manipulation. However this advancement has also brought the problem such as copyright issues. For copyright protection of digital multimedia, watermarking [1] has been proposed. A signal (watermark) is embedded into the data which will indicate whether the content is copyrighted or not. Most of digital video watermarking schemes are based on the techniques of image watermarking. Video watermarking [2] requires specific approaches as it is characterized by temporal and inter frame characteristics. There are two categories for embedding the watermark [3] in a video frame based on the domain which is used for hiding the watermark bits namely the spatial domain and the transform domain. The first one is the spatial domain watermarking where embedding and detection is performed by directly manipulating the pixel intensity value of the video frame. Least significant bit (LSB) is the simplest technique in the spatial domain techniques [4] which directly modifies the intensities of some selected pixels. The second category is the transform domain watermarking, in which the watermark is embedded by changing the frequency components of the video frame. The transformation adopted may be Discrete Cosine transform (DCT), Discrete Fourier Transform (DFT) and Discrete Wavelet transform (DWT) etc. After Applying transformation, the watermark is embedded in the transformed coefficients such that watermark is not visible. The transform domain watermarking scheme are relatively more robust than the spatial domain watermarking particularly in lossy compression, noise addition, pixel removal, cropping, rescaling and rotation.

Discrete wavelet transform (DWT) is computationally more efficient than other transforms like DFT and DCT because of its excellent time-frequency localization properties, DWT is very suitable to identify areas in the host video frames where watermark can be embedded imperceptibility. It is known that there exists some amount of correlation between wavelet coefficients even after the decomposition of the video frame.

Wang et al. [5] adopt a key dependent wavelet transform. To take advantage of the localisation and multi resolution property of the wavelet transform. Tao et al. [6] put forward a discrete wavelet based multiple watermarking algorithm, where to improve the robustness the watermark is embedded on the LL and HH sub bands. Wang and Lin [7] proposed a tree based watermarking algorithm. Lou et al. [8] introduce an integer wavelet to protect the copyright of digital data by utilizing encryption technique to enhance the security.

Yung et al. [9] proposed a multiple logo watermarking scheme by on integer wavelet. Where the watermark is permuted using the Arnold transform and is embedded by modifying the coefficients of the HH and LL sub bands. Lin et al.[10] proposed a DWT based blind watermarking scheme by scrambling the watermark using the chaos sequence. Jeebananda Panda et al.[11] proposed a hybrid watermarking scheme based on integer wavelet and Singular value decomposition, where watermark is embedded after performing a chaotic scrambling.

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Principal component analysis (PCA) has the property of removing the correlation among the data and is used to hybridize the algorithm i.e. wavelet coefficients, which helps in distributing the watermark bits over the sub-bands used for embedding thus resulting in robust watermarking scheme which is robust to almost all attacks. The PCA can be used in different ways in image and video watermarking methods. Here we have presented a new approach that incorporates wavelet transformation, principal component analysis and Arnold cat map scrambling technique. It was found that the proposed technique is robust to a wide range of attacks.

Section II presents the proposed watermarking method and Section III shows experimental results of the proposed method. Conclusion is presented in Section IV.

II. RELATED BACKGROUND

This section briefly describes the techniques and methods that have been used by the watermarking schemes in the paper, namely. The discrete wavelet transform, Principal component analysis and the Arnold transform.

A. Discrete Wavelet Transform

The DWT is commonly used in signal processing applications. 2D Discrete Wavelet Transform (DWT) decomposes a video frames into sub images, 3 details and 1 approximation. The approximation sub images is lower resolution approximation image (LL) however the details sub images are horizontal (HL), vertical (LH) and diagonal (HH) detail components. The main advantage of wavelet transform is its compatibility with the model aspect of the Human Visual System (HVS) as compared to FFT or DCT. In general most of the image energy is concentrated at the lower frequency coefficient sets LL and therefore embedding watermarks in these coefficient sets may degrade the image significantly. Embedding in the low frequency coefficient sets, however, could increase robustness significantly. On the other hand, the high frequency coefficient sets HH include the edges and textures of the image and the human eye is not generally sensitive to changes in such coefficient sets. This allows the watermark to be embedded without being perceived by the human eye. For a one level decomposition, the two dimensional discrete wavelet transform of the image function f(x,y) can be written as

$$\mathrm{LL} = [(f(x,y) * \phi(-x)\phi(-y))(2n,2m)]_{(n,m)\in Z^2} \quad (1)$$

$$\mathrm{LH} = [(f(x,y) * \phi(-x)\psi(-y))(2n,2m)]_{(n,m)\in Z^2} \quad (2)$$

$$\mathrm{HL} = [(f(x,y) * \psi(-x)\phi(-y))(2n,2m)]_{(n,m)\in Z^2} \quad (3)$$

$$\mathrm{HH} = [(f(x,y) * \phi(-x)\phi(-y))(2n,2m)]_{(n,m)\in Z^2} \quad (4)$$

B. Principal Component Analysis

Principal component analysis (PCA) is a mathematical procedure that is concerned with data reduction and interpretation by explaining the variance-covariance structure of the data with the help of linear combination of the original variables. Moreover, principal component analysis can also be thought as a mathematical tool that transform a number of correlated variables into uncorrelated variables called the principal components.To obtain the Principal components of matrix I, firstly calculate the covariance matrix

$$C_I = E\{(I - m) \times (I - m)^T\} \quad (5)$$

Where E, m and T denote expectation operation, mean of matrix X and matrix transpose, respectively. The principal components of X are the eigenvectors of C_I which is obtain as

$$C_I\Phi=\lambda\Phi \quad (6)$$

Where Φ and λ are the matrices of the eigenvectors and the eigen values defined as $\Phi=(e_1,e_2,e_3,...,e_n)$ and $\lambda=(\lambda_1,\lambda_2,\lambda_3,\dots,\lambda_n)$. The matrix Φ is an orthogonal matrix called basis function of PCA. Principal component analysis transforms the correlated image into uncorrelated coefficients by taking the inner product of the image with basis function denoted by Φ

$$\mathrm{Y} = \Phi^T I \quad (7)$$

Where Y is the PC matrix which represents the principle component of matrix I.

C. Arnold Cat Map

Two dimensional Arnold cat map shuffles the pixels positions of the original image without changing the pixels gray level intensities. The 2D Arnold cat map can be obtained by

$$X' = [X + pY]mod(n) \quad (8)$$

$$Y' = [qX + (pq + 1)Y]mod(n) \quad (9)$$

Here, (X', Y') represents the new position of (X, Y) after Arnold’s cat transform and n is the dimension of the image. p and q are the initial values in which the sensitivity of cat map depends. Therefore p and q can be used as keys.

The main aim for using the Arnold transform is to provide security to the watermarking scheme, by scrambling the watermark before embedding.

D. Binary watermark

The advantages of binary watermark over the colour watermark are that there is a lot of complexity in embedding a value for each intensity value for a colour watermark or a gray scale watermark. At the same time in the extraction process it is difficult to get a true colour value.

III.THE ALGORITHMS USED

In this section different algorithms are presented which were performed in order to do a comparative study to bring out the proposed method.

A. Scrambled watermark embedded on the principal components of the wavelet coefficients

In this algorithm the host video frame is decomposed to wavelet coefficients using 3 level DWT from there the principal component is calculated and the scrambled watermark which is scrambled watermark using Arnold

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transformism embedded on the principal component. The detailed algorithm for embedding and extraction watermark is discussed in the following

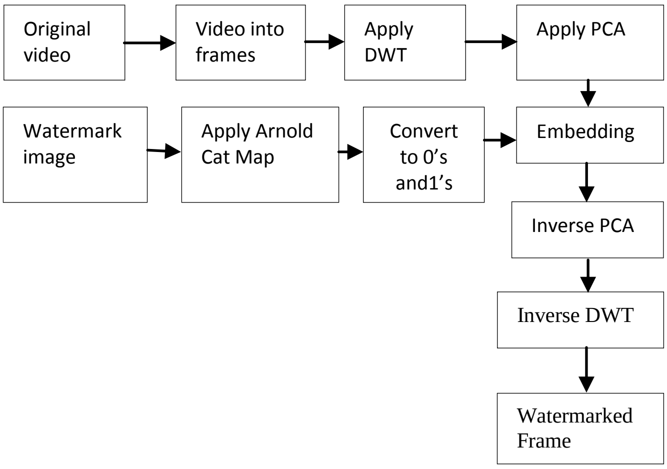

Fig.1. Watermark embedding algorithm for watermarking scheme where scrambled watermark is applied on Principal components of the Wavelet coefficients.

Watermark Embedding

Step1. The Host video is read and is divided into video frames.
Step2. From each frame the RGB components is separated and from there the red component is selected for embedding the watermark.
Step3. A 3 level DWT is performed on the red color component of the video frame. The diagonal (HH_{34}) detailed component of the wavelet transform is selected to embedding the watermark.
Step4. The diagonal (HH_{34}) detailed component is divided into non-overlapping blocks and PCA is applied to obtain the Principal components for embedding the watermark.
Step5. The binary watermark image BW is read and Arnold Cat Map is performing on the watermark image. The initial value and the number of iterations is hold as the security for the proposed watermarking algorithm.
Step6. Convert the scrambled binary watermark into a vector of $BW' = \{bw_1', bw_2', \ldots, bw_{m,n}'\}$ of '0's and'1's.**Step7.** The watermark is embedded into the Principal components PCB of each non-overlapping block using the following Equation.

$$PCB'(m,n) = PCB(m,n) + k.w(m,n) \qquad (10)$$

Where, k is the embedding strength. The PCB' and PCB are the modified principal components and the original principal components.
Step8. Apply inverse PCA on the modified Principal components of the HH_{34} band to obtain the modified wavelet coefficients.
Step9. Apply inverse DWT to obtain the Red component of the frame. Then reconstruct the watermarked frame X_w.

Watermark Extraction

Step1. Read the watermarked video and divide it into video frames.
Step2. From each watermarked frame the RGB colour component is separated and from there component is selected for extracting the watermark.
Step3. Apply 3 levels DWT on the red component of the watermarked video frame. The multi-level DWT is applied to obtain HH_{34} detailed component as same as in the embedding procedure.
Step4. Divide the sub band HH_{34} into non overlapping block.
Step5. Block based PCA is applied on each non overlapping block of HH_{34}subband to obtain the watermarked Principal components PCB'.
Step6. The watermark is extracted from each non-overlapping block using the following equation

$$BW' = (PCB' - PCB)/k. \qquad (11)$$

Where PCB' and PCB are the principal components of watermarked and original video frame and k is the embedding strength.
Step7. Apply Arnold Cat map on the extracted watermark and apply thresholding to obtain the embedded watermark image.

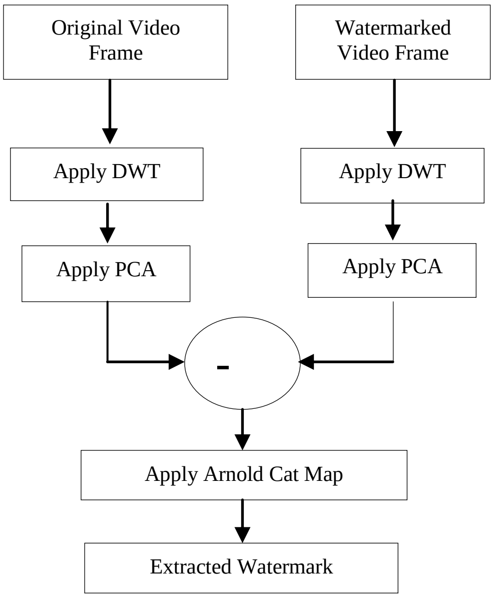

Fig.2. Watermark Extraction Algorithm for watermarking scheme where scrambled watermark is applied on Principal components of the Wavelet coefficients.

B. Scrambled watermark embedded on the wavelet coefficient

In this the host video frame is decomposed using three 3 level DWT and the scramble watermark obtain from Arnold transform is embedded on the wavelet coefficients. The algorithm for embedding and the extraction watermark is discussed in the following.

Embedding

Step1. Read the video frames and select the red component for embedding the watermark.
Step2. Apply 3 levels DWT on the Red component and select HH_{34} sub band and divide it into non-overlapping blocks.

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Step3. Read the binary watermark image.
Step4. Apply Arnold Cat Map on the binary image and convert the scrambled image into vectors of 0's and 1's.
Step5. The watermark bits is inserted on each non-overlapping blocks of the wavelet coefficients as.

$$cH' = cH + k.W \qquad (12)$$

Where cH is the wavelet coefficient obtained after apply 3 level DWT, k is the embedding strength and W is the watermark bit obtained after scrambling. cH' is the modified wavelet coefficient.
Step6. Apply inverse 3 levels DWT
Step7. Merge colour component to obtain the watermarked frame.

Extraction

Step1. Read the watermarked Frame and select the Red colour component for extraction.
Step2. Apply 3 level DWT on the Red colour Component and select HH_{34} sub band and divide it into non-overlapping blocks.
Step3. The watermark bits is extracted from each non-overlapping blocks by as

$$W' = (cH_w - cH)/k. \qquad (13)$$

Where cH_w is the discrete wavelet coefficient obtained after applying 3 levels DWT. And cH is the Discrete Wavelet coefficient of the Host video frame.
Step4. Convert back to binary image and apply Arnold Cat map to the extracted watermark bits to obtain the watermark image.
C. Principal components of the scrambled watermark embedded on the wavelet coefficients
In this, the host video frame is decomposed using 3 level DWT and the principal components of the scrambled watermark is embedded on the obtained wavelet coefficients. The detailed embedding and extraction algorithm is discussed in the following

Embedding

Step1. Read the video frame and select Red colour component for embedding.
Step2. Apply 3 levels DWT to the Red component, select HH_{34} sub band and divide it into non-overlapping blocks.
Step3. Read the binary Watermark.
Step4. Apply Arnold Cat map to watermark image and convert it into 0's and 1's.
Step5. Apply PCA on the scrambled watermark bits.
Step6. The watermark bits is embedded into each non-overlapping blocks of the wavelet coefficients as

$$cH' = cH + \alpha k.W_{pca} \qquad (14)$$

where cH is the wavelet coefficient after 3 level DWT, W_{pca} is the principal components after applying PCA in scrambled watermark bits and αk is the embedding strength.
Step7. Apply inverse 3 levels DWT
Step8. Merge colour to obtain the watermarked frame.

Extraction

Step1. Read the watermarked frame and select the red colour component for watermark extraction.
Step2. Apply 3 levels DWT on the red colour component, select the HH_{34} sub band and divide it into non-overlapping blocks.
Step3. The watermark bits is extracted from each non-overlapping blocks using the equation as

$$W'_{Pca} = (cH_w - cH)/k. \qquad (15)$$

Where cH_w is the coefficient obtains after DWT on the watermarked frame and cH is the coefficient obtain after DWT on the original video frame.
Step4. Apply inverse PCA.
Step5. Convert the extracted watermark into binary image.
Step6. Apply Arnold cat map to obtain the watermark image.

D. The principal components of the scrambled watermark is embedded on the principal components of the wavelet coefficients

In this, the host video frame is decomposed using 3 levels DWT and the principal components of the wavelet coefficients is calculated. The principal components of the scrambled watermark are embedded on the principal components of the wavelet coefficients. The detail embedding and the extraction algorithm is discussed in the following.

Embedding

Step1. Read the Video Frames and select red colour component for watermark insertion.
Step2. Apply 3 levels DWT on the Red component and select HH_{34} sub-band and divide it into non-overlapping blocks.
Step3. Apply based PCA on the non-overlapping blocks.
Step4. Read the binary watermark.
Step5. Apply Arnold Cat Map on the watermark image and convert it to vectors of 0's and 1's.
Step6. Apply PCA on the scrambled watermark image.
Step7. The watermark bits are inserted on each non-overlapping block using the equation

$$PCA' = PCA + k.W_{pca} \qquad (16)$$

Where PCA' is the modified Principal components and PCA is the principal components obtain after applying PCA on the HH_{34} sub-band. k is the embedding strength.
Step8. Apply inverse PCA on the modified Principal components.
Step9. Apply inverse DWT on the obtained.
Step10. Merge the colour component to obtain the watermarked frame.

Extraction

Step1. Read the watermarked video frame and select the red colour component for watermark extraction.
Step2. Apply 3 levels DWT on the red colour component and select the HH_{34} sub band and divide it into non-overlapping blocks.
Step3. Apply PCA on the non-overlapping blocks to obtain the principal component PCAw.

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Step4. The watermark bit are extracted from each non-overlapping using the equation

$$W'_{Pca}W'_{Pca} = (\mathrm{PCA_w} - \mathrm{PCA})/k \qquad (17)$$

Where $\mathrm{PCA_w}$ is the Principal component obtained after applying PCA on the watermarked frame. And PCA is the Principal components of the original Video frame.

Step5. Apply inverse PCA on the extracted watermark bits.

Step6. Convert the bits into binary image and apply Arnold Cat map to obtain the watermark image to obtain the extracted watermark.

IV.EXPERIMENTAL RESULTS

For the experimental analysis sample video of sequence ‘Xylophone.avi’ of dimension 512×512 and binary watermark logo ‘apple.gif’ of size 32×32 is used for all the algorithms. For all the algorithms both the p and q value for Arnold cat map scrambling function is chosen to be 1. The embedding strength for the entire algorithm is set to 22. Fig3. and Fig4. Shows the original video frame and the watermark in the experiment.

Fig.3. Original Frame

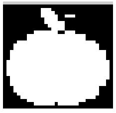


Fig.4. Original watermark

For evaluating the perceptual quality of the watermarking schemes, Peak Signal to Noise Ratio (PSNR) is used which is given by

$$\mathrm{PSNR} = 10\log\frac{256^2}{\mathrm{MSE}} \qquad (18)$$

$$\mathrm{MSE} = \sum_{i=1}^{M}\sum_{j=1}^{N}[I(i,j) - I'(i,j)]^2 \qquad (19)$$

Where M,N are the size of the frame. I, I’ are the original and watermarked video frame.

Also the Bit error is used to measure the robustness the algorithm

$$\mathrm{BER} = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} W(i,j)\oplus W'(i,j)}{M.N} \qquad (20)$$

Where W and W’ is the original and extracted watermark.

Normalised cross-correlation method is also used to measure similarity between the watermark and the extracted watermark

$$\mathrm{NC} = \frac{\sum_i\sum_j W(i,j)W'(i,j)}{\sqrt{\sum_i\sum_j W(i,j)\sum_i\sum_j W(i,j)}} \qquad (21)$$

Where W and W’ are the original and watermark image.

To measure the robustness of the watermarking scheme some attacks are applied to the watermarked frame.

The attack analysis of the watermarking schemes is as shown below.

Algorithm A→ Scrambled watermark embedded on the principal components of the wavelet coefficients.

Algorithm B→ Scrambled watermark embedded on the wavelet coefficient.

Algorithm C→ Principal Components of the scrambled watermark embedded on the wavelet coefficients.

Algorithm D→ the principal components of the scrambled watermark is embedded on the principal components of the wavelet coefficients

Attacks	Bit error			
	Algorithm A	Algorithm B	Algorithm C	Algorithm D
Salt&pepper noise(0.001)	0.0079	0.0107	0.0225	0.0098
Salt&pepper noise (0.01)	0.0615	0.1250	0.2063	0.1025
Poisson noise	0.0225	0.2432	0.2280	0.0586
Speckle noise(0.001)	0.0137	0.7627	0.0371	0.0291
Speckle Noise (0.01)	0.0332	0.2539	0.2329	0.0732
Gaussian noise(0.001)	0.0049	0.2510	0.1672	0.0273
Gaussian noise(0.01)	0.1877	0.3145	0.3936	0.2471
Gaussian Filter[2 2]	0.0303	0.1094	0.1028	0.0488

Attacks	Bit error			
	Algorithm A	Algorithm B	Algorithm C	Algorithm D
Gaussian Filter[3 3]	0.0078	0.0527	0.0090	0.0081
Gaussian Filter[5 5]	0.0079	0.0547	0.0100	0.0090
Median Filter[2 2]	0.0771	0.1063	0.1040	0.1387
Median Filter[3 3]	0.1309	0.3398	0.1484	0.1357
Median Filter[5 5]	0.2964	0.4287	0.3457	0.3032
Mean Filter[2 2]	0.0303	0.1094	0.1028	0.0488
Mean Filter[3 3]	0.4075	0.4600	0.4292	0.4277
Mean Filter[5 5]	0.4575	0.5706	0.4707	0.4756
Histo-equal	0.0527	0.2285	0.0420	0.0031
Gamma-correction	0.0020	0.2070	0.0052	0.0003
Cropping (10%)	0.0020	0.1709	0.2161	0.0031
Cropping (20%)	0.0743	0.1094	0.0859	0.8083
Cropping (30%)	0.1495	0.3359	0.3291	0.9801

Table.1. Comparison between algorithms in terms of bit error

Attacks	Normalised Correlation			
	Algorithm A	Algorithm B	Algorithm C	Algorithm D
Salt & pepper noise(0.001)	0.9927	0.9893	0.9783	0.9901
Salt & pepper noise(0.01)	0.9440	0.7345	0.8192	0.8900
Poisson noise	0.9754	0.8915	0.8011	0.9494
Gaussian noise(0.001)	0.9898	0.8021	0.8373	0.9711
Gaussian noise(0.01)	0.8373	0.6855	0.5895	0.7251
Speckle noise(0.001)	0.9934	0.7627	0.9602	0.9168
Gaussian Filter[2 2]	0.9788	0.9500	0.9024	0.9450

Attacks	Normalised correlation			
	Algorithm A	Algorithm B	Algorithm C	Algorithm D
Gaussian Filter[3 3]	0.9927	0.9473	0.9901	0.9921
Gaussian Filter[5 5]	0.9934	0.9453	0.9845	0.9910
Mean Filter[2 2]	0.9788	0.7890	0.9024	0.9458
Mean Filter[3 3]	0.6136	0.5908	0.5696	0.5823
Mean Filter[5 5]	0.5600	0.4600	0.4919	0.5823
Median Filter [2 2]	0.9125	0.7634	0.8499	0.8300
Median Filter [3 3]	0.7621	0.6602	0.7089	0.7589
Median Filter [5 5]	0.3964	0.5713	0.6438	0.6949
Histo-equal	0.9024	0.7715	0.9446	0.9538
Gamma-correction	0.9982	0.7930	0.9821	0.9993
Cropping (10%)	0.9643	0.8402	0.8205	0.9403
Cropping (20%)	0.9287	0.8906	0.8879	0.9012
Cropping (30%)	0.8503	0.6641	0.6420	0.8083

Table.2. Comparison between Algorithms using Normalised Correlation

From the table it is observed that the Algorithm A i.e. the algorithm where the host video frame is decomposed using 3 level DWT and the scrambled watermark is embedded on the principal component of the wavelet coefficients obtained after decomposing the host video frame gives a better result under attack as compared to the other three algorithm, except for gamma-correction and histogram equalisation attack where the Algorithm 4 i.e. the algorithm where the principal component of the scrambled watermark is embedded on the principal component of the wavelet coefficient obtained after decomposing the host video frame , gives a better result.

For the proposed Algorithm-A, the PSNR value between watermarked and the original video frame without attack is found to be 44.3278 and the Bit error rate of the extracted watermarked is found to be 0.0068, normalised correlation .9892.

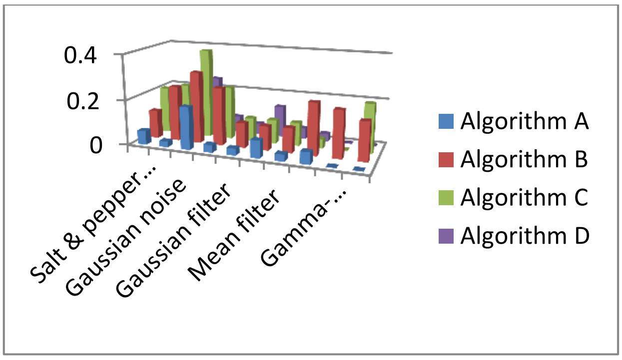


Fig.5. Bar chart for bit error

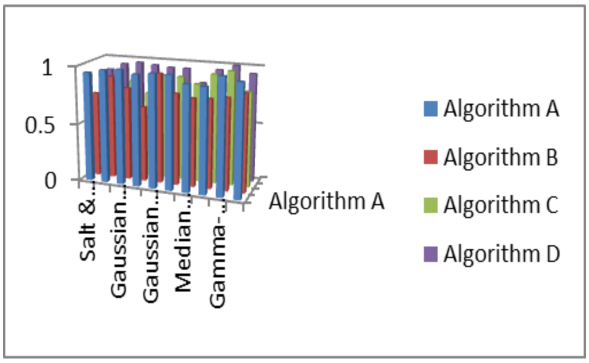


Fig.6. Bar chart for Normalised correlation

Figure below shows some of the watermarked image after attacks and their corresponding extracted watermark.

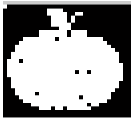
Watermarked Frame after attack	Extracted Watermark
	

Fig.7. after Gaussian Noise attack

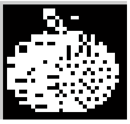
Watermarked Frame after attack	Extracted watermark
	

Fig.8. after cropping attack

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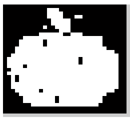
Watermarked Frame after attack	Extracted watermark
	

Fig.9. after Gamma Correction attack

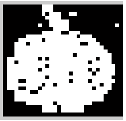
Watermaked Frame after attack	Extracted Watermark
	

Fig.10. After histogram correction attack

V. CONCLUSION

After analysing the performance of all the algorithms after attacks it was found that the proposed watermarking Algorithm-A gives a better performance than the other algorithms. The proposed watermarking method is robust against a wide variety of attacks such as the Gaussian noise, salt and pepper noise attack, speckle noise, Poisson attack, cropping, Gaussian filtering Median filtering, Histogram-equalization and Gamma correction. It is observed all the algorithms could not withstand rotation attack which can be dealt in the future. The proposed watermarking algorithm gives a great level of imperceptibility, which is major requirement for a watermarking technique.

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