

CHAPTER 6

RESULTS AND DISCUSSION

Video watermarking is an area that has gained interest due to the increased demand for content copyright protection. The field has proved to be challenging due to various aspects starting from its huge size, different format used and susceptibility to attacks. In this research work, enhanced solutions that address the problem of watermarking digital video data are considered. The watermarking solutions are provided for both uncompressed and compressed domains. The impact of the enhancement operations proposed has been evaluated to ascertain its performance and this chapter presents the results of these experiments.

6.1. EXPERIMENTAL SETUP

During performance evaluation, 100 videos were used. All the videos were collected from YouTube (www.youtube.com) and <http://www.elementaltechnologies.com/resources/4k-test-sequences>. The files were obtained both in compressed and uncompressed formats. Twelve videos (6 uncompressed and 6 compressed) were taken as test videos, namely, foreman, mobile, phone, cactus, news and coastguard. Sample frames from each video are shown in Figure 6.1a-f. The sample videos selected were with different bit rates. The length of the videos on average ranges between 2.13 minutes to 10.32 minutes. The average frame rate per second is between 23.9 and 29.9.

The copyright images used during experiments are presented in Figure 6.2a and b and nested watermarks using these two images were created using the watermark creation procedure mentioned in Chapter 5. The proposed system was developed using MATLAB 2009 and the experiments were tested using Pentium IV machine with 8GB RAM.







Uncompressed	Compressed
 <p>(860MB)</p>	 <p>(36 MB)</p>
<p>(a) Foreman (352 x 288)</p>	
 <p>1.2GB</p>	 <p>57MB</p>
<p>(b) Mobile (352 x 289)</p>	
 <p>(1.3GB)</p>	 <p>(58.9MB)</p>
<p>(c) Phone (352 x 288)</p>	



Figure 6.1 : Sample Frames

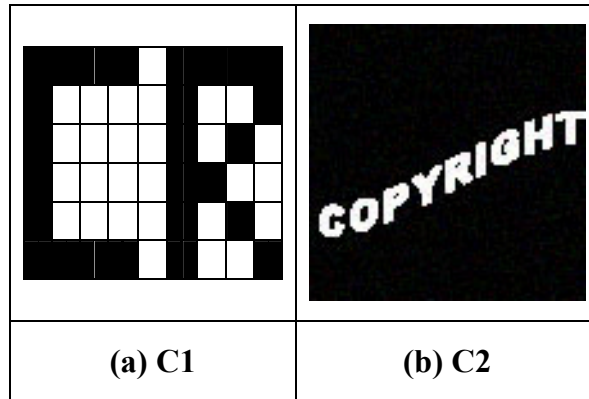


Figure 6.2 : Copyright Images

6.1.1. Performance Parameters

The proposed watermarking algorithms were evaluated for their efficiency on five characteristics. A description of the characteristics and the performance metric used during performance evaluation is shown in Table 6.1.

TABLE 6.1

WATERMARK CHARACTERISTICS AND PERFORMANCE METRICS

Characteristics	Description	Metric Used
Capacity or Payload	Number of bits of watermark image embedded into an image	PSNR
Degree of Transparency or Perceptibility and Imperceptibility	Calculates the perceptual distortion between the original and watermarked image. A watermark is imperceptible if the original cover signal and the marked signal are perceptually indistinguishable else the watermark is called perceptible.	PSNR
Robustness and Security	Resistance to watermark attacks	PSNR,NC
Complexity	Speed of embedding and extracting the watermark	Execution time

In the table, PSNR is Peak Signal to Noise Ratio and NC is Normalized Correlation. The method of using these metrics is discussed below.

- **Peak Signal to Noise Ratio**

PSNR is often used as a quality measurement between the original and an watermarked image. The higher PSNR is the better quality of the watermarked image. It is measured in dB (decibels). To compute the PSNR, the block first calculates the mean-square error using the following equation:

$$\text{MSE} = \frac{\sum_{M,N} [I_1(m,n) - I_2(m,n)]^2}{M * N} \quad (6.1)$$

In the previous equation, M and N are the number of rows and columns in the input images, m and n are the intensity of pixels in rows and column, respectively. Then, the block computes the PSNR for gray scale images using the Equation (4.2). In the equation, $R (=255)$ is the maximum fluctuation in the input frame data.

$$\text{PSNR} = 10 \log_{10} \left[\frac{R^2}{\text{MSE}} \right] \quad (6.2)$$

For color images with three RGB values per pixel, the definition of PSNR is the same except the MSE, which will be the sum over all squared value differences divided by image size and by three. The PSNR for color images with color components, R, G and B is given as below:

$$\text{PSNR} = 10 \log_{10} \left[\frac{255^2}{\frac{\text{MSE}(R) + \text{MSE}(G) + \text{MSE}(B)}{3}} \right] \quad (6.3)$$

In the previous equation, $R (=255)$ is the maximum fluctuation in the input frame data.

- **Normalized Correlation**

The parameter used to analyze the proposed algorithm with respect to attacks is Normalized correlation (NC) and is calculated using Equation (6.4).

$$\text{NC (Normalized correlation)} = \frac{\sum_{i=1}^M \sum_{j=1}^N W(i,j)W'(i,j)}{\sum_{i=1}^M \sum_{j=1}^N W(i,j)^2} \quad (6.4)$$

where $W(i, j)$ denotes the (i, j) th pixel of original watermark, $W'(i, j)$ is the (i, j) th pixel of extracted watermark. $M \times N$ is the size of watermark. NC gives the similarity measure between the original and extracted watermark. The maximum value of NC is 1.

- **Complexity**

The complexity of the proposed algorithm is measured using the execution speed of the proposed algorithms. It is defined as the time taken in seconds to embed and extract the watermark.

6.1.2. Watermark Attacks

The robustness and security of the proposed watermarking techniques is analyzed using a set of processing and geometric manipulations made to the watermarked video frames. The manipulations made are termed as ‘Watermark Attacks’ and is defined as an attempted modification or damage of digital data to identify the hidden watermark illegally. During performance evaluation a total of 13 attacks, categorized into six groups, were selected (Table 6.2). They are, frame attacks (average, drop and swap), geometric attacks (cropping and rotation), removal attacks (collusion), noise attacks (impulsive and Gaussian), processing attacks (Sharpening, blur and brighten) and compression attacks (JPEG and MPEG), were considered. For simplicity, they are referred using the numeric codes presented in Column 3 of Table 6.2.

TABLE 6.2
ATTACKS CONSIDERED

S.No.	Category	Type	Code
1	Frame Attacks	Average (average of current frame and its two nearest neighbors is used to replace the current frame)	1
		Drop (Number of frames dropped)	2
		Swap (exchange of two randomly selected frames)	3
2	Geometric Attack	Cropping (10 pixels)	4
		Rotation (10°)	5
3	Removal Attack	Collusion (Type I)	6
4	Noise Attacks	Impulsive (3 x 3)	7
		Gaussian (3 x 3)	8
5	Processing Attacks	Sharpening (3 x 3)	9
		Blur (3 x 3)	10
		Brighten (3 x 3)	11
6	Compression Attacks	MPEG (50%)	12
		JPEG (50%)	13

6.1.3. Coding Scheme

The study proposed two algorithms for watermarking uncompressed videos and three algorithms for watermarking compressed videos. For ease of discussion, a coding scheme for denoting the various algorithms proposed in the study is used during discussion in this chapter (Table 6.3).

TABLE 6.3
CODING SCHEME

Algorithms	Code Used
Watermarking Techniques for Uncompressed Domain	
Human Visual System Based Watermarking Algorithm	HVS
Geometric Wrapping Based Watermarking Algorithm	GEO
Wavelet Packets Based Watermarking Algorithm	DWPT
Enhanced Wavelet Packet based watermarking algorithm based on Geometric Warping with HVS based criteria using neural network combined with Dynamic Block Selection Algorithm	WGDBS
Enhanced Wavelet Packet based watermarking algorithm based on Geometric Warping with HVS based criteria using neural network combined with Static Block Selection Algorithm	WGSBS
Watermarking Techniques for Compressed Domain	
Discrete Cosine Transformation (DCT) Based Watermarking Algorithm	DCT
DCT-SVD Combined with Clustering Based Watermarking Algorithm	DCT-SVD
Discrete Wavelet Transformation (DWPT) Based Watermarking Algorithm	DWT
DWPT-SVD Combined with Clustering Based Watermarking Algorithm	DWPT-SVD
Feature Point Based Algorithm	FPBA

6.2. EXPERIMENTAL RESULTS OF WATERMARKING ALGORITHMS FOR UNCOMPRESSED VIDEOS

This section presents the results of experiments that were conducted to evaluate the selected characteristics of the watermarking algorithms.

6.2.1 Capacity

The performance of the two proposed algorithms, WGDBS and WGSBS is presented in Table 6.4 for the selected test videos when embedded with the two copyright images.

TABLE 6.4

PSNR (dB) OF WATERMARKING ALGORITHMS FOR UNCOMPRESSED DOMAIN

Video File	Copyright Image C1					Copyright Image C2				
	HVS	GEO	DWPT	WGDBS	WGSBS	HVS	GEO	DWPT	WGDBS	WGSBS
Foreman	35.56	39.15	37.23	42.01	40.61	36.56	39.52	38.20	42.73	41.54
Mobile	34.42	37.65	35.98	40.57	39.05	34.78	38.58	36.33	40.63	39.43
Phone	34.23	37.29	36.02	40.84	38.90	34.31	37.73	36.40	41.71	38.98
Cactus	34.11	37.38	35.57	40.08	38.50	34.91	37.72	35.86	40.86	39.21
News	33.44	36.22	34.86	39.58	38.05	33.73	36.99	35.16	40.47	38.85
Coastguard	34.27	36.96	35.41	40.57	38.63	34.99	37.39	35.82	41.26	38.77

From the results, it can be seen that while both the proposed algorithms, WGDBS and WGSBS, have increased the performance in terms of capacity when compared conventional (HVS and DWPT) and existing (GEO) algorithms, the WGDBS algorithm presents maximum efficiency in terms of capacity. On average, the WGDBS algorithm showed an efficiency gain of 15.47%, 7.88% and 11.89% when compared with HVS, GEO and DWPT algorithms respectively.

Figures 6.3-6.8 shows the PSNR values of different frames for the selected test videos.

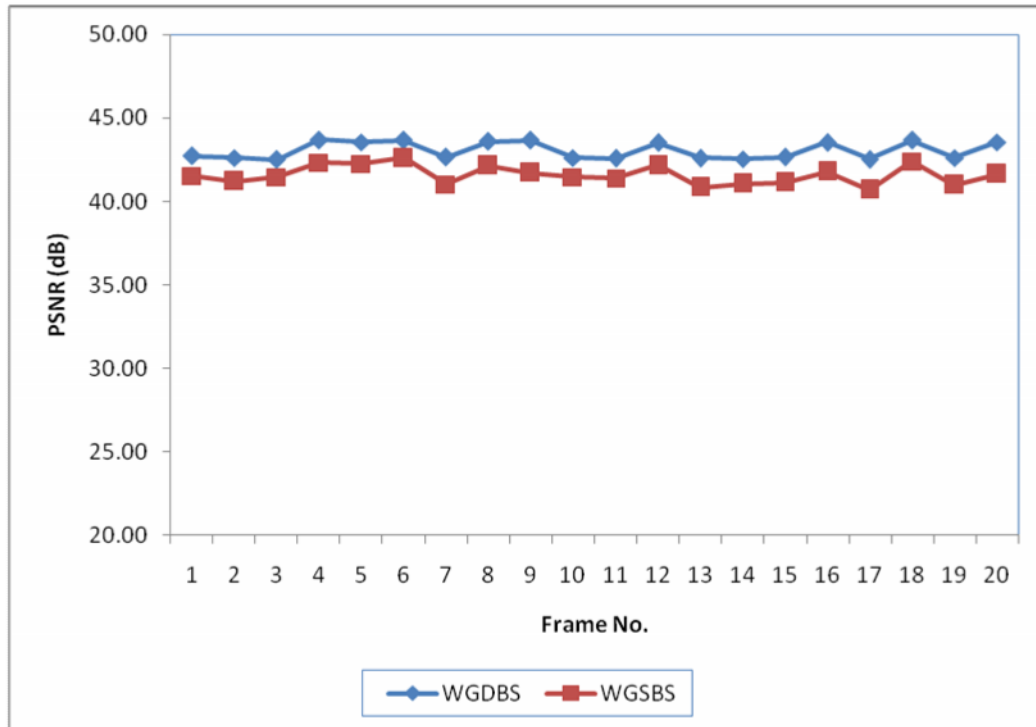


Figure 6.3 : PSNR of Foreman (Uncompressed)

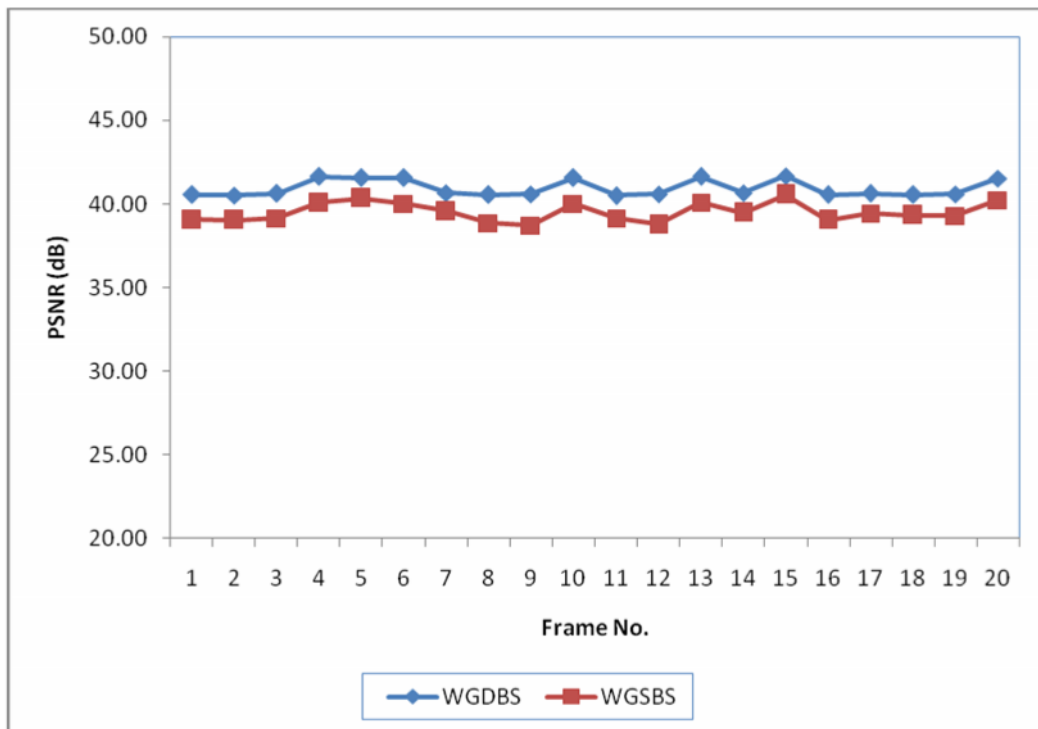


Figure 6.4 : PSNR of Mobile (Uncompressed)

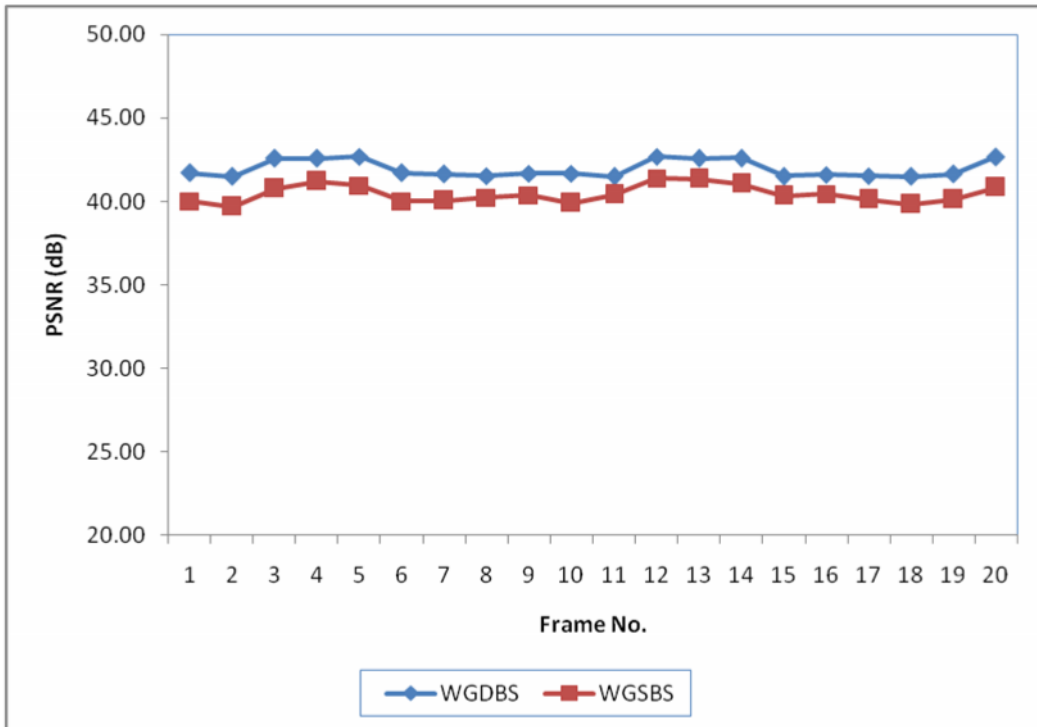


Figure 6.5 : PSNR of Phone (Uncompressed)

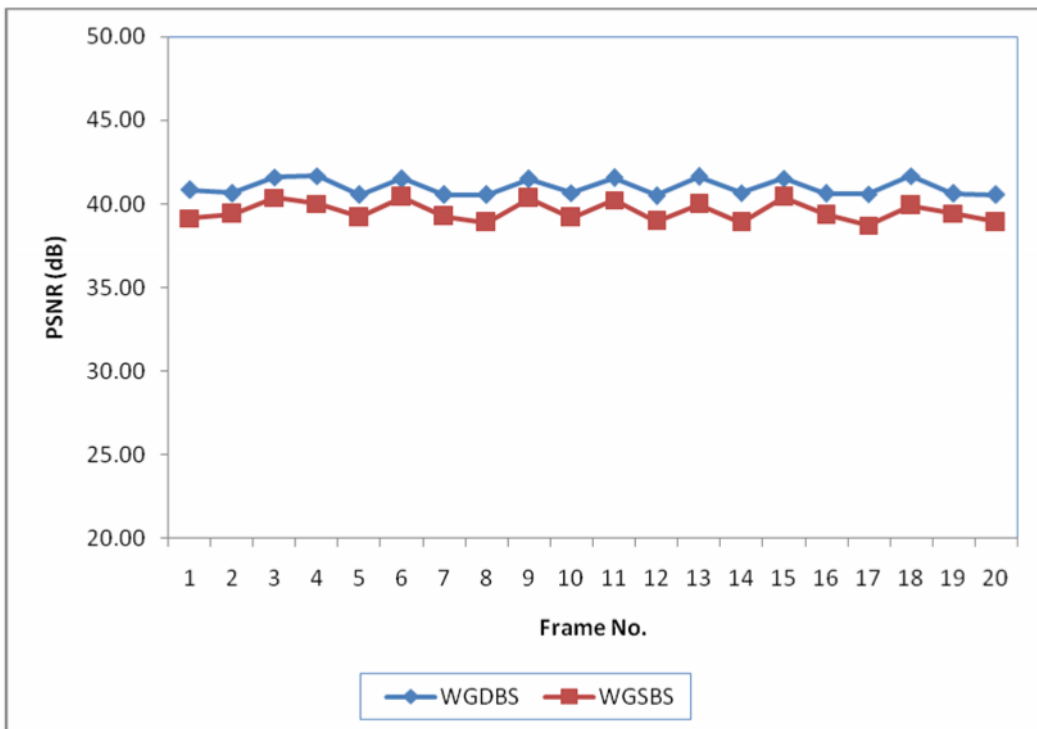


Figure 6.6 : PSNR of Cactus (Uncompressed)

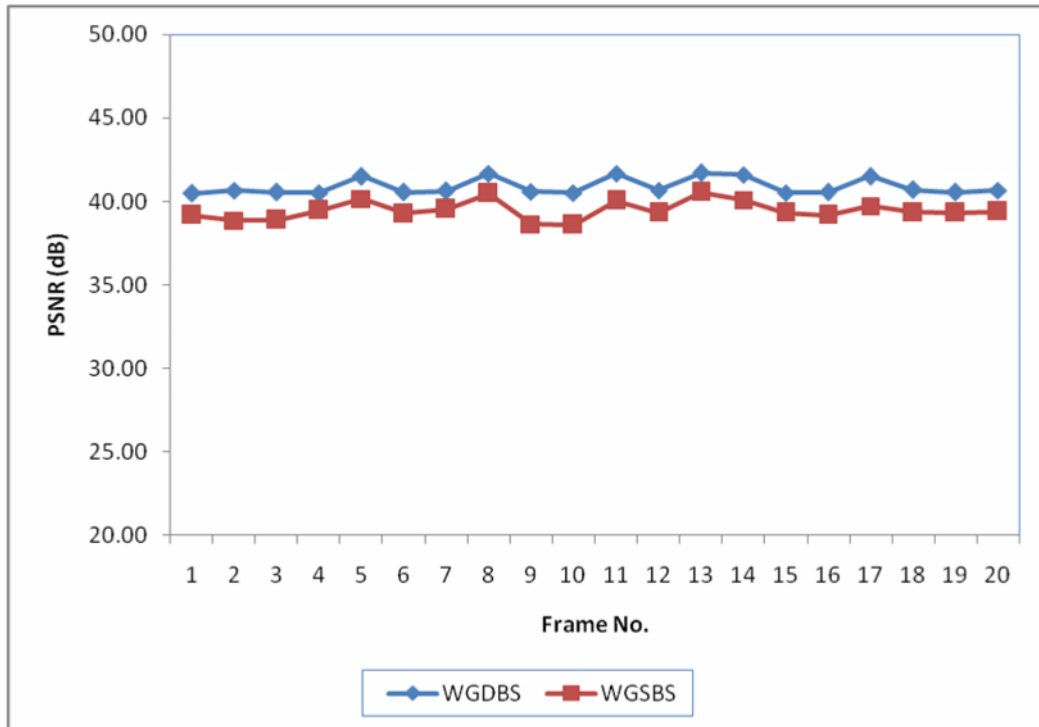


Figure 6.7 : PSNR of News (Uncompressed)

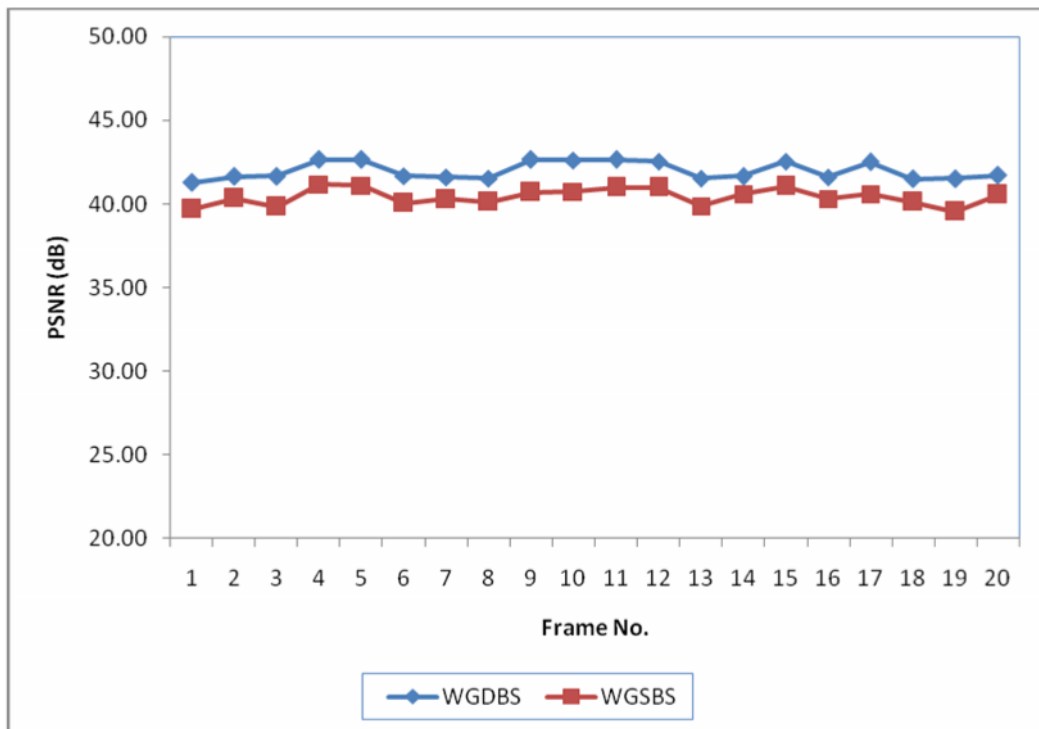


Figure 6.8 : PSNR of Coastguard (Uncompressed)

From the figure results, it is evident that the proposed algorithms are consistent in maintaining the visual quality of the frames. The results also prove that the algorithm satisfy the two main characteristic requirement of watermarking, namely, capacity (payload) and transparency (imperceptibility). This is evident from the high PSNR values obtained by the proposed algorithms which indicate that minimum distortion is introduced by the inclusion of watermark.

6.2.2. Robustness (Security)

The next parameter considered during the evaluation of the proposed watermarking algorithms for uncompressed videos is its robustness against attacks. Tables 6.5 to 6.10 show the PSNR of the original watermark and the detected watermarked images with and without the selected 13 attacks. The NC values obtained for the six selected test videos are shown in Tables 6.11 to 6.16. In the tables code 0 represents No attack and the rest of numeric codes have meanings as given in Table 6.2.

The best result was obtained when no attack was performed. The average PSNR values of HVS algorithm was 42.99dB, GEO algorithm was 43.83dB, DWPT algorithm was 43.79dB, WGDBS algorithm was 48.11dB and WGSBS was 45.56dB. This shows that both the proposed algorithms in uncompressed domain are resistant to attacks and therefore provide maximum security.

The results pertaining to NC values also show maximum performance when no attack was performed on the watermarked video. The average NC values of 0.74, 0.82, 0.77, 0.86 and 0.85 were obtained by HVS, GEO, DWPT, WGDBS, WGSBS algorithms respectively. The near to unity values obtained show that the proposed algorithms are good at resisting attacks and does not degrade watermarked video quality even in the presence of attacks.

TABLE 6.5

ROBUSTNESS (PSNR) – UNCOMPRESSED FOREMAN VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	HVS	GEO	DWPT	WGDB _S	WGSB _S	HVS	GEO	DWPT	WGDB _S	WGSB _S
0	42.85	45.00	44.39	48.32	45.78	42.97	45.85	44.40	48.78	46.65
1	42.82	44.12	43.91	47.69	45.50	43.76	44.69	44.69	47.95	46.21
2	42.70	44.02	43.47	47.67	45.45	43.02	44.58	44.13	48.45	45.70
3	42.68	43.89	43.24	47.55	45.38	42.95	43.93	43.87	48.34	45.69
4	42.04	42.13	42.39	47.04	44.55	42.81	42.81	42.95	47.42	44.73
5	41.93	42.11	42.37	46.81	44.24	41.99	42.42	43.09	46.94	44.60
6	42.39	43.06	42.97	47.24	44.90	42.47	43.76	43.29	48.16	45.53
7	42.64	43.48	43.04	47.51	45.23	43.58	44.39	43.22	48.05	45.95
8	42.50	43.28	43.01	47.38	45.00	42.94	43.77	43.31	48.08	45.85
9	42.30	42.63	42.96	47.22	44.73	42.49	43.35	43.02	47.73	45.61
10	42.18	42.53	42.86	47.10	44.72	42.88	42.72	43.70	47.63	44.72
11	42.05	42.36	42.56	47.06	44.67	42.34	42.90	43.28	47.11	45.40
12	41.73	41.52	42.37	46.74	43.91	41.79	42.32	43.19	46.91	44.70
13	41.42	41.40	41.90	46.24	43.80	42.28	41.53	42.84	46.38	44.10

TABLE 6.6

ROBUSTNESS (PSNR) – UNCOMPRESSED MOBILE VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	HVS	GEO	DWPT	WGDB _S	WGSBS	HVS	GEO	DWPT	WGDB _S	WGSBS
0	42.75	44.20	44.84	48.20	45.15	42.09	45.95	44.09	49.00	46.44
1	43.02	45.24	44.23	48.13	46.50	43.52	45.16	45.00	48.28	46.67
2	43.45	45.06	43.24	48.82	46.12	44.50	45.07	44.55	48.40	45.83
3	42.17	43.58	44.38	48.06	46.31	42.02	44.56	44.26	49.37	46.33
4	43.06	42.56	42.94	48.75	44.19	42.45	43.54	42.86	48.38	44.78
5	42.67	43.14	43.81	46.30	45.53	41.85	44.91	43.64	46.53	44.93
6	42.13	44.12	44.00	48.15	45.99	42.18	43.43	44.21	48.78	45.97
7	42.74	43.98	43.61	48.09	45.77	44.84	45.75	44.12	48.28	45.76
8	43.64	44.02	43.97	47.80	44.64	42.99	43.32	43.72	49.70	45.89
9	43.19	42.71	43.13	48.36	45.87	42.98	44.98	44.81	48.72	46.25
10	42.99	42.56	42.95	48.80	45.63	43.86	43.71	43.42	48.96	44.71
11	42.32	42.34	42.12	48.37	45.30	43.31	42.77	44.46	48.80	45.86
12	41.61	41.92	42.33	46.17	44.32	42.19	42.00	44.06	47.62	44.46
13	42.31	41.99	42.66	46.05	44.85	43.09	42.87	42.79	46.30	45.75

TABLE 6.7

ROBUSTNESS (PSNR) – UNCOMPRESSED PHONE VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	HVS	GEO	DWPT	WGDB _S	WGSBS	HVS	GEO	DWPT	WGDB _S	WGSBS
0	43.41	45.20	44.79	49.77	45.92	42.49	46.50	45.25	48.06	47.66
1	42.62	44.18	43.69	48.90	46.94	43.23	44.75	45.39	48.80	46.34
2	42.76	44.98	43.76	48.53	46.22	43.82	45.07	45.36	49.94	45.95
3	43.25	43.84	44.85	47.05	46.03	43.99	44.75	44.20	49.35	45.80
4	42.58	43.70	43.74	47.77	44.12	43.30	43.82	42.33	48.04	44.52
5	41.69	43.41	43.21	47.02	44.87	41.06	42.57	44.64	46.74	45.09
6	42.38	43.87	42.96	48.34	45.91	42.13	43.83	43.38	49.57	46.43
7	42.51	44.39	43.70	47.14	46.50	44.31	44.37	43.16	48.56	45.60
8	43.31	43.12	43.09	48.17	44.96	42.98	43.04	44.17	48.66	45.01
9	43.03	42.86	43.89	48.95	44.07	42.20	44.19	44.69	48.20	45.33
10	43.49	42.35	42.52	47.47	44.29	42.93	42.29	43.78	47.49	44.97
11	42.76	42.21	42.52	47.86	45.24	43.64	43.48	44.87	47.71	46.37
12	42.54	41.39	43.88	46.34	43.66	42.75	43.19	44.97	47.41	44.24
13	42.13	41.59	42.28	46.29	43.99	43.04	42.07	43.16	47.21	44.16

TABLE 6.8

ROBUSTNESS (PSNR) – UNCOMPRESSED CACTUS VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	HVS	GEO	DWPT	WGDB _S	WGSBS	HVS	GEO	DWPT	WGDB _S	WGSBS
0	43.38	45.07	44.67	48.38	45.95	43.05	45.18	44.33	48.84	46.95
1	43.68	45.41	44.67	48.29	47.71	44.54	46.62	45.68	49.88	47.11
2	43.40	46.17	44.12	49.65	47.07	44.63	45.42	44.41	49.05	45.54
3	42.97	43.73	44.05	48.78	46.98	43.71	45.14	44.46	50.73	46.05
4	44.01	42.38	43.16	49.49	44.36	42.56	44.10	43.32	49.90	44.75
5	43.88	43.69	43.87	47.61	45.19	42.96	44.39	43.46	47.15	45.07
6	43.23	45.68	44.57	48.57	45.69	42.17	44.34	44.57	48.95	46.87
7	43.47	43.27	44.68	48.39	45.84	44.81	46.31	45.69	49.64	45.92
8	43.10	44.02	43.18	47.56	44.22	43.75	44.44	44.97	50.72	46.69
9	43.37	43.79	44.00	49.13	46.35	42.97	45.21	45.85	49.15	47.04
10	42.16	43.33	42.03	48.42	45.62	43.21	43.84	43.44	49.46	45.20
11	43.54	43.58	43.47	48.56	45.57	43.27	42.18	44.97	48.78	46.52
12	41.03	42.24	43.42	46.41	45.17	42.70	43.66	44.10	47.05	45.89
13	42.56	41.42	42.67	46.16	45.57	43.07	42.03	42.79	46.35	46.26

TABLE 6.9

ROBUSTNESS (PSNR) – UNCOMPRESSED NEWS VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	HVS	GEO	DWPT	WGDB _S	WGSBS	HVS	GEO	DWPT	WGDB _S	WGSBS
0	42.33	45.72	45.77	48.69	46.81	43.12	46.54	45.68	48.75	47.40
1	43.93	44.39	44.65	47.76	45.40	44.76	45.30	45.36	47.43	46.55
2	43.57	44.97	43.16	47.80	45.76	43.60	44.47	44.77	49.70	46.05
3	43.66	43.31	43.54	47.67	45.16	42.73	43.02	43.38	49.44	46.90
4	42.09	43.46	42.73	48.12	44.74	43.65	43.65	42.29	47.74	44.60
5	41.62	43.84	43.58	47.29	44.29	41.89	43.65	44.12	47.42	45.76
6	42.78	44.29	42.13	48.92	44.96	42.78	43.33	44.26	49.41	45.68
7	42.14	44.48	44.32	47.51	45.25	44.86	45.07	43.98	48.91	45.35
8	43.15	44.42	43.60	48.55	44.60	43.32	44.91	43.98	48.86	46.33
9	43.32	43.37	43.93	47.13	45.37	43.88	43.55	43.66	47.47	45.10
10	42.04	43.55	43.27	47.26	44.42	42.08	42.01	44.41	48.73	44.98
11	43.58	42.98	42.38	47.40	45.67	43.22	43.17	44.08	47.34	46.25
12	42.09	42.55	42.62	47.52	43.85	41.65	42.88	44.03	46.22	45.62
13	41.34	41.49	42.93	47.10	44.11	43.81	41.64	42.63	46.81	44.33

TABLE 6.10

ROBUSTNESS (PSNR) – UNCOMPRESSED COASTGUARD VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	HVS	GEO	DWPT	WGDB _S	WGSBS	HVS	GEO	DWPT	WGDB _S	WGSBS
0	42.20	45.78	45.32	48.37	45.83	43.50	46.88	44.30	48.55	47.42
1	44.48	46.67	45.62	49.84	46.98	44.23	46.77	44.44	49.76	46.99
2	44.78	45.63	44.54	48.57	46.35	44.63	45.81	45.24	49.99	45.92
3	43.57	44.10	44.54	49.62	46.36	43.00	44.59	44.51	49.57	46.59
4	43.48	43.31	42.34	49.17	45.59	43.50	44.48	42.80	48.02	45.01
5	43.59	44.94	43.65	47.40	45.57	42.39	44.58	44.48	46.73	45.55
6	43.35	44.91	44.37	48.24	45.64	43.21	44.62	44.91	48.10	46.20
7	43.94	43.41	44.73	48.09	45.70	44.81	46.12	45.15	48.13	46.58
8	44.07	44.34	43.72	47.76	44.48	42.33	43.89	44.58	49.12	45.85
9	44.68	43.94	43.62	49.50	46.67	43.17	44.58	45.74	48.11	46.44
10	43.38	42.05	43.67	48.14	46.80	43.50	44.61	44.54	49.72	45.62
11	43.16	42.92	42.78	49.06	46.16	43.23	43.84	44.13	49.70	46.25
12	41.93	42.51	42.15	46.81	44.29	42.30	44.62	42.82	48.09	45.79
13	43.11	41.47	42.77	46.53	45.17	43.15	43.19	43.37	46.27	45.09

TABLE 6.11

ROBUSTNESS (NC) – UNCOMPRESSED FOREMAN VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	HVS	GEO	DWPT	WGDB _S	WGSB _S	HVS	GEO	DWPT	WGDB _S	WGSB _S
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1	0.73	0.81	0.76	0.85	0.84	0.76	0.85	0.79	0.88	0.87
2	0.71	0.80	0.75	0.84	0.82	0.75	0.82	0.77	0.88	0.85
3	0.70	0.79	0.74	0.84	0.82	0.74	0.82	0.77	0.88	0.85
4	0.67	0.75	0.70	0.80	0.79	0.70	0.78	0.73	0.84	0.82
5	0.67	0.75	0.69	0.79	0.78	0.69	0.78	0.73	0.83	0.81
6	0.69	0.77	0.73	0.81	0.80	0.72	0.81	0.75	0.84	0.83
7	0.70	0.78	0.74	0.83	0.82	0.73	0.81	0.76	0.86	0.85
8	0.70	0.78	0.74	0.82	0.81	0.73	0.82	0.76	0.85	0.85
9	0.68	0.77	0.72	0.81	0.80	0.71	0.80	0.76	0.85	0.82
10	0.67	0.76	0.70	0.81	0.79	0.70	0.79	0.73	0.84	0.83
11	0.67	0.75	0.70	0.81	0.79	0.70	0.78	0.74	0.83	0.83
12	0.66	0.74	0.69	0.79	0.77	0.68	0.77	0.71	0.82	0.81
13	0.65	0.74	0.69	0.79	0.77	0.68	0.77	0.72	0.81	0.80

TABLE 6.12

ROBUSTNESS (NC) – UNCOMPRESSED MOBILE VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	HVS	GEO	DWPT	WGDB _S	WGSBS	HVS	GEO	DWPT	WGDB _S	WGSBS
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1	0.76	0.84	0.80	0.88	0.87	0.79	0.88	0.82	0.90	0.89
2	0.73	0.84	0.78	0.88	0.86	0.78	0.84	0.80	0.91	0.89
3	0.73	0.82	0.76	0.88	0.85	0.77	0.85	0.80	0.90	0.88
4	0.70	0.78	0.74	0.83	0.82	0.73	0.81	0.77	0.87	0.86
5	0.70	0.77	0.73	0.83	0.81	0.73	0.82	0.77	0.86	0.83
6	0.72	0.81	0.75	0.84	0.82	0.75	0.84	0.78	0.88	0.86
7	0.74	0.82	0.77	0.87	0.84	0.77	0.83	0.79	0.89	0.88
8	0.74	0.81	0.77	0.85	0.84	0.76	0.85	0.79	0.89	0.87
9	0.71	0.80	0.75	0.85	0.83	0.74	0.83	0.79	0.88	0.85
10	0.71	0.80	0.74	0.83	0.83	0.73	0.83	0.76	0.87	0.86
11	0.69	0.79	0.72	0.83	0.83	0.73	0.81	0.76	0.87	0.87
12	0.69	0.77	0.71	0.83	0.80	0.72	0.79	0.75	0.86	0.83
13	0.69	0.77	0.71	0.82	0.80	0.72	0.81	0.75	0.84	0.83

TABLE 6.13

ROBUSTNESS (NC) – UNCOMPRESSED PHONE VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	HVS	GEO	DWPT	WGDB _S	WGSBS	HVS	GEO	DWPT	WGDB _S	WGSBS
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1	0.72	0.78	0.74	0.83	0.82	0.75	0.82	0.77	0.85	0.85
2	0.68	0.79	0.72	0.82	0.80	0.72	0.81	0.75	0.86	0.84
3	0.68	0.77	0.72	0.82	0.80	0.72	0.80	0.75	0.86	0.83
4	0.66	0.73	0.68	0.78	0.76	0.69	0.77	0.71	0.82	0.81
5	0.65	0.72	0.68	0.77	0.75	0.67	0.76	0.71	0.80	0.79
6	0.68	0.76	0.70	0.80	0.78	0.70	0.80	0.73	0.82	0.81
7	0.68	0.76	0.71	0.82	0.80	0.71	0.79	0.75	0.84	0.83
8	0.68	0.76	0.71	0.79	0.79	0.71	0.80	0.73	0.83	0.82
9	0.65	0.75	0.71	0.78	0.77	0.70	0.79	0.74	0.83	0.79
10	0.65	0.74	0.69	0.79	0.77	0.69	0.77	0.72	0.82	0.82
11	0.64	0.74	0.68	0.78	0.76	0.68	0.76	0.71	0.81	0.81
12	0.64	0.71	0.66	0.77	0.75	0.67	0.74	0.69	0.80	0.79
13	0.62	0.72	0.67	0.77	0.75	0.66	0.76	0.69	0.79	0.77

TABLE 6.14

ROBUSTNESS (NC) – UNCOMPRESSED CACTUS VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	HVS	GEO	DWPT	WGDB _S	WGSBS	HVS	GEO	DWPT	WGDB _S	WGSBS
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1	0.75	0.81	0.77	0.87	0.86	0.77	0.86	0.80	0.88	0.87
2	0.70	0.82	0.76	0.86	0.83	0.75	0.83	0.79	0.88	0.87
3	0.71	0.79	0.73	0.86	0.84	0.74	0.83	0.79	0.87	0.87
4	0.67	0.76	0.71	0.82	0.80	0.72	0.79	0.74	0.85	0.84
5	0.69	0.75	0.71	0.80	0.80	0.71	0.80	0.75	0.83	0.80
6	0.70	0.78	0.72	0.82	0.81	0.73	0.83	0.76	0.86	0.84
7	0.73	0.81	0.76	0.85	0.83	0.74	0.82	0.77	0.88	0.86
8	0.71	0.79	0.74	0.83	0.81	0.75	0.83	0.78	0.87	0.85
9	0.69	0.77	0.74	0.83	0.80	0.72	0.81	0.78	0.86	0.83
10	0.69	0.78	0.72	0.81	0.80	0.71	0.81	0.73	0.85	0.85
11	0.67	0.76	0.71	0.81	0.80	0.70	0.79	0.74	0.85	0.85
12	0.67	0.75	0.69	0.80	0.78	0.70	0.77	0.73	0.84	0.81
13	0.68	0.76	0.68	0.80	0.77	0.69	0.79	0.74	0.82	0.80

TABLE 6.15

ROBUSTNESS (NC) – UNCOMPRESSED NEWS VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	HVS	GEO	DWPT	WGDB _S	WGSBS	HVS	GEO	DWPT	WGDB _S	WGSBS
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1	0.77	0.86	0.79	0.88	0.88	0.80	0.90	0.83	0.92	0.90
2	0.75	0.84	0.79	0.88	0.85	0.78	0.87	0.81	0.91	0.90
3	0.75	0.83	0.77	0.88	0.87	0.77	0.87	0.82	0.91	0.88
4	0.71	0.79	0.74	0.84	0.83	0.75	0.82	0.77	0.87	0.86
5	0.71	0.79	0.73	0.84	0.82	0.73	0.81	0.76	0.86	0.85
6	0.73	0.82	0.76	0.86	0.83	0.76	0.85	0.79	0.89	0.86
7	0.74	0.82	0.77	0.87	0.86	0.77	0.84	0.81	0.90	0.88
8	0.75	0.83	0.77	0.86	0.86	0.76	0.86	0.79	0.89	0.88
9	0.73	0.82	0.77	0.85	0.84	0.75	0.85	0.79	0.89	0.86
10	0.72	0.80	0.74	0.85	0.84	0.75	0.83	0.77	0.87	0.87
11	0.71	0.80	0.75	0.84	0.82	0.74	0.82	0.77	0.86	0.86
12	0.69	0.78	0.72	0.82	0.81	0.72	0.81	0.75	0.87	0.85
13	0.70	0.78	0.73	0.82	0.81	0.72	0.81	0.75	0.84	0.84

TABLE 6.16

ROBUSTNESS (NC) – UNCOMPRESSED COASTGUARD VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	HVS	GEO	DWPT	WGDB _S	WGSBS	HVS	GEO	DWPT	WGDB _S	WGSBS
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1	0.78	0.85	0.81	0.89	0.89	0.81	0.89	0.83	0.92	0.90
2	0.75	0.85	0.79	0.90	0.88	0.79	0.86	0.82	0.92	0.91
3	0.74	0.83	0.78	0.89	0.87	0.79	0.87	0.82	0.91	0.89
4	0.71	0.80	0.75	0.85	0.84	0.74	0.83	0.78	0.89	0.87
5	0.71	0.78	0.74	0.84	0.83	0.75	0.84	0.78	0.88	0.84
6	0.74	0.82	0.76	0.86	0.84	0.76	0.86	0.80	0.89	0.87
7	0.75	0.83	0.78	0.89	0.86	0.78	0.84	0.81	0.91	0.89
8	0.75	0.82	0.79	0.87	0.86	0.78	0.86	0.81	0.90	0.89
9	0.73	0.82	0.77	0.87	0.85	0.76	0.84	0.80	0.90	0.86
10	0.72	0.81	0.76	0.85	0.84	0.75	0.84	0.78	0.89	0.87
11	0.70	0.81	0.74	0.85	0.84	0.74	0.82	0.78	0.89	0.88
12	0.71	0.78	0.73	0.84	0.82	0.73	0.81	0.77	0.88	0.85
13	0.71	0.79	0.72	0.83	0.82	0.73	0.82	0.77	0.85	0.84

6.2.3. Imperceptibility

From the various results, it can be seen that the visual quality of the image (high PSNR) and resistance capacity of the algorithms to various attacks (high NC) is efficient, indicating that the proposed algorithms introduce minimum degradation even in the presence of attacks. Moreover, from the results obtained from Tables and Figures presented in this chapter, it is evident that the proposed algorithms show better performance when compared with existing and conventional counterparts. Thus, it can be concluded that the proposed algorithms exhibit maximum imperceptibility characteristic.

6.2.4 Complexity

The complexity of the algorithm is analyzed with respect to time taken to embed and extract the watermark. The total execution time calculated as the sum of embedding and extraction time without attacks is shown in Table 6.17 The displayed values are in seconds.

TABLE 6.17

COMPLEXITY IN TERMS OF EXECUTION SPEED (Seconds) FOR UNCOMPRESSED DOMAIN

Video File	Copyright Image C1					Copyright Image C2				
	HVS	GEO	DWPT	WGDBS	WGSBS	HVS	GEO	DWPT	WGDBS	WGSBS
Foreman	36.55	28.29	32.81	20.41	22.14	35.52	27.82	31.95	19.25	21.61
Mobile	36.58	28.25	32.27	20.60	22.19	35.66	27.21	31.32	19.81	21.13
Phone	35.99	27.11	31.86	19.89	21.80	34.58	26.75	30.02	18.97	20.48
Cactus	35.62	27.07	31.90	19.82	21.28	34.14	26.38	30.26	18.52	20.44
News	35.70	27.68	31.07	19.55	21.67	34.77	26.80	30.91	18.75	20.39
Coastguard	34.06	26.65	30.01	18.96	20.10	33.89	25.02	30.00	17.31	19.00

From the results, it is evident that the proposed algorithms reduce time complexity and hence are suitable for time critical applications like the Internet.

6.3. PERFORMANCE EVALUATION OF WATERMARKING ALGORITHMS FOR COMPRESSED DOMAIN

The results of experiments conducted to evaluate the watermarking algorithms designed for compressed video is presented in this section for the selected five characteristics, namely, capacity, transparency, imperceptibility, security and complexity.

6.3.1 Capacity

Table 6.18 presents the PSNR values to analyze the capacity of the three proposed algorithms, DCT-SVD, DWPT-SVD and FPBA for the selected test videos when embedded with the two copyright images.

TABLE 6.18

CAPACITY OF WATERMARKING ALGORITHMS FOR COMPRESSED DOMAIN

Video File	Copyright Image C1					Copyright Image C2				
	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA
Foreman	43.88	45.71	44.97	47.66	46.55	44.66	46.05	45.02	47.80	47.51
Mobile	41.70	44.57	43.15	47.96	46.07	42.36	44.57	43.49	48.42	46.17
Phone	42.45	45.07	44.03	48.08	47.06	43.33	45.71	44.70	48.76	47.61
Cactus	42.03	45.10	43.47	47.85	46.22	42.57	45.60	44.25	48.61	47.11
News	41.43	45.07	43.27	48.00	46.48	42.39	45.44	43.36	48.12	46.89
Coastguard	42.10	44.91	43.31	47.62	46.14	42.83	45.54	43.40	47.99	46.94

From the results, it can be seen that the proposed enhanced algorithms for watermarking compressed videos have shown better performance than the conventional counterparts. Among the three proposed algorithms, the method combining wavelet packets and SVD clustering algorithm showed high capacity

characteristics when compared with DCT-SVD and FPBA algorithms. The DWPT-SVD algorithm showed an average efficiency gain of 8.75% when compared over DWT based watermarking algorithm. The same algorithm showed an average efficiency gain of 5.81% and 2.79% over DCT-SVD and FPBA watermarking algorithms.

Figures 6.9 to 6.14 show the PSNR values obtained at different frames of the selected test videos in compressed form.

From the figure results, it is clear that the proposed algorithms are consistent in maintaining the visual quality of the frames. Thus, from the various results, it can be concluded that the algorithm satisfied the payload and transparency properties required by a watermarking algorithm.

6.3.2. Robustness (Security)

The robustness of the proposed watermarking algorithms for compressed videos are analyzed using 13 attacks grouped into 6 categories, namely, frame attacks, geometric attacks, removal attacks, noise attacks, processing attacks and compression attacks. The evaluation was performed through the comparison of PSNR to analyze the amount of distortion introduced in the watermarked video and NC to analyze the similarity between the original and extracted watermark. The results pertaining to PSNR values are presented in Tables 6.19 to 6.24 and NC values in Tables 6.25 to 6.30, respectively for the six selected test videos. In the tables, code 0 represents No attack and the rest of numeric codes have meanings as given in Table 6.1.

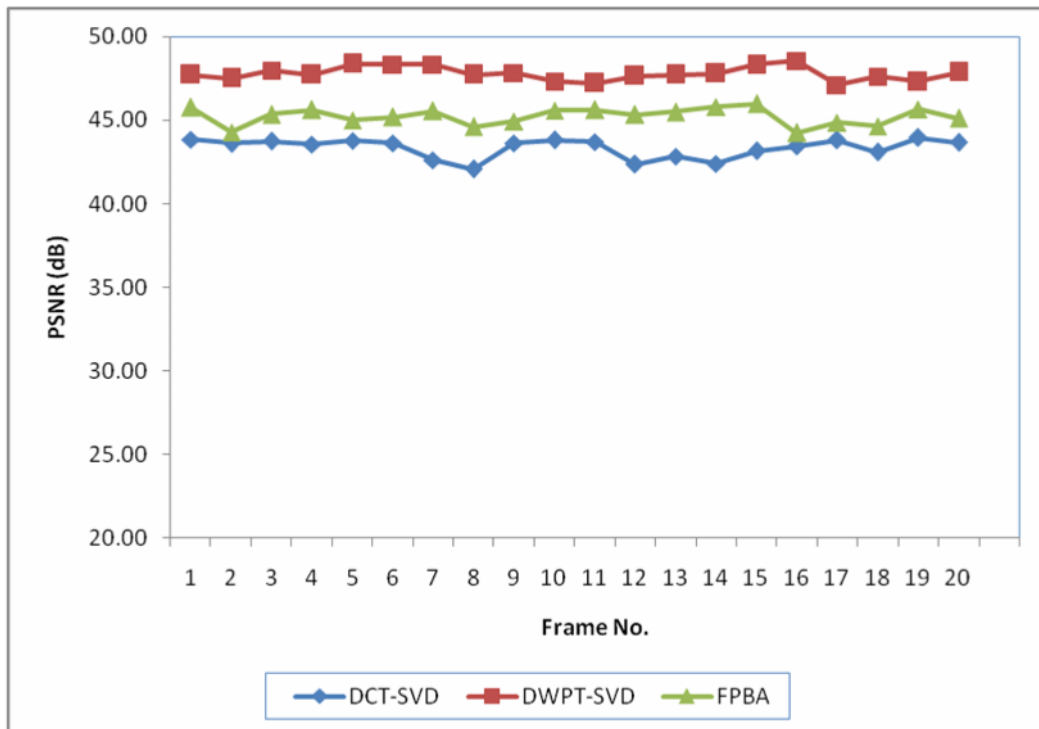


Figure 6.9 : PSNR of Foreman (Compressed)

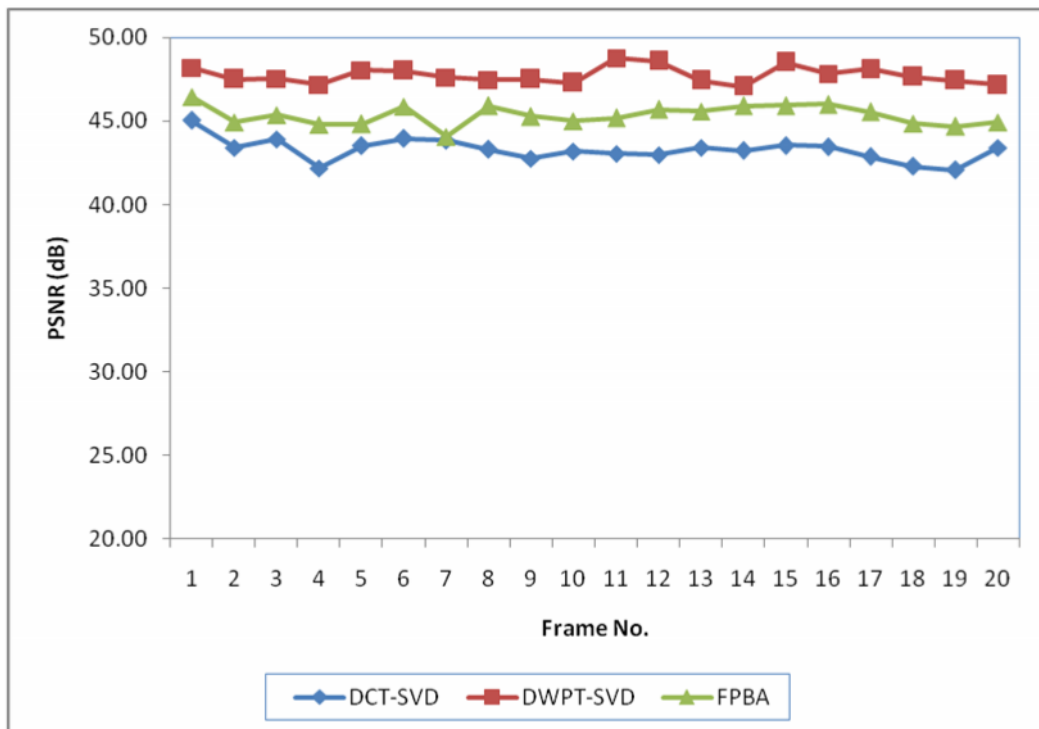


Figure 6.10 : PSNR of Mobile (Compressed)

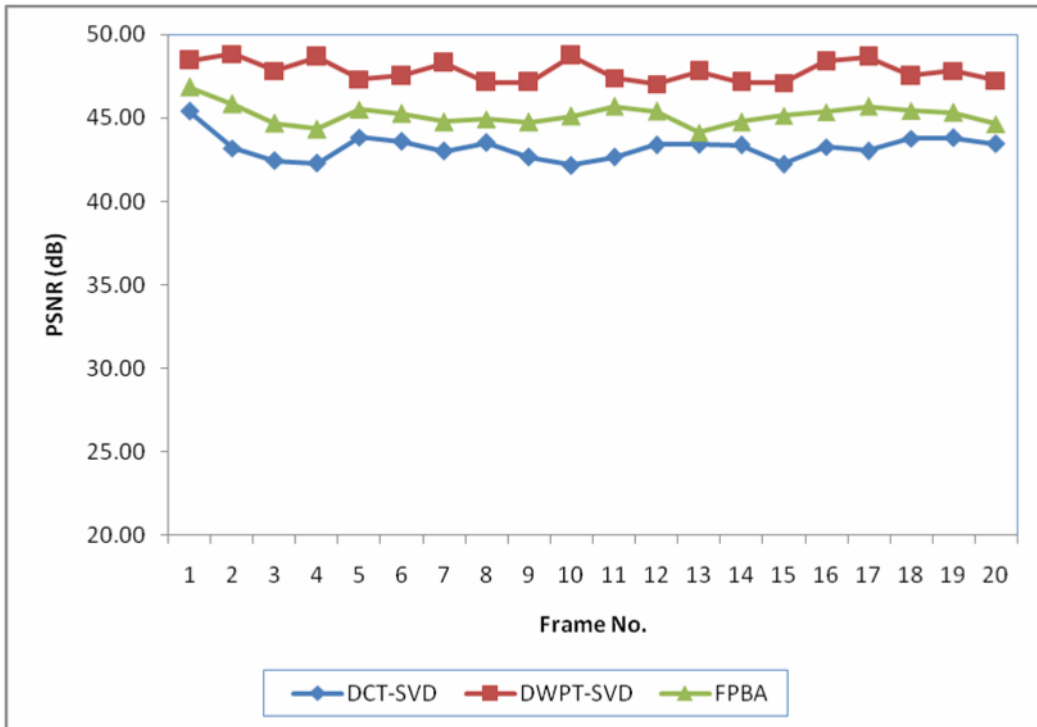


Figure 6.11 : PSNR of Phone (Compressed)

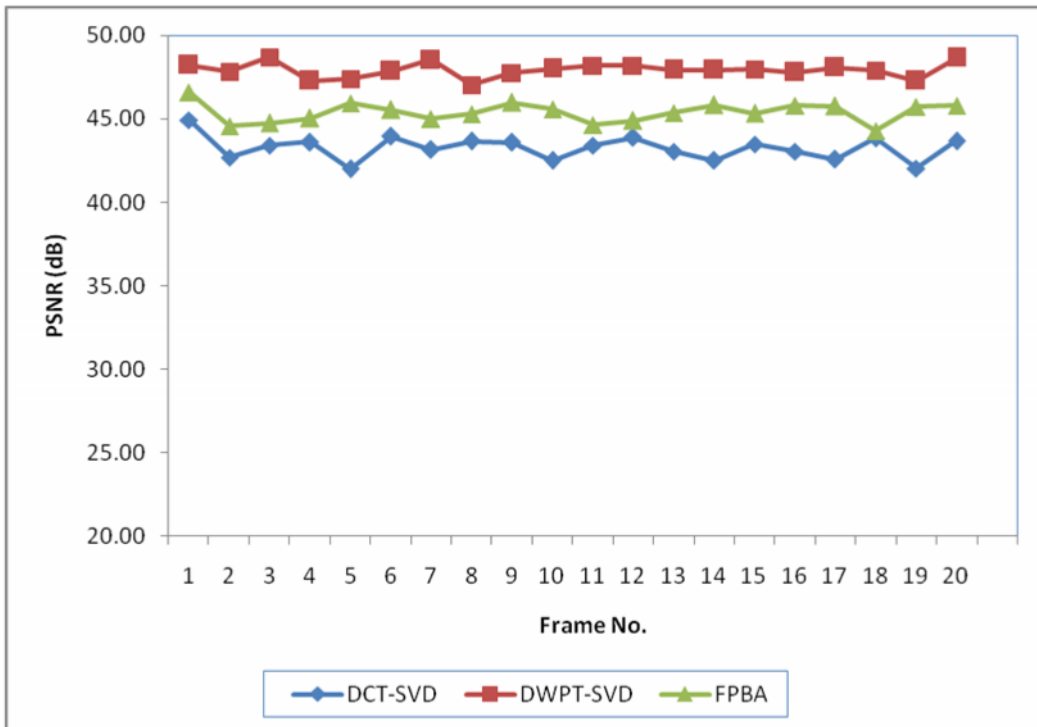


Figure 6.12 : PSNR of Cactus (Compressed)

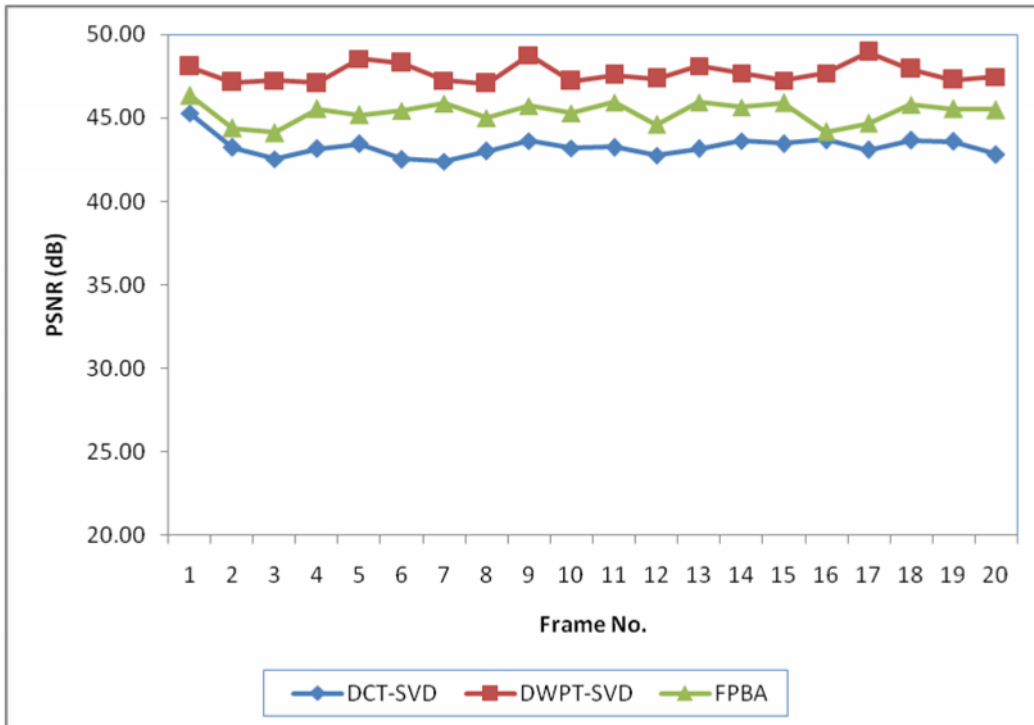


Figure 6.13 : PSNR of News (Compressed)

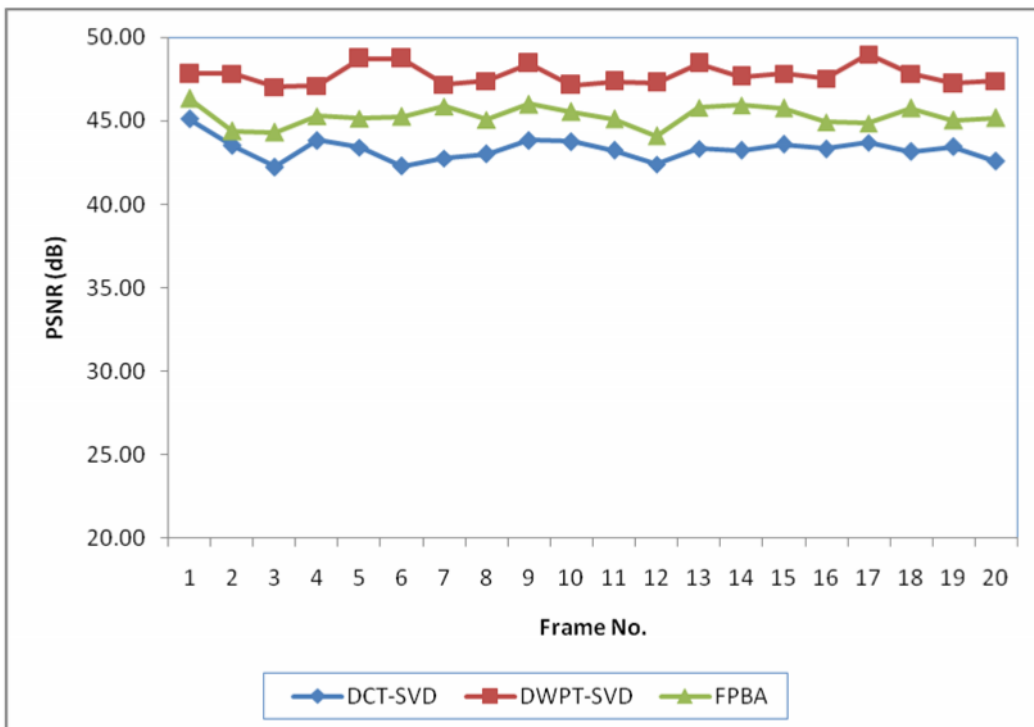


Figure 6.14 : PSNR of Coastguard (Compressed)

TABLE 6.19

ROBUSTNESS (PSNR) – COMPRESSED FOREMAN VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA
0	45.21	46.66	46.03	48.47	47.48	46.09	47.04	46.15	48.57	48.16
1	44.82	46.55	45.87	47.66	46.64	45.81	46.61	46.40	47.91	46.79
2	44.62	46.44	45.40	47.04	46.55	44.84	46.52	45.60	47.51	47.21
3	44.31	46.36	45.31	46.99	46.54	45.01	46.97	46.03	47.93	47.19
4	43.87	45.42	44.50	46.11	45.57	44.74	46.54	45.47	46.22	45.65
5	43.62	45.34	44.31	46.00	45.44	44.43	45.71	44.42	46.18	46.12
6	44.03	45.73	44.90	46.90	45.97	44.89	45.91	44.96	46.90	46.32
7	44.29	46.15	44.97	46.95	46.23	44.91	46.69	45.39	47.36	47.11
8	44.25	46.02	44.92	46.91	46.22	45.18	46.41	45.05	47.43	46.84
9	43.92	45.71	44.86	46.70	45.91	43.95	46.55	45.23	47.46	46.63
10	43.91	45.61	44.61	46.39	45.74	44.42	46.26	44.65	47.25	46.58
11	43.88	45.60	44.57	46.36	45.62	44.22	46.08	44.65	47.25	46.49
12	43.24	45.20	44.22	45.91	45.38	43.95	45.41	44.92	46.85	45.57
13	43.22	44.86	44.22	45.75	45.13	43.37	45.33	44.56	46.33	45.65

TABLE 6.20

ROBUSTNESS (PSNR) – COMPRESSED MOBILE VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA
0	46.06	46.33	46.17	49.84	47.83	46.22	48.12	47.51	49.78	49.24
1	44.37	47.05	46.27	47.85	47.77	45.65	47.12	46.55	48.09	47.47
2	45.60	46.95	46.11	48.35	47.36	45.67	46.71	46.35	48.51	48.39
3	45.87	46.50	46.22	47.63	47.45	46.10	47.20	46.32	48.44	47.50
4	43.70	45.88	44.46	47.15	46.26	45.89	46.43	45.90	47.84	46.71
5	44.17	45.67	44.99	47.07	46.69	45.04	45.95	45.14	47.34	46.57
6	44.31	45.65	45.30	47.00	46.24	44.12	46.26	44.47	47.56	46.58
7	44.14	45.98	45.83	47.46	46.28	45.03	47.83	45.57	48.85	47.97
8	44.47	46.18	44.53	47.26	46.53	46.09	46.59	46.09x	47.82	47.79
9	44.31	45.12	44.45	47.67	46.17	44.82	46.13	45.51	48.33	47.11
10	43.37	46.94	44.47	46.33	46.44	44.02	46.31	45.96	47.28	47.00
11	44.21	45.49	44.88	47.32	46.76	44.76	46.81	44.93	48.54	47.00
12	44.27	46.34	45.99	46.91	46.78	43.07	46.38	45.64	47.18	46.50
13	44.27	45.00	44.82	45.51	45.19	43.42	45.91	45.43	47.01	46.50

TABLE 6.21

ROBUSTNESS (PSNR) – COMPRESSED PHONE VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA
0	45.89	47.30	46.30	48.21	47.32	46.16	47.69	47.14	49.67	49.40
1	45.76	47.10	46.48	47.56	47.30	46.09	46.55	46.62	48.56	47.57
2	44.18	46.20	46.10	48.02	46.53	44.53	46.34	45.89	47.55	47.13
3	44.38	46.56	46.04	46.93	46.65	45.86	47.68	47.58	48.02	47.90
4	43.72	45.34	45.37	46.75	46.51	44.57	46.45	46.25	47.49	46.92
5	43.01	45.96	45.44	46.85	46.86	45.26	46.89	44.41	47.64	45.62
6	44.34	45.10	45.07	46.05	46.16	45.11	45.88	45.55	46.69	46.09
7	45.75	46.76	44.71	47.76	47.50	45.39	47.66	46.29	47.66	47.16
8	45.63	47.26	44.91	46.82	47.33	45.20	46.17	45.39	47.17	46.97
9	44.22	45.92	45.53	47.07	46.21	44.83	46.14	45.62	47.46	46.73
10	44.01	45.45	44.70	46.79	46.27	45.20	47.72	45.84	48.62	47.89
11	44.05	46.59	44.55	47.40	46.92	44.22	46.27	44.35	48.88	46.71
12	43.62	45.97	45.07	46.97	46.22	43.73	46.50	45.04	47.14	46.94
13	43.56	44.38	44.17	46.41	45.72	44.40	45.43	45.04	47.65	46.79

TABLE 6.22

ROBUSTNESS (PSNR) – COMPRESSED CACTUS VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA
0	46.46	47.94	47.14	48.34	48.08	45.17	47.61	46.22	48.97	48.38
1	45.99	48.30	46.10	48.00	48.75	45.42	47.87	47.16	48.54	48.54
2	45.28	47.88	46.90	48.44	48.15	45.49	47.53	46.81	49.55	48.41
3	45.30	47.76	46.98	48.40	47.12	44.59	47.10	46.29	48.63	47.89
4	44.45	45.81	45.16	47.57	47.25	45.07	47.55	46.05	47.64	47.31
5	44.97	46.60	45.70	47.07	46.71	45.19	46.12	45.92	47.51	46.57
6	44.14	46.89	45.66	48.31	47.16	45.88	46.02	45.22	47.08	46.57
7	45.66	47.74	45.70	48.38	46.63	45.39	48.00	46.45	49.72	48.76
8	45.27	46.15	45.15	47.83	46.69	45.28	46.58	46.19	48.49	47.52
9	44.26	46.01	45.04	48.82	47.59	44.25	47.55	45.81	48.86	47.57
10	44.22	46.65	45.32	48.83	47.79	44.47	46.76	45.92	48.10	47.31
11	44.26	45.65	44.75	48.44	47.34	44.04	46.38	45.65	49.94	47.33
12	44.16	46.89	45.54	47.94	47.00	44.83	45.12	45.77	47.75	47.27
13	45.48	45.75	45.05	46.07	45.98	43.91	45.16	45.00	48.14	46.71

TABLE 6.23

ROBUSTNESS (PSNR) – COMPRESSED NEWS VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA
0	45.82	47.24	46.51	48.61	47.93	46.01	48.24	47.53	48.82	48.37
1	44.53	46.83	45.68	47.33	47.98	45.78	46.78	46.11	48.15	47.06
2	44.60	46.70	46.82	48.42	46.60	43.27	45.51	44.98	47.34	46.65
3	44.07	46.51	46.46	47.97	47.20	45.90	46.60	46.83	47.59	47.07
4	44.88	45.93	45.10	47.87	46.20	44.85	46.96	45.37	47.26	47.54
5	43.50	45.08	44.82	46.06	45.37	43.58	45.77	44.63	47.70	46.28
6	44.84	45.05	45.79	47.04	46.23	43.99	45.70	44.44	47.74	46.38
7	44.75	46.13	45.61	47.83	47.70	44.09	46.51	45.84	48.87	47.66
8	45.57	46.25	44.51	47.30	46.31	45.83	46.99	45.26	48.36	47.13
9	43.87	45.50	44.72	46.77	46.02	44.99	47.94	46.93	48.35	46.86
10	43.96	45.58	44.91	47.46	45.39	43.88	45.66	44.29	48.17	47.65
11	43.32	46.07	45.77	47.68	46.95	44.48	46.43	45.15	47.90	47.16
12	43.25	45.11	44.34	45.89	45.44	43.24	46.30	45.58	47.99	46.74
13	44.25	45.68	45.18	46.12	46.60	43.03	45.26	44.74	47.22	46.34

TABLE 6.24

ROBUSTNESS (PSNR) – COMPRESSED COASTGUARD VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA
0	45.27	47.57	46.49	49.99	47.66	45.76	47.03	46.66	49.12	48.17
1	44.30	48.14	47.37	48.95	48.66	45.03	47.53	46.94	48.11	47.97
2	46.29	47.05	46.59	49.10	47.81	45.21	47.57	46.36	49.96	48.74
3	44.05	46.61	45.54	48.61	47.15	46.10	48.38	47.60	49.98	48.83
4	43.16	46.78	44.01	47.11	46.82	45.51	47.30	46.12	47.84	47.79
5	43.86	45.68	44.97	47.02	46.96	44.82	45.27	45.08	47.96	46.07
6	44.82	46.25	45.19	48.36	47.25	45.05	46.48	45.95	47.87	47.57
7	45.13	46.30	45.98	47.26	46.84	45.57	48.25	46.00	49.03	48.52
8	45.10	46.70	45.90	47.57	46.76	44.98	46.66	45.54	47.99	47.67
9	44.27	45.74	45.19	48.77	46.98	44.35	47.38	46.17	49.70	48.96
10	43.15	45.65	44.03	47.39	46.39	45.76	46.80	46.14	48.66	47.35
11	44.98	45.98	45.04	47.83	46.79	44.32	46.46	45.37	49.14	47.03
12	44.68	46.87	46.18	47.87	47.14	44.93	47.10	45.03	47.70	47.58
13	45.80	45.05	44.49	46.51	46.32	43.13	45.86	45.05	48.06	47.55

TABLE 6.25

ROBUSTNESS (NC) – COMPRESSED FOREMAN VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1	0.75	0.82	0.76	0.88	0.87	0.77	0.85	0.79	0.92	0.90
2	0.74	0.81	0.74	0.86	0.86	0.77	0.83	0.77	0.89	0.89
3	0.72	0.80	0.74	0.86	0.85	0.74	0.84	0.77	0.89	0.88
4	0.68	0.76	0.71	0.82	0.80	0.71	0.78	0.74	0.85	0.84
5	0.67	0.76	0.70	0.81	0.80	0.71	0.78	0.74	0.84	0.84
6	0.70	0.78	0.73	0.84	0.83	0.74	0.80	0.76	0.86	0.85
7	0.71	0.79	0.74	0.85	0.84	0.73	0.83	0.78	0.88	0.87
8	0.71	0.79	0.74	0.85	0.83	0.74	0.82	0.77	0.88	0.86
9	0.70	0.78	0.72	0.83	0.82	0.72	0.82	0.75	0.86	0.86
10	0.69	0.77	0.72	0.83	0.82	0.71	0.80	0.74	0.86	0.84
11	0.69	0.77	0.71	0.82	0.81	0.72	0.79	0.74	0.85	0.84
12	0.67	0.75	0.70	0.81	0.79	0.70	0.78	0.74	0.85	0.82
13	0.65	0.74	0.69	0.79	0.78	0.68	0.76	0.71	0.81	0.82

TABLE 6.26

ROBUSTNESS (NC) – COMPRESSED MOBILE VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1	0.79	0.85	0.78	0.91	0.91	0.79	0.89	0.81	0.95	0.94
2	0.76	0.84	0.77	0.90	0.90	0.79	0.86	0.81	0.92	0.93
3	0.75	0.83	0.77	0.88	0.88	0.77	0.88	0.81	0.90	0.91
4	0.70	0.78	0.73	0.84	0.84	0.74	0.82	0.76	0.87	0.88
5	0.71	0.78	0.73	0.84	0.84	0.74	0.80	0.78	0.86	0.87
6	0.74	0.82	0.76	0.86	0.86	0.77	0.84	0.78	0.90	0.88
7	0.74	0.82	0.78	0.87	0.86	0.76	0.86	0.80	0.91	0.89
8	0.73	0.82	0.78	0.88	0.87	0.76	0.85	0.79	0.90	0.90
9	0.72	0.82	0.74	0.85	0.85	0.76	0.85	0.79	0.90	0.89
10	0.72	0.79	0.75	0.86	0.85	0.74	0.83	0.78	0.89	0.87
11	0.71	0.79	0.75	0.86	0.84	0.74	0.81	0.77	0.88	0.86
12	0.70	0.78	0.73	0.84	0.82	0.74	0.80	0.77	0.88	0.85
13	0.68	0.76	0.72	0.81	0.80	0.70	0.79	0.74	0.83	0.86

TABLE 6.27

ROBUSTNESS (NC) – COMPRESSED PHONE VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1	0.73	0.80	0.74	0.86	0.86	0.76	0.83	0.76	0.91	0.89
2	0.73	0.78	0.72	0.84	0.85	0.75	0.81	0.75	0.87	0.87
3	0.70	0.78	0.72	0.83	0.83	0.71	0.83	0.76	0.87	0.86
4	0.66	0.73	0.69	0.79	0.79	0.70	0.76	0.73	0.83	0.82
5	0.64	0.74	0.69	0.79	0.79	0.69	0.76	0.73	0.82	0.81
6	0.68	0.76	0.71	0.81	0.81	0.72	0.77	0.74	0.84	0.83
7	0.70	0.77	0.73	0.84	0.82	0.72	0.81	0.76	0.85	0.85
8	0.70	0.77	0.72	0.82	0.82	0.71	0.80	0.76	0.87	0.83
9	0.68	0.75	0.70	0.81	0.79	0.71	0.79	0.73	0.84	0.83
10	0.68	0.74	0.69	0.80	0.80	0.69	0.78	0.72	0.83	0.83
11	0.66	0.75	0.68	0.79	0.79	0.71	0.78	0.73	0.83	0.82
12	0.65	0.74	0.67	0.79	0.78	0.68	0.77	0.71	0.82	0.80
13	0.63	0.72	0.68	0.76	0.76	0.65	0.75	0.68	0.80	0.78

TABLE 6.28

ROBUSTNESS (NC) – COMPRESSED CACTUS VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1	0.77	0.84	0.76	0.89	0.88	0.77	0.86	0.80	0.94	0.91
2	0.74	0.82	0.75	0.87	0.87	0.78	0.84	0.79	0.90	0.92
3	0.72	0.81	0.75	0.86	0.85	0.75	0.85	0.78	0.89	0.89
4	0.68	0.76	0.70	0.83	0.82	0.72	0.80	0.75	0.85	0.86
5	0.69	0.76	0.70	0.82	0.82	0.73	0.79	0.76	0.85	0.86
6	0.71	0.80	0.74	0.83	0.83	0.74	0.81	0.76	0.89	0.85
7	0.72	0.79	0.77	0.85	0.85	0.74	0.85	0.79	0.89	0.87
8	0.70	0.81	0.77	0.85	0.84	0.74	0.84	0.78	0.88	0.87
9	0.69	0.80	0.73	0.83	0.83	0.73	0.83	0.78	0.87	0.87
10	0.71	0.76	0.74	0.85	0.83	0.72	0.82	0.75	0.88	0.84
11	0.68	0.77	0.73	0.84	0.83	0.73	0.80	0.74	0.85	0.84
12	0.67	0.76	0.71	0.82	0.79	0.73	0.79	0.75	0.86	0.82
13	0.66	0.74	0.70	0.80	0.79	0.69	0.77	0.71	0.80	0.83

TABLE 6.29

ROBUSTNESS (NC) – COMPRESSED NEWS VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1	0.78	0.85	0.79	0.93	0.91	0.82	0.90	0.83	0.96	0.93
2	0.78	0.84	0.78	0.91	0.91	0.82	0.86	0.81	0.94	0.93
3	0.76	0.85	0.78	0.91	0.89	0.78	0.89	0.81	0.92	0.93
4	0.71	0.81	0.75	0.85	0.85	0.75	0.81	0.77	0.89	0.88
5	0.71	0.81	0.74	0.86	0.85	0.74	0.82	0.78	0.88	0.88
6	0.75	0.82	0.77	0.88	0.86	0.78	0.85	0.79	0.90	0.90
7	0.76	0.83	0.78	0.90	0.88	0.78	0.86	0.81	0.92	0.90
8	0.74	0.82	0.78	0.88	0.88	0.78	0.86	0.81	0.92	0.89
9	0.74	0.82	0.76	0.87	0.86	0.77	0.87	0.79	0.91	0.91
10	0.74	0.82	0.76	0.87	0.86	0.75	0.84	0.78	0.89	0.88
11	0.73	0.81	0.75	0.86	0.86	0.75	0.82	0.79	0.88	0.88
12	0.70	0.80	0.74	0.86	0.82	0.75	0.81	0.77	0.89	0.85
13	0.69	0.77	0.73	0.82	0.83	0.71	0.80	0.76	0.86	0.86

TABLE 6.30

ROBUSTNESS (NC) – COMPRESSED COASTGUARD VIDEO

Attacks	Copyright Image C1					Copyright Image C2				
	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1	0.81	0.87	0.80	0.93	0.92	0.81	0.91	0.83	0.97	0.96
2	0.78	0.85	0.79	0.91	0.91	0.81	0.87	0.82	0.94	0.93
3	0.76	0.84	0.79	0.90	0.89	0.78	0.90	0.82	0.92	0.92
4	0.71	0.79	0.74	0.86	0.86	0.76	0.84	0.78	0.90	0.88
5	0.73	0.80	0.74	0.86	0.86	0.76	0.82	0.80	0.89	0.87
6	0.75	0.83	0.77	0.87	0.87	0.78	0.86	0.79	0.91	0.89
7	0.76	0.83	0.80	0.89	0.88	0.78	0.87	0.82	0.92	0.90
8	0.75	0.84	0.79	0.90	0.88	0.78	0.87	0.80	0.91	0.91
9	0.74	0.84	0.76	0.87	0.86	0.77	0.87	0.80	0.91	0.91
10	0.74	0.81	0.77	0.88	0.87	0.76	0.85	0.79	0.90	0.88
11	0.72	0.80	0.76	0.88	0.86	0.76	0.82	0.78	0.89	0.88
12	0.71	0.80	0.74	0.85	0.83	0.75	0.82	0.79	0.89	0.86
13	0.70	0.78	0.73	0.83	0.82	0.72	0.81	0.76	0.87	0.85

From the results pertaining to the analysis of robustness of the proposed watermarking algorithms in compressed domain, it is clear that all the three proposed algorithms are resistant to attacks. This is clear from the high PSNR and near to unity NC values obtained by all the six test videos.

6.3.3. Imperceptibility

The high PSNR values and high NC values obtained show that the proposed algorithms designed for compressed videos introduce minimum degradation to the watermarked videos even in the presence of attacks. This is evident from Table and Figure results projected in this section. All the proposed algorithms exhibit increased performance when compared with existing and conventional counterparts, indicating that the proposed watermarking algorithms for compressed videos have also improved imperceptibility feature.

6.3.4 Complexity

The complexity of the proposed watermarking algorithms designed for compressed domain, in terms of execution speed measured in seconds, is presented in Table 6.31.

TABLE 6.31
COMPLEXITY IN TERMS OF EXECUTION SPEED (Seconds) FOR
COMPRESSED DOMAIN

Video File	Copyright Image C1					Copyright Image C2				
	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA	DCT	DCT-SVD	DWT	DWPT-SVD	FPBA
Foreman	18.31	14.81	14.66	11.46	13.33	17.02	13.03	13.42	10.07	12.32
Mobile	18.15	14.31	14.96	11.22	13.42	17.76	13.68	13.66	10.06	12.01
Phone	17.84	13.70	13.46	10.08	12.57	16.36	12.66	12.84	9.41	11.32
Cactus	17.82	13.80	13.59	10.53	12.80	16.45	12.84	12.66	9.81	11.86
News	17.75	13.80	13.66	10.80	12.50	16.18	12.27	12.73	9.82	11.50
Coastguard	16.38	12.17	12.67	9.82	11.71	15.84	11.48	11.60	8.96	10.76

The results related to the speed of embedding and extracting watermarks from compressed videos, show that the proposed algorithms are less complex and hence achieve watermarking operations at maximum speed. Among the three proposed models, the DWPT-SVD algorithm was the fastest.







6.4. VISUAL RESULTS

The visual results of the watermarked mobile video (Figure 6.1b) and the extracted copyright image are shown in Figures 6.15 and 6.16 while using watermarking algorithms designed for uncompressed and compressed domains respectively.

The visual results confirm the facts obtained from the previous sections and show WGDBS in uncompressed domain and DWPT-SVD in compressed domain as algorithms that provide maximum efficiency. Similar results were obtained for all other test videos also.

6.5. CHAPTER SUMMARY

This chapter presented the experimental results of the various algorithms proposed for watermarking compressed and uncompressed videos. From the results it was found that the proposed algorithms perform satisfactorily in terms of payload and transparency. The algorithms were able to hide copyright image into the cover video in an efficient manner with minimum distortions. The algorithms were robust against the 13 selected attacks, which showed that the security aspect of the algorithms were also efficient. The embedded watermark is secured in a multiple step fashion by the proposed algorithm. The first is the usage of visual cryptography, the second is the usage of frame selection and region selection algorithm which makes the watermark difficult to interpret. All these put together makes the proposed algorithm highly secure. The research work is concluded with future research directions in the next chapter, Summary and Conclusion.

	
<p align="center">Original Frame</p>	<p align="center">Original Copyright Image</p>
	
<p align="center">HVS Algorithm</p>	
	
<p align="center">GEO Algorithm</p>	

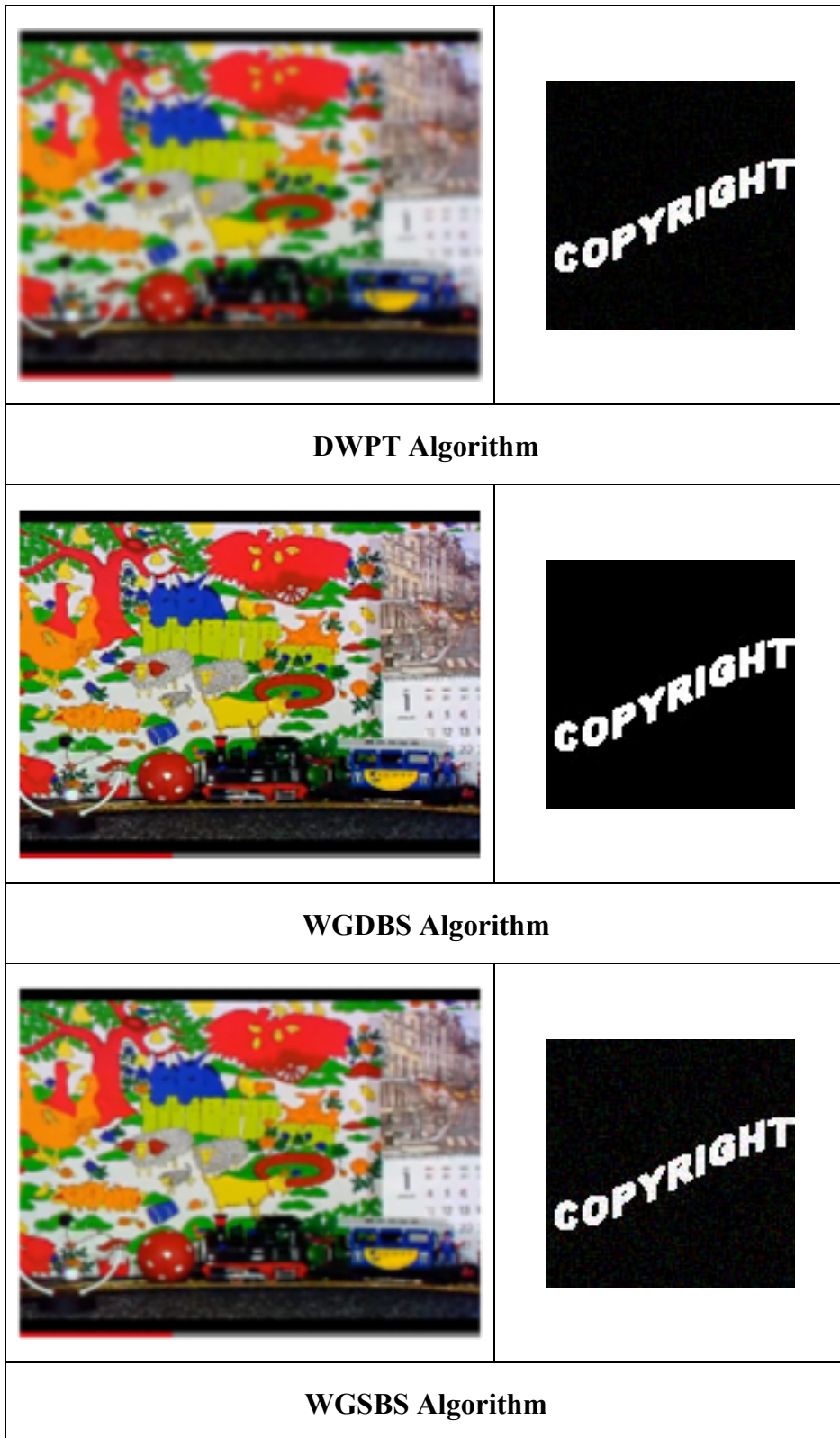








Figure 6.15 : Visual Results in Uncompressed Domain

	
<p align="center">Original Frame</p>	<p align="center">Original Copyright Image</p>
	
<p align="center">DCT Algorithm</p>	
	
<p align="center">DCT-SVD Algorithm</p>	

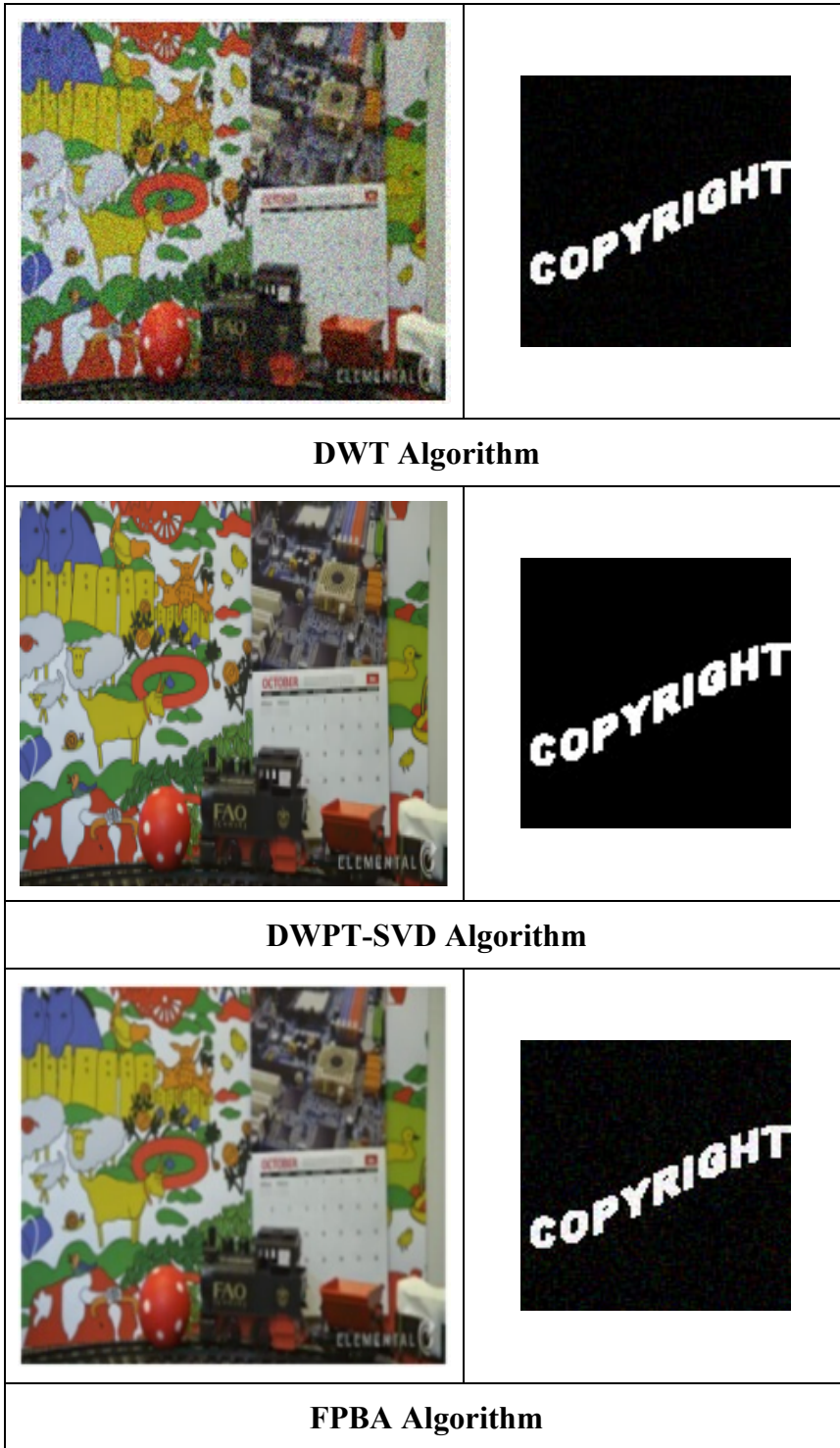


Figure 6.16 : Visual Results in Compressed Domain