Deblocking of Gray Scale Images and Videos Using 3D Spatial Filtering

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Abstract: Digital images are compressed at high compression ratios for storage and communication purposes and are thereby affected by visual blocking artifact. Various filtering techniques are available for reducing the visual blocking artifact of compressed images. In this paper, a 3D spatial filter which uses a negative like image of the image to be deblocked to reduce the compression artifact of the compressed image. The Mean Structural Similarity Index Measure (MSSIM) and Peak Signal to Noise Ratio (PSNR) are used in this paper to assess the quality of the restored images. The results obtained show that these techniques effectively remove the compression artifact from the compressed digital images.
Keywords: Block DCT Transform, blocking artifact, weighted average, 3D Filtering

1. Introduction

The Block DCT transform based compression has been in use for the compression of digital images over a long period of time because of its high energy compaction ability. Millions of images have already been compressed and coded using the above technique all over the world. When the digital images are compressed at high compression ratio using the block DCT transform, it results in visual artifact like blocking artifact and ringing artifact. Blocking artifact is the visibly noticeable discontinuity at the border of the adjacent blocks and it is caused by the break of correlation between the adjacent blocks. Ringing artifact is caused by the loss of high frequency components in the signal and it can be noticed near the real edges of the images.

Theory of projection on to convex sets can be used [2-5] to reduce the blocking artifact from the compressed digital images. Using Wavelet transform [4,6] and Rational filters [7] also, the compression artifact in digital images can be reduced. Adaptive filters [8-10] are also very effective in the removal of artifact from the compressed digital images. A frequency domain approach is used in [11] to detect the blocking artifact and to remove it.

Weighted averaging of pixels [12-14] also has been in use for reducing the blocking artifact. Weighted sums of symmetrically aligned pixel quartets are used in [12] to remove the blocking artifact of the image. In Adaptive fuzzy filters [13], weighted averaging of pixels within a window is used for the removal of blocking and ringing artifact. Adaptive bilateral filters [14] also use weighted averaging of pixels within a window to remove compression artifacts. However, the technique used to calculate the weights in each of the above methods is different. A new weighted averaging technique which uses a negative like image of the compressed image is used in this work to remove the blocking artifact of compressed digital images.

The proposed technique used is discussed in section 2 and the simulation results in section 3. The concluding remarks are given in section 4.

2. Removal of Blocking Artifact

A.Weighted Averaging with Negative Like Image

When the digital images are compressed at high compression ratio using Block DCT transform, visible blocking artifact is resulted in the image. The blocking artifact is produced in the image due to the loss of correlation between the adjacent blocks. Discontinuity at the block

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edges can be measured by finding the difference in intensity between the adjacent pixels which belong to the adjacent blocks at the border of the block. In this method, this difference is minimized by replacing the pixels at the block boundaries by the weighted average of the pixels and the corresponding pixels in its negative image. But, the discontinuity will now be shifted to the inner pixels. So, the inner pixels are also replaced by the weighted average of the pixels and the corresponding pixels in its negative image in such a way that discontinuity is totally removed from the image.

In order to reduce the blocking artifact, the change in the pixel values from the original value should be nullified. If a pixel value is increased due to artifact, it should be reduced which can be achieved by adding a fraction of its negative pixel value. Similarly if a pixel value is reduced due to artifact, it can be increased by subtracting a fraction of its negative pixel value. The weight of the pixel and that of its negative pixel must be normalized so that the sum of the weights will remain as unity.

Usually generated negative image cannot be used for the artifact removal because the value of the pixel and its negative pixel should never be the same for the technique to be effective. A negative like image I_n, is obtained corresponding to the compressed image I, as follows. Let (i,j) represent the spatial location of the pixel within the image.

If $I(i, j) \leq 127.5$, then

$I_n(i, j) = I(i, j) + 127.5$

else $I_n(i, j) = I(i, j) - 127.5$ (1)

127.5 is the middle value of the intensity range.

Let x(i,j) be a pixel at the vertical boundary of a block in the compressed image and y(i,j) be the corresponding pixel in its negative image. Then, the discontinuity at the vertical edge

$$\delta_{xv}(i, j) = x(i, j) - x(i, j+1) \quad (2)$$

The new value of x(i,j) which should replace the old value of x(i,j) is calculated as follows.

$$k_1(i, j) = \frac{-\delta_{xv}(i, j)}{2(y(i, j) - x(i, j))} \quad (3)$$

$$x_{new}(i, j) = (1 - k_1(i, j)) * x(i, j) + k_1(i, j) * y(i, j) \quad (4)$$

The new value of x(i,j+1) is calculated as follows

$$\delta_{xv}(i, j+1) = x(i, j+1) - x(i, j) \quad (5)$$

$$k_1(i, j+1) = \frac{-\delta_{xv}(i, j+1)}{2(y(i, j+1) - x(i, j+1))} \quad (6)$$

$$x_{new}(i, j+1) = (1 - k_1(i, j+1)) * x(i, j+1) + k_1(i, j+1) * y(i, j+1) \quad (7)$$

Similarly if x(i,j) be a pixel at the horizontal boundary of a block in the compressed image and y(i,j) be the corresponding pixel in its negative image. Then, the discontinuity at the horizontal edge,

$$\delta_{xh}(i, j) = x(i, j) - x(i+1, j) \quad (8)$$

The new value of x(i,j) which should replace the old value of x(i,j) is calculated as follows.

$$k2(i, j) = \frac{-\delta_{xh}(i, j)}{2(y(i, j) - x(i, j))} \quad (9)$$

$$x_{new}(i, j) = (1 - k_2(i, j)) * x(i, j) + k_2(i, j) * y(i, j) \quad (10)$$

The new value of x(i+1,j) is calculated as follows

$$k_2(i+1, j) = \frac{-\delta_{xv}(i=1, j)}{2\left(y(i=1, j) - x(i=1+1, j)\right)} \tag{11}$$

$$x_{new}(i+1, j) = \left(1 - k_2(i+1, j)\right) * x(i+1, j) + k_2(i+1, j) * y(i+1, j) \tag{12}$$

The values of δx_v and δx_h are scaled down from the border to the inner most pixel of the block using a scaling matrix which is explained below.

The equations used in [12] to generate weight matrix is used here to generate the scaling matrix. Let x_1 represent the row or column numbers of the scaling matrix respectively.

$$W_{r1}(x_1) = \left((v - e) * \frac{(x_1 - 1)}{(k - 1)}\right) + e \tag{13}$$

$$e_{k1} = \frac{(2k-1)v - e}{k-1} \tag{14}$$

$$W_{r2}(x) = e_{k1} - W_{r1}(x) \tag{15}$$

$$W_{rL}(x_1) = \max\left(W_{r1}(x_1), W_{r2}(x_1)\right) \tag{16}$$

$$e_{k2} = v - e \tag{17}$$

$$W_{rQ}(x_1) = e_{k2} * \left(\frac{(x-1)^2}{k(1-k)}\right) + e_{k2} * \frac{(1-2k)(x-1)}{k(1-k)} + e \tag{18}$$

$$W_r(x_1) = 2\left(W_{rL}(x_1)\right) - W_{rQ}(x_1) \tag{19}$$

where the variables e=1 and k=4 and v=0. The variation of Wr as a function of pixel positions from border to inner most pixel of an image block is given in Figureure 1.

δx_h and δx_v are multiplied with W to get the scaled δx_h and δx_v values for each pixels within each image block. The upper side of the matrix W is multiplied with δx_h which correspond to the upper horizontal boundary of each image block and the lower side of the matrix is multiplied with δx_h which correspond to the lower horizontal boundary of the block. Similarly the left side of the matrix W is multiplied with δx_v which correspond to the left vertical boundary of each image blocks and the right side of the matrix is multiplied with δx_v which correspond to the right vertical boundary of the block. Scaling matrix formation is shown in Figureure 2.

Let the Figureure3 represent the pixel positions of an 8X8 image block. For computing k_2(i,j) of the pixels A_1 to A_{12}, δx_h correspond to the upper horizontal border, scaled by corresponding values of the matrix W is used and for computing k_2(i,j) for the pixels B_1 to B_{12} , δx_h correspond to the lower horizontal border, scaled by corresponding values of the matrix W is used. Similarly, For computing k_1(i,j) for the pixels C_1 to C_{12} , δx_v correspond to the left vertical border, scaled by corresponding values of the matrix W is used and for computing k_1(i,j) for the pixels D_1 to D_{12} , δx_v correspond to the right vertical border, scaled by corresponding values of the matrix W is used. The scaled values of δx for the pixels F_1 to F_3 are calculated as the averages of δx_h and δx_v, correspond to A_1 and C_1, A_7 and C_7 and A_{11} and C_{11} respectively. The scaled values of δx for the pixels G_1 to G_3, H_1 to H_3 and J_1 to J_3 are also calculated the same way. Now, all the pixels within each block of the image are replaced by the weighted average of the pixel values and the corresponding pixels of its negative image using the Equation 20.

$$I_{new}(i, j) = \left(1 - k(i, j)\right) I(i, j) + k(i, j) I_n(i, j) \tag{20}$$

where k(i,j) will be either k_1(i,j) or k_2(i,j) depending on the position of the pixel replaced.

B. 3D- Spatial Filtering

The technique discussed above reduces only blocking artifacts. Inorder to improve the deblocking and also to remove other artifacts from the compressed images, the technique used above is modified. In addition to the weighted averaging between the image and its negative like image, spatial weighted averaging is done in the horizontal direction, in the negative image plane. Each pixel in the image is replaced by the weighted average of the pixel, corresponding pixel in its negative like image and pixels in a window of size 3X3 around the pixel in the negative like image. In the negative like image plane, $I_n(I,j)$ is given a fixed weight of 0.5 and its surrounding pixels within a window of size 3X3 is given a fixed weight of 1/16, for the filtering operation.

The filtered image in this case is obtained using the Equation 21 which is given below.

$$\boldsymbol{I_{new}(i.j)} = (1-\boldsymbol{k(i,j)})\boldsymbol{I(i,j)} + \boldsymbol{k(i,j)I_n(i,j)} * \frac{1}{2} + \sum_{\boldsymbol{N \in Wn}} \boldsymbol{k(i,j)I_N(i,j)} * \frac{1}{16} \tag{21}$$

where $I_N(I,j)$ represent the neighboring pixels of $I_n(i.j)$ within a window of size 3X3.

Since filtering is done between two planes (image plane and its negative like image plane) and horizontally along the negative image like plane (2D), the filtering is named as 3D spatial filtering.

It is observed that with 3D spatial filter, the deblocking has been improved considerably.

C. Blocking Artifact Removal from Videos

The technique explained above can be applied to the videos as well for the removal of blocking artifact. The 3D spatial filtering is done in each frame of the video. It is observed that video quality is improved by this filtering.

3. Simulation Results and Discussions

The proposed technique is implemented using MATLAB software. Simulation is done in a 2.80 GHz, Intel core [TM]2 CPU system with 3.24 GB of RAM. MATLAB 8 tool box is used to implement the proposed filter. Gray scale images compressed at high and medium compression ratios are used for the experiments.

A. Result of Weighted Averaging with Negative Like Image

The Boat image compressed at a compression ratio of 96.1266 % is displayed in Figureure 4(a) and the Zelda image compressed at a compression ratio of 97.1634% in Figureure 4(b). These images clearly show the presence of blocking artifact in it. A part of the compressed image is enlarged and displayed in Figureure 5(a) so that blocking artifact will be clearly visible. The negative image of the Boat image generated using the Equation 1 is displayed in Figureure 6(a) and that of the Zelda image is displayed in Figureure 6(b). These negative images generated are used for the removal of blocking artifact.

The Boat image with artifact as seen in the Figureure 4(a) is replaced by the weighted average of the image and its negative image using Equations 4, 7, 10, 13 and 20. The resultant image is displayed in Figureure 7(a). It is clear from the image that the blocking artifact which was present in the compressed image has been effectively removed. Similarly, the blocking artifact of the Zelda image is removed and the resultant image is displayed in Figureure 7(b). In order to show the effect of the technique more clearly, the same portion of the image which has been displayed in Figureure 5(a) is enlarged and displayed in Figureure 5(b), after the removal of blocking artifact.

The PSNR values and the mean square error values are normally used to measure the quality of the reconstructed images. But, PSNR or MSE does not correlate well with the human perception of quality [15] because of the following reasons. Firstly, the digital pixel values, on which the MSE is typically computed, may not exactly represent the light stimulus entering the eye. Secondly, simple error summation, like the one implemented in the MSE formulation, may be markedly different from the way the HVS and the brain arrives at an assessment of the perceived distortion. Thirdly, the two distorted image signals with the same amount of error energy may have very different structure of errors, and hence different perceptual quality. So, in this paper the mean structural similarity index (MSSIM) is used as a measure of the quality of the artifact removed image.

The result obtained using the proposed method is compared with other methods which basically uses weighted averaging for the removal of
artifacts from the digital images. The MSSIM values
are calculated for various images and are tabulated in Table1.The results show that the proposed method is better compared to other methods in removing the blocking artifact from the compressed digital images. Experiments are conducted on 10 standard images compressed at high compression ratio. Results show that on an average, the MSSIM values of the images restored using the proposed method improved by 1.10%, 2.49%, 1.14% and 1.89% compared to the methods given in [12], [13], [14] and [15] respectively.

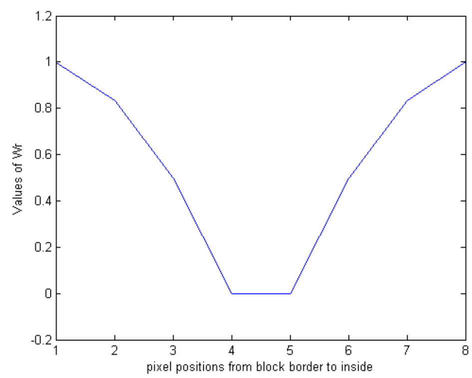


Figure 1. Variation of Wr(x1) as a function of x1.

F_1	A_1	A_2	A_3	A_4	A_5	A_6	G_1
C_1	F_2	A_7	A_8	A_9	A_{10}	G_2	D_1
C_2	C_7	F_3	A_{11}	A_{12}	G_2	D_7	D_2
C_3	C_8	C_{11}	E_1	E_2	D_{11}	D_8	D_3
C_4	C_9	C_{12}	E_3	E_4	D_{12}	D_9	D_4
C_5	C_{10}	H_3	B_{11}	B_{12}	J_3	D_{10}	D_5
C_6	H_2	B_7	B_8	B_9	B_{10}	J_2	D_6
H_1	B_1	B_2	B_3	B_4	B_5	B_6	J_1

Figure 3. Pixel positions of an 8X8 image block.

Figure 4a. Compressed Boat image (CR=24.96)

Figure 4b. Compressed Zelda image (CR=35.40)

Wr (1)	Wr (1)	Wr (1)	Wr (1)	Wr (1)	Wr (1)	Wr (1)	Wr (1)
Wr (1)	Wr (2)	Wr (2)	Wr (2)	Wr (2)	Wr (2)	Wr (2)	Wr (1)
Wr (1)	Wr (2)	Wr (3)	Wr (3)	Wr (3)	Wr (3)	Wr (2)	Wr (1)
Wr (1)	Wr (2)	Wr (3)	Wr (4)	Wr (4)	Wr (3)	Wr (2)	Wr (1)
Wr (1)	Wr (2)	Wr (3)	Wr (4)	Wr (4)	Wr (3)	Wr (2)	Wr (1)
Wr (1)	Wr (2)	Wr (3)	Wr (3)	Wr (3)	Wr (3)	Wr (2)	Wr (1)
Wr (1)	Wr (2)	Wr (2)	Wr (2)	Wr (2)	Wr (2)	Wr (2)	Wr (1)
Wr (1)	Wr (1)	Wr (1)	Wr (1)	Wr (1)	Wr (1)	Wr (1)	Wr (1)

Figure 2. 8X8 block of scaling matrix.

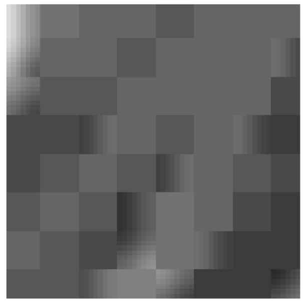


Figure 5a. A small part of compressed digital image

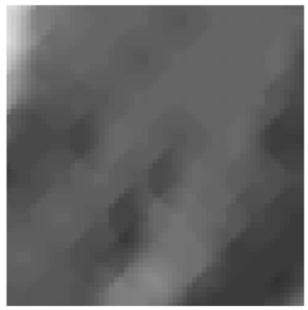


Figure 5b. Same image part after the removal of artifact

Figure 6a. Negative boat Image

Figure 6b. Negative Zelda image

Figure 7a. Deblocked Boat Image Using WANLI

Figure 7(b) Deblocked Zelda Image Using WANLI

Table 1. Comparison of MSSIMs

Image\Method	*Using [12]*	*Using [13]*	*Using [14]*	*Using [15]*	*WANLI*
Lena CR=31.73	0.924	0.912	0.925	0.912	0.932
Building CR=10.80	0.948	0.934	0.946	0.931	0.952
Barbara CR=21.16	0.890	0.852	0.892	0.899	0.905
Green Pepper CR=25.46	0.892	0.880	0.889	0.880	0.896
Gold hill CR=24.96	0.877	0.876	0.878	0.881	0.884
Boat CR=24.96	0.912	0.911	0.912	0.911	0.918
Bridge CR=19.42	0.919	0.911	0.917	0.913	0.966
Crowd CR=21.01	0.935	0.929	0.934	0.929	0.935
Girl face CR=31.53	0.917	0.905	0.917	0.905	0.920
Zelda CR=35.40	0.941	0.922	0.941	0.922	0.947

B. Result of 3D Spatial Filtering

Experiments have been conducted on various standard images which were compressed at medium and high compression ratios. Results are tabulated in Table 2 and Table 3.

The results show the improvement in the deblocking by the 3D spatial filter over the weighted averaging with negative like image (WANLI) method. For images compressed at medium compression ratio, the PSNR values on an average improved by 0.76% and MSSIM values improved by 0.17% over the WANLI method. For images compressed at high compression ratio, the PSNR values on an average improved by 0.37% and MSSIM values improved by 0.29% over the WANLI method. This shows the superiority of the 3D spatial filtering method over the WANLI method. The Boat image (CR=24.96) and the Zelda image (CR=35.40) filtered using the 3D spatial filter is displayed in Figureures 8(a) and 8(b) respectively. These images show the effectiveness of 3D spatial filtering in deblocking the compressed images.

Table 2. Comparison of WANLI method and 3D Spatial Filter for Images Compressed at Medium Compression Ratio

Image	*CR*	*PSNR*		*MSSIM*	
		WANLI	*3D SF*	*WANLI*	*3D SF*
Lena	19.56	30.92	31.19	0.966	0.967
Barbara	11.99	24.58	25.11	0.959	0.961
Boat	13.76	27.71	28.00	0.948	0.949
Clown	14.39	29.22	29.51	0.948	0.949
Girlface	21.23	31.01	31.17	0.956	0.957
Bridge	9.05	24.56	24.61	0.953	0.955
Couple	12.72	27.58	27.81	0.953	0.955
Crowd	12.11	28.18	28.50	0.973	0.974
Man	11.53	27.66	27.70	0.954	0.955
Tank	22.44	29.65	29.74	0.902	0.905
Trucks	13.13	27.28	27.43	0.945	0.948
Zelda	21.94	32.86	32.97	0.974	0.975

Table 3. Comparison of WANLI method and 3D Spatial Filter for Images Compressed at High Compression Ratio

Image	*CR*	*PSNR*		*MSSIM*	
		WANLI	*3D SF*	*WANLI*	*3D SF*
Lena	31.73	28.52	28.63	0.932	0.933
Barbara	21.16	23.62	23.88	0.905	0.910
Boat	24.96	25.58	25.72	0.918	0.920
Clown	22.74	26.65	26.80	0.901	0.902
Girlface	31.53	28.83	28.85	0.920	0.927
Bridge	19.42	22.86	22.92	0.966	0.969
Couple	23.24	25.34	25.47	0.901	0.903
Crowd	21.01	25.63	25.76	0.935	0.937
Man	20.79	25.52	25.56	0.890	0.892
Tank	43.02	28.11	28.13	0.822	0.824
Trucks	27.98	25.55	25.60	0.862	0.866
Zelda	35.40	30.21	30.23	0.947	0.948

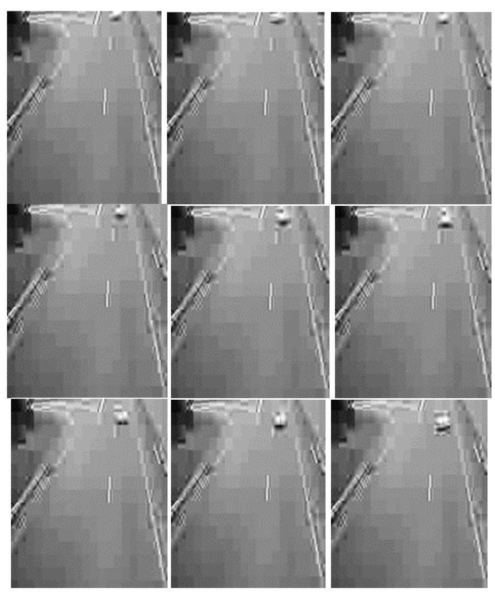
Figure 8a. Deblocked Boat Image Using 3D SF

Figure 7b. Deblocked Zelda Image Using 3D SF

3.3 Blocking Artifact Removal from Videos

The first twenty one frames of the car traffic video, compressed at high compression ratio have been displayed in Figureure 9. The visual quality of the frames is severely affected.

Using the weighted averaging technique, blocking artifact has been removed from each frame of the video. The resultant video frames are displayed in Figure 10 which show that the proposed technique is very effective in removing blocking artifacts of video frames also. The values of the MSSIM calculated for the various car traffic video frames have been plotted in Figureure 11(a). The MSSIM values have been consistent in all the video frames. Similarly, PSNR values of the video have also been calculated and plotted in Figureure 11(b).



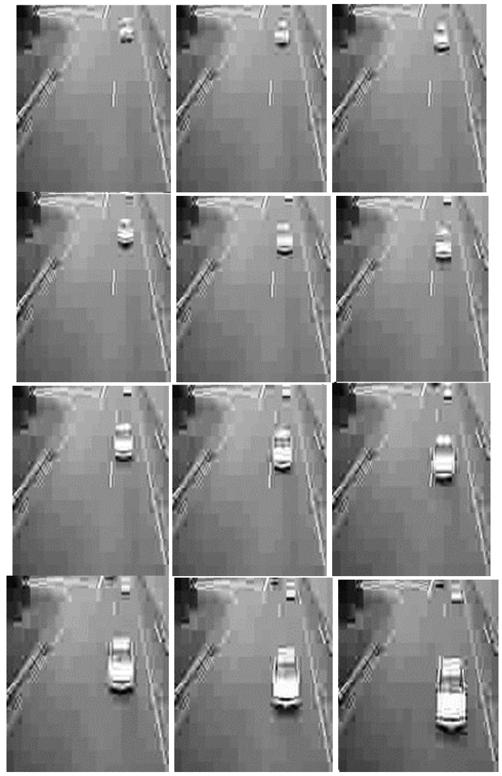


Figure 9 Frames 1-21 of Car Traffic Video with Artifacts

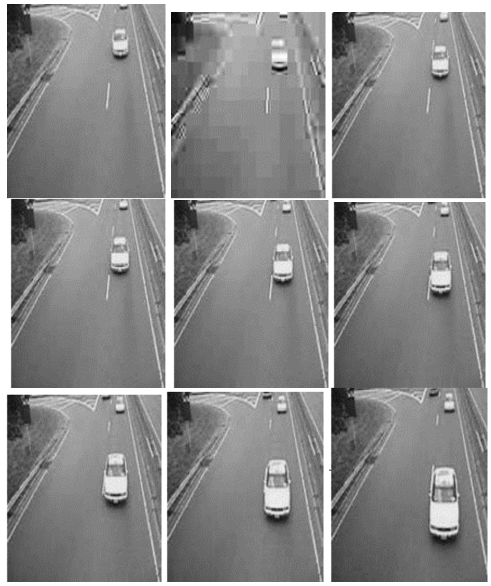


Figure 10. Frames 1-21 of Car Traffic Video after Deblocking

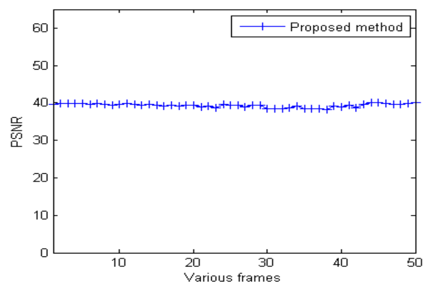


Figure 10(a) PSNR vs Frames

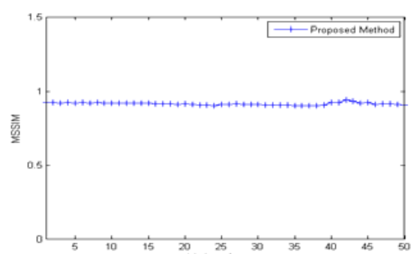


Figure 10(b) MSSIM vs Frames

4. Conclusion

A 3D spatial filtering technique which uses weighted averaging of the compressed image and its negative image has been proposed in this paper, to remove the compression artifacts from the images which have been compressed at high and medium compression ratio, using block DCT transform. The results show that this technique performs better than other methods which use weighted averaging for the removal of blocking artifact. The proposed method is found to be very effective in removing the blocking artifact of video frames as well. The mean structural similarity index measure (MSSIM) values and PSNR values of the restored image are calculated and is compared with other methods which use weighted averaging.

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