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A COMPARATIVE FRAMEWORK FOR BLOCKING ARTIFACTS REMOVAL OF DIGITAL IMAGES USING HYBRID MECHANISM

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Abstract

The restoration of an image with blocking artifacts due to compression at low bit rates is a challenging task and blocking artifact measurement algorithms have an important role to play in the computer vision field. An artifacts removal technique is an important step towards the reliability and security of image processing area that delivers a better understanding in many applications like pattern recognition, object classification, surveillance system and many more. We know that the removal of art objects is a scientific method used to provide better image analysis and for this purpose many methods of removal of art objects were already made by researchers during the processing of images such as line, motion, pattern, and hair. But in availability of group of artifacts in an image, they do not achieve an acceptable result. In this research, we proposed a comparative framework for blocking artifacts removal of digital images using hybrid mechanism. The main contribution of this research is developing a new neuro-fuzzy system-based hybrid artifacts removal mechanism to achieve better blocking artifacts efficiency. To remove artifact from an image the proposed framework has its own impact in quality parameters such as Peak Signal to Noise Ratio (PSNR), Mean Square Error (MSE), and Structural Similarity (SSIM) with the execution time. At last, the performance parameters of proposed framework is compare for all five techniques such as line, motion, pattern, hair and combination of all with each other and we observed that the achieved results justify the proposed hybrid artifact removal method in the field of image processing.

Keywords:

Artifacts, Line, Motion, Pattern, Hair, Neuro-Fuzzy, Image processing, PSNR, MSE, SSIM, Execution Time

1. INTRODUCTION

The image manipulation process such as image compression, decompression, watermarking, hiding, enhancement, medical imaging etc. causes image quality degradations such as blocking and ringing artifacts [1]. There are lots of artifacts are generated in an image such as line, motion, pattern, hair removal, and many more hybrid. Our goal is as follows: we would like to removal different kind of artifacts from images using different mechanisms that would be beneficial for image analysis toolboxes [2]. Basically, an artifact of an image is any element from an image that is not in the original image and sometimes the result of improper functioning of the image, and sometimes the result of natural processes or structures of the human body [3]. It is important to get acquainted with the appearance of antiquities because antiquities can be obscure, disrupted by pathology. Therefore, graphic art can lead to false positives and false benefits. To achieve the improvement of image quality in photography, many techniques to reduce art have been proposed and these methods can be divided into five stages as in Fig.1.

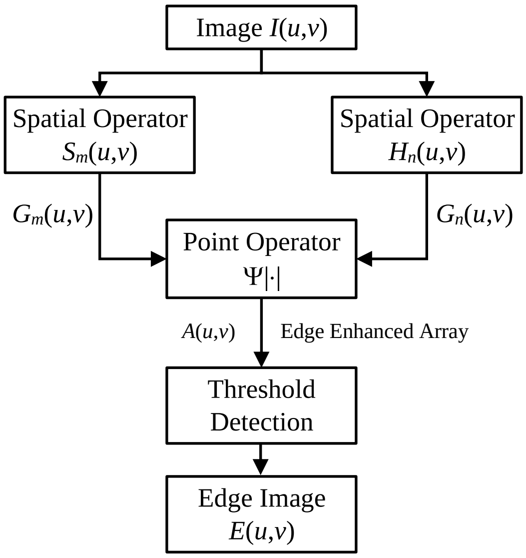


Fig.1. Image Artifacts

The image is a collection of pixels according to a tow size list that shows visual art objects as shown in the image above. One of the most important artistic elements of an image is its edges and the edges of the image are directly connected or related to the shape and contrast of the pixel distribution [4]. Overall, our contribution to the reduction of graphic arts is mainly in three areas:

A comparative artifacts reduction framework is designed to take advantage of the information in image to achieve effective removal outcomes.

In the framework, total five models are considered for the artifact's removal such as line, motion, pattern, hair removal, and hybrid of them. This hybrid model can not only effectively remove the line, motion, pattern and hair effects between but also be helpful for removing all blocking artifacts together.

To validate the proposed comparative model, a comparative analysis with the all strategies is performed in the name of performance parameters such as Peak Signal to Noise Ratio (PSNR), Mean Square Error (MSE), Entropy and Structural Similarity (SSIM) with Execution Time.

The rest of this research article is organized as follows. Section 2 will introduce work related to the analysis of the existing framework for the reduction of art objects. In Section 3, we will introduce a detailed process and the test results are shown to test the proposed method in Section 4. Finally, we conclude this work in section 5 with some future possibilities.

2. RELATED WORK

Recently, artifacts removal-based approaches have shown the most advanced results in many computer-vision fields, such as medical image segmentation, diseases classification and recognition, understanding of pixel pattern and so on. Gambhir et al. [5] they had proposed a reduction in the artifact of compressed DCT images using values obtained from the function of the s-shaped membership which obtained a pixel section at the edge of the Gaussian indirect edge detector.

Gambhir et al. [6] suggested a double-splitting algorithm that separates each block to insert a smooth block or edge block using a histogram based fuzzy edge classifier. In the encoder, smooth image blocks are inserted into its mean value and the edge block is compressed using an abstract transition. In the decoder, a reconstructed image obtained using fair value and a decrease in the use of inverse fuzzy transform, contains a reduced artifact using the Gaussian block improvement scheme.

Manu and Mehtre [7] used a blind process using blockchain art and entropy histograms to detect image distortion. In this research work, the authors have suggested a touch-up approach to images that use blocking and blurring objects that are fraudulent measures. The classification of images as distorted or not, is done based on the normal deviation of entropy histograms and prevents the distinct conversion of cosine. Model test results from publicly available photographic datasets show that the proposed method exceeds existing methods with accuracy [7].

Marsh et al. [8] they had conducted a study to remove the blockade of art objects in JPEG-compressed images using the neural network. The main objective of this study was to develop a neural network that would improve the quality of JPEG compressed images, regardless of the degree of compression. The authors decided to integrate the neural network into a process previously performed after conducting many studies. In this way, the Alpha filter is used to send JPEG process pressed images to reduce noise and antiquities.

Yeh et al. [9] they had conducted a study on deep compressed image reduction based on several image combinations. In this research work, the authors have presented an in-depth framework and here, the inclusion image is first sampled while naturally reducing the barrier art objects. Thereafter, a moderate image enhancement model was used to combine low-resolution (low-resolution) versions with an input image (with complex art) to measure blocking elements. After that, by removing the scaled art objects in the input image, the blocking objects can be removed too and most of the image details are stored simultaneously. The presented method is well applicable to any vision-based computer systems with digital visual codec embedded.

It has been observed after the detailed literature survey related to the image artifacts removal and removal of blocking artifacts from images has much potential which can be explored. Some points are listed below giving the explanation regarding the gaps in research work done in the Table.1.

Based on the above research in the field of artifacts removal in order to improve image quality, we have presented a comparative framework. for the artifacts removal and we focus to develop a new approach with the hybridization of several artifact removal approach.

Table.1. Gaps in Existing Artifacts Removal

Sl. No.	Challenging Issues
1	In existing work, the concept of fuzzy based approach has been applied but still hybridization-based approach is unexplored to remove the artifacts of image and increases quality of an image.
2	Over the years various methods and techniques have been applied to detect and remove the artifacts. Artificial neural networks have great scope for enhancing the image quality.
3	The loss of information from the images is more by utilizing the available edge detection approaches during the artifact removal.

3. MODEL AND METHODOLOGY

The used material and method for the comparative framework to remove image artifact is discussed in this section of article. In image processing field, the concept of blocking artifact measurement algorithms has an important role for image analysis. By using such an algorithm into the image processing, it becomes possible to optimize the image quality enhancement parameters or control the bit allocation to reduce blocking artifacts. In recent years, many blocking artifact reduction algorithms have been proposed, so the brief details about the proposed comparative framework to remove image artifact is given in the below section of this paper with flowchart in Fig.2.

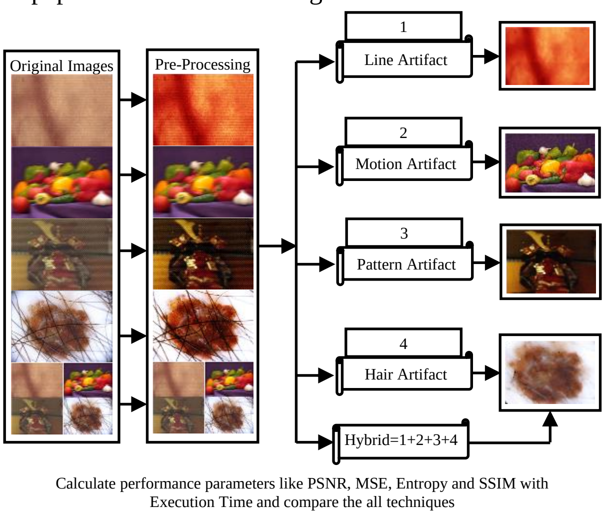


Fig.2. Flowchart of Comparative Framework of Artifact Removal Techniques

The Fig.2 shows the comparative flowchart with the proposed framework and we explain the working of each technique in below section. Based on the above-mentioned framework, we design and develop an architecture for the simulation of proposed model using five different techniques such as line, motion, pattern, hair, and hybrid mechanism. The basic implementation steps are given as:

Design a comparative framework and upload image for further processing on image and the algorithm of image uploading is written as:

Algorithm 1: Image Uploading

Image = Image Uploading (Image File)

Start

For m = 1 $\rightarrow N$ // N = Number of image files for uploading

[Filename, Pathname] = Browse (Select folder)

Full file = concatenate (Pathname, Filename)

Image [m] = image read (Full file)

End For

Return: Image

End Function

Based on the above algorithm, we upload image having artifacts for simulation and the flow of algorithm is shown in the Fig.3.

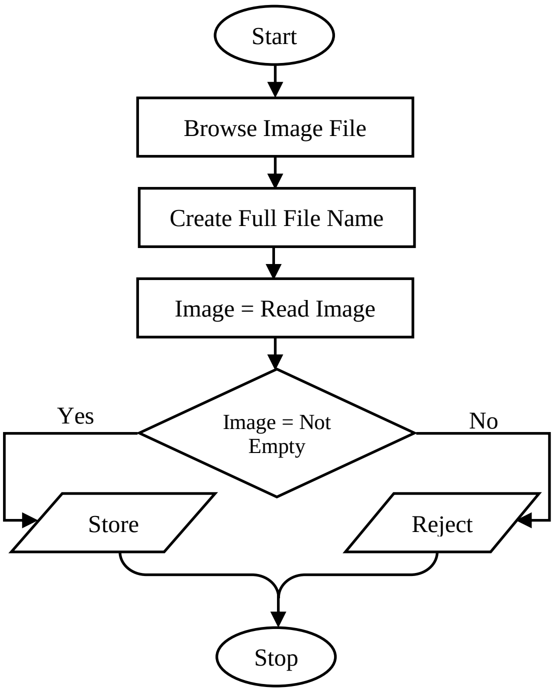


Fig.3. Flow of Algorithm 1

Apply pre-processing for image quality improvement on the uploaded image. In the pre-processing steps, image is converted into double precision and then quality enhancement is applied according to the requirements. Here, the concept of Color Fidelity based Enhancement (CFE) is used and the algorithm of CFE is written as:

Algorithm 2: CFE as Pre-processing

Pre-processed Image = CFE (Image)

Start

Define Color Fidelity Coefficient, zeta=0.5

D-Image = (Image/255) // Double precision image to create small data, so that minimum memory occupy

RGB =D-Image (Row, Col, 1/2/3) // where, 1 for Red, 2 for Green and 3 for Blue Plane of Image

New Coefficient according to pane of image, τ_{RGB}=0.5, 0.6 and 0.7 // Threshold for Red, Green and Blue Plane respectively

Critic Image =([RGB - min(RGB)])/(max(RGB) - min(RGB))

[Row, Col, Plane] = Size (Critic Image)

For J = 1$\rightarrow$Row

For K = 1$\rightarrow\in$Col

If Critic Image (J, K) <= τ_{RGB}

Pre-processed Image (J,K) =2×(Critic Image(J,K)^2)

Else

Pre-processed Image (J,K)=1-2×(1-Critic Image(J,K)^2)

End If

End For

End For

Pre-processed image=(Pre-processed mage)$^{(\tau_{RGB}+\zeta)}$

Return: Pre-processed Image

End Function

Pre-processing algorithm is used to make a compatible data according to the system requirements and the flow of pre-processing algorithm is shown in the Fig.4.

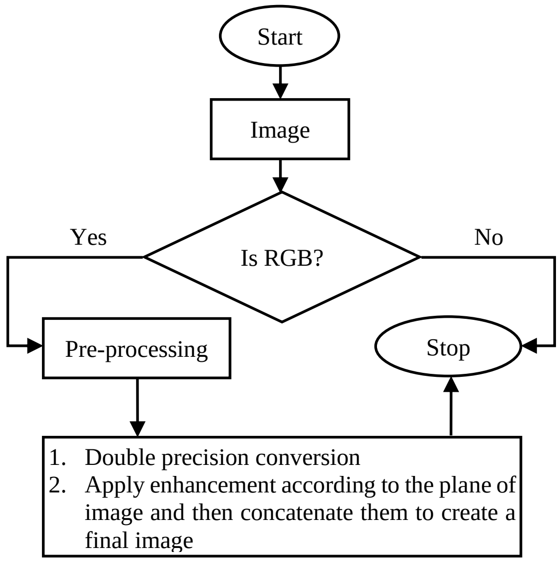


Fig.4. Flow of Algorithm 2

After the pre-processing, total framework is divided into five sections named as line artifact removal, motion artifact removal, pattern artifact removal, hair artifact removal, and hybrid artifact removal.

3.1 LINE ARTIFACT REMOVAL

It is the basic type of artifacts and mainly occurs due to presence of noise in image. A method for removing line artifacts from images without changing the actual image quality is presented in this research. The method utilizes the concept of Gaussian Filter to detect line frequencies and use spectral domain filtering to remove line segments from images. How to remove line art from an image with edgy regions, and high-power regions, means a method that contains the following steps:

Step 1: Generating a gradient image and an intensity image from original images.

Step 2: Replacing every edgy region with non-edgy regions to generate a modified image using gradient image with Gaussian Filter.

Step 3: Replacing high intensity regions with low intensity regions within image using threshold intensity.

Step 4: Eliminating line artifacts from modified image and construct a new image without any artifacts.

Another cause of line artifacts on the image is the use of electronic circuit errors during capturing. It may be also caused by variations in the image during over-sampling. It would be desirable to remove line artifacts from the image caused by over-sampling without changing original quality. The algorithm of line artifact removal is written as:

Algorithm 3: Line Artifact Removal (LAR)

Modified Image = LAR (Pre-processed Image (*PI*))
Start
[Rows, Cols, Plans] = Size (*PI*)
For *m* = 1→Plans
For *n* = 1→*Rows*
For *k* = 1→*Cols*
Modified Image = Gaussian Filter (*PI*)
Using given equation Gaussian filter is applied

$$GF(m,n)=\frac{1}{2\pi\sigma^2}e^{-\frac{m^2+n^2}{2\sigma^2}}$$

Where, σ is the standard deviation
End For
End For
End For
Return: Modified Image
End Function

Using the above algorithm, we remove the line artifacts from image and the sample is shown in the Fig.5.

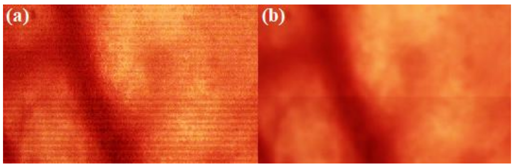


Fig.5. Sample Line Artifact Removal

The Fig.5 depicted the process of line artifact removal from the image using LAR algorithm 3 and Fig.5(a) represents the original image and Fig.5 (b) represents the modified image after artifact removal.

3.2 MOTION ARTIFACT REMOVAL

It is a movement-based artifact that occurs with object movement during image acquisition. The acquisition of an image usually takes some times and during this period objects should be in still position. Movement of the the object degrades the image quality and its artistic products such as breathing, blurring and lubrication. This work focuses on reducing the effect of motion on images and on the motion artifact algorithm removal is written as:

Algorithm 4: Motion Artifact Removal (MAR)

Modified Image = MAR (Pre-processed Image (PI))
Start
[*Rows*, *Cols*, *Plans*] = Size (*PI*)
For *m* = 1→Plans
For *n* = 1→Rows
For *k* = 1→Cols
I = Double Precision (PI)
Define noise variance, *NV* = 0.000001
Estimated Ratio, *R* = *NV* / variance (*I*)
LEN = 21 // linear motion of a camera
THETA = 11 // angle of degrees
PSF = f-special ('*Motion*', *LEN*, *THETA*)
Modified Image = Wiener filter (*I*, *PSF*, *R*)
Using given equation Wiener filter is applied

$$WF(m,n)=\frac{H(m,n)}{|H(m,n)|^2+K}$$

Where, *K* is the frequency coefficient of filter
End For
End For
End For
Return: Modified Image
End Function

Using the above algorithm, we remove the motion artifacts from image and the sample is shown in the Fig.6.

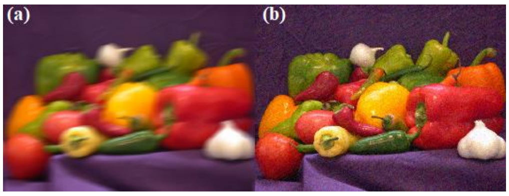


Fig.6. Sample Motion Artifact Removal

The Fig.6 depicted the process of motion artifact removal from the image using MAR algorithm 4 and Fig.6 (a) represents the original image and Fig.6 (b) represents the modified image after motion artifact removal.

3.3 PATTERN ARTIFACT REMOVAL

The pattern is usually photographic art produced by various digital imaging techniques and computers. Basically, patterns appear in a picture in many cases such as printing, photography, etc. A pattern on an object being photographed can interfere with the shape of the light sensors to generate unwanted artifacts. This work focuses on the reduction of pattern artifacts on the images using the multidimensional filtering with convolution and the algorithm of pattern artifact removal is written as:

Algorithm 5: Pattern Artifact Removal (PAR)

Modified Image = PAR (Pre-processed Image (*PI*))
Start
[*Rows*, *Cols*, *Plans*] = Size (*PI*)
For *m* = 1→Plans
For *n* = 1→ Rows

For k = 1→Cols

I = Double Precision (*PI*)

Transformed, T = Fourier (I)

Modified Image = Convolutional (I, T)

Here, multi-dimensional filter is applied

End For

End For

End For

Return: Modified Image

End Function

Using the above algorithm, we remove the pattern artifacts from image and the sample is shown in the Fig.7.

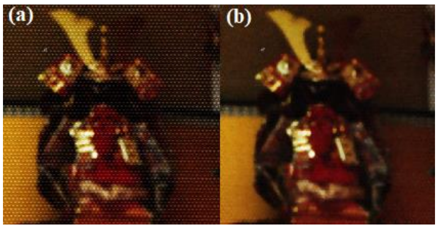


Fig.7. Sample Pattern Artifact Removal

The Fig.7 depicted the process of pattern artifact removal from the image using PAR algorithm 5 and Fig.7(a) represents the original image and Fig.7(b) represents the modified image after pattern artifact removal.

3.4 HAIR ARTIFACT REMOVAL

In medical science, hair artifact is most affecting section and need to minimize this by utilizing hair removal approaches. This work focuses on the removal of hair artifacts on the images using the Hair Artifact Removal (HAR) method and the algorithm is written as:

Algorithm 6: Hair Artifact Removal (HAR)

Modified Image = HAR (Pre-processed Image (*PI*))

Start

[*Rows*, *Cols*, *Plans*] = Size (*PI*)

For m = 1→Plans

For n = 1→Rows

For k = 1→Cols

RPI = Resize (*PI*, [512 512])

Set radius, r = 7 // to create a circular mask

[X, Y] = mesh grid (1→*Row*)

Create a mask,

Mask = $(X\text{-}280)^2+(Y\text{-}280)^2<280^2$

Set threshold, TH = 5 // to identify hair pixel

CI = Close (*RPI*, *Element*) // to close extra part

Diff = double (*CI*) - double (*RPI*)

DI = Dilated (Diff >thresh) // Apply dilation

Modified Image = *PI* (*DI*)

End For

End For

End For

Return: Modified Image

End Function

Using the above algorithm, we remove the hair artifacts from image and the sample is shown in the Fig.8.

The Fig.8 depicted the process of hair artifact removal from the image using HAR algorithm 6 and Fig.8 (a) represents the original image and Fig.8 (b) represents the modified image after pattern artifact removal.

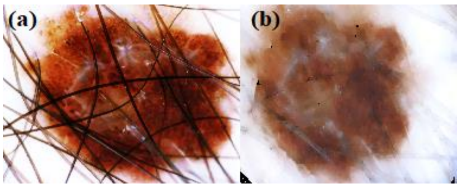


Fig.8. Sample Hair Artifact Removal

3.5 HYBRID ARTIFACT REMOVAL

In this approach, we combined all of the artifact removal techniques to minimize artifact effect in an image such as line, motion, pattern, hair etc. This hybridization focuses on the removal of all types of artifacts on the images using the Hybrid Artifact Removal (HYAR) method with Neuro-Fuzzy Logic and the algorithm is written as:

Algorithm 7: Hybrid Artifact Removal (HYAR)

Modified Image = HYAR (Pre-processed Image (*PI*))

Start

[*Rows*, *Cols*, *Plans*] = Size (*PI*)

For m = 1→Plans

For n = 1→Rows

For k = 1→Cols

Modified_Image=*LAR*(*PI*)+*MAR*(*PI*)+*PAR*(*PI*)+*HAR*(*PI*)

Image = Fuzzy (Modified Image, Rulesets)

To optimized the Image, ANN is used

Index = Find index of Image

If index is normal then

O_Image(i) = Image (*index*)

Else

Mark as irrelevant pixel

End If

Call ANN using training data (T), number of group (G) and Neurons (N)

NF-Structure = NEWFF (T, *Group*, N)

NF-Structure = TRAIN (NF-Structure, T, G)

CP = Current pixel of Image

Output = SIM (NF-Structure, *CP*)

If Output ∈ O_Image

Modified Image = Validated

Else

Modified Image = Remove pixel

End If

End For

End For

End For

Return: Modified Image

End Function

Using the above algorithm, we remove the all types of artifacts from image and the neuro-fuzzy system looks to be the ideal solution. Basically, the uses of a learning algorithm that is derived from or enthused by Artificial Neural Network (ANN) theory to regulate its parameters based on the concept of fuzzy sets and rules is known as a neuro-fuzzy system. Fuzzy logic relies on the definition of fuzzy set and a fuzzy set (*S*) of a universe of discourse (*U*) is categorized by a membership function. By using the concept of fuzzy logic, developers are allowed to set rule for artifact types as graded categories with feedforward neural network. The architecture of neuro-fuzzy system is shown in the Fig.9.

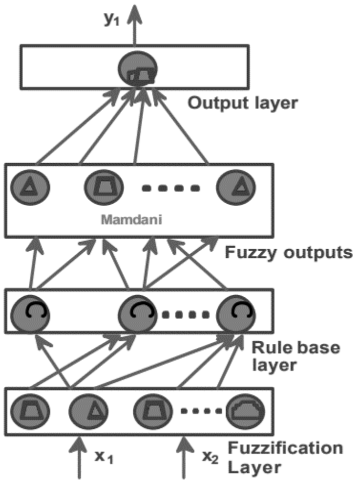
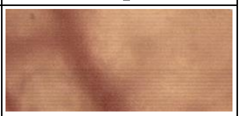
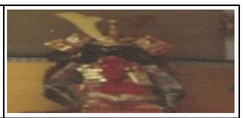
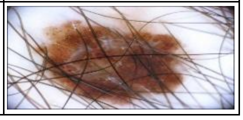


Fig.9. Neuro-Fuzzy System

The node functions, architecture and learning parameters are shown in the Fig.9 that is adapted according to an ANN procedure. The developing neuro-fuzzy model can adapt to Mamdani or Takagi Sugeno type Fuzzy Inference System (FIS). Here, we define the input and output layers and hidden layers are selected using the concept of fuzzy rulesets. Fuzzification layer and the rule antecedent layer functions are similar and the consequential part of rule determined according to a system of thinking according to the type of art problem, which will be appropriately replaced by a square error.

Table.2. Used Sample Images

Artifacts	Samples
Line	
Motion	
Pattern	
Hair	

Finally, calculate the performance parameters of the proposed project with accuracy, PSNR, MSE, Entropy and SSIM and Duration. The above method and algorithms show the process steps of the proposed model in some specific images. Sample photos are provided in the Table 2.

The simulation results of proposed comparative framework using five different methods are is described in the below section of paper.

4. RESULTS AND ANALYSIS

In this section, we describe the simulation results of the proposed comparative framework to remove image artifacts and the simulation results based on the PSNR, MSE, SSIM and Time is given in the Table 3.

Table.3. Evaluation of Performance Parameters

Images	PSNR	MSE	SSIM	Time (s)
Line	44.89	2.12	0.062	1.16
Motion	48.86	0.85	0.037	0.43
Pattern	48.71	0.88	0.018	18.28
Hair	55.53	0.18	0.78	5.12
Hybrid	49.89	0.72	0.74	4.69

In the point of view of better artifacts removal from, the proposed comparative framework has achieved better performance in terms PSNR that is shown in the Table.3 based on the comparison with different artifacts removal techniques such as line, motion, pattern, hair and Hybridization of all.

To calculate the PSNR, we use the given equation of PSNR:

$$\text{PSNR}=10\times\log 255^2/MSE \quad (1)$$

where, *MSE* is calculated using the given equation:

$$MSE=\frac{1}{mn}\sum_{i=0}^{m}\sum_{j=0}^{n}\left[I(i,j)-E((i,j))\right]^2 \quad (2)$$

where, *m* and *n* is the row and column of an image and *I* is original image with artifacts and *E* is an enhanced image. According to the above figure, we observed that the PSNR value in case of hybrid approach is better than others rather than hair artifacts. The MSE comparison is shown in the Table.3.

Similar to the PSNR, MSE for hybrid method is better than other method rather than hair artifacts removal approach. For more validation of proposed hybrid approach, we also compare some other parameters like SSIM and Execution time in Table.3 respectively.

Above simulation results based on the SSIM and Execution Time, the effectiveness of proposed hybrid artifact removal method has its own impact. To minimize the artifact removal problems, fuzzy logic-based hybrid approach has been proposed and outperform than other techniques. It has been shown that fuzzy logic-based artifacts removal approach can remove all artifacts more appropriately than others. This allows reducing MSE and is useful in adapting design rules with respect to changing contexts in an image in terms of artifacts.

5. CONCLUSION AND FUTURE WORK

This research article has highlighted some artifacts problems which affect current image capturing methods. In this paper, a comparative framework is presented to remove different types of artifacts from images for better image analysis. The main focus of this research is to develop a hybrid artifacts removal approach by utilizing the concept of fuzzy logic that can remove all types of artifacts from images. Basically, we present a comparative study of five different artifact removal approach such as line, motion, pattern, hair and their combination. The obtained and achieved results of proposed fuzzy logic-based hybrid approach in terms of PSNR, MSE, SSIM and Execution Time have great impact in the area of artifacts removal. The obtained parameters values are favorably acceptable under consideration to show the effectiveness of proposed fuzzy logic-based hybrid approach as compare to other approaches. In future, proposed hybrid artifacts removal method could be develop for the medical images like CT-scan, MRI and X-ray images based on the machine learning concept for fast and robust response.

REFERENCES

[1] Y. Yang , N.P. Galatsanos and A.K. Katsaggelos, "Projection-Based Spatially Adaptive Reconstruction of Block-Transform Compressed Images", *IEEE Transactions on Image Processing*, Vol. 4, No. 7, pp. 896-908, 1995.

[2] Y. Yang and N.P. Galatsanos, "Removal of Compression Artifacts using Projections onto Convex Sets and Line Process Modeling", *IEEE Transactions on Image Processing*, Vol. 6, No. 10, pp. 1345-1357, 1997.

[3] T.P. O'Rourke and R.L. Stevenson, "Improved Image Decompression for Reduced Transform Coding Artifacts", *IEEE Transactions on Circuits and Systems for Video Technology*, Vol. 5, No. 6, pp. 490-499, 1994.

[4] X. Zhang, R. Xiong, S. Ma and G. Wen, "Reducing Blocking Artifacts in Compressed Images via Transform-Domain Non-Local Coefficients Estimation", *Proceedings of IEEE International Conference on Multimedia and Expo*, pp. 836-841, 2012.

[5] D. Gambhir and N. Rajpal, "Fuzzy Edge Detector based Blocking Artifacts Removal of DCT Compressed Images", *Proceedings of International Conference on Circuits, Controls and Communications*, pp. 1-6, 2013.

[6] D. Gambhir and N. Rajpal, "Image Coding using Fuzzy Edge Classifier and Fuzzy F-Transform: Dualfuzzy", *International Journal of Fuzzy Computation and Modelling*, Vol. 1, No. 3, pp. 235-251, 2015.

[7] V.T. Manu and B.M. Mehtre, "Blind Technique using Blocking Artifacts and Entropy of Histograms for Image Tampering Detection", *Proceedings of 2nd International Workshop on Pattern Recognition*, pp. 1-15, 2017.

[8] R. Marsh and M.N. Amin, "Removal of Blocking Artifacts from JPEG-Compressed Images using a Neural Network", *Proceedings of IEEE International Conference on Electro Information Technology*, pp. 255-258, 2020.

[9] C.H. Yeh, C.H. Lin, M.H., Lin and M.J. Chen, "Deep Learning-Based Compressed Image Artifacts Reduction based on Multi-Scale Image Fusion", *Information Fusion*, Vol. 67, pp. 195-207, 2021.

[10] Z. Wang, D. Liu, S. Chang, Q. Ling and Y. Yang, "D3: Deep Dual-Domain based Fast Restoration of JPEG-Compressed Images", *Proceedings of IEEE Conference on Computer Vision and Pattern Recognition*, pp. 2764-2772, 2016.

[11] J. Guo and H. Chao, "Building Dual-Domain Representations for Compression Artifacts Reduction", *Proceedings of European Conference on Computer Vision*, pp. 628-644, 2016.

[12] X. Zhang, W. Yang, Y. Hu and J. Liu, "Dmcnn: Dual-Domain Multi-Scale Convolutional Neural Network for Compression Artifacts Removal", *Proceedings of IEEE International Conference on Image Processing*, pp. 390-394, 2018.

[13] K. He, X. Zhang, S. Ren and J. Sun, "Deep Residual Learning for Image Recognition", *Proceedings of IEEE Conference on Computer Vision and Pattern Recognition*, pp. 770-778, 2016.

[14] F. Shen, R. Gan and G. Zeng, "Weighted Residuals for Very Deep Networks", *Proceedings of International Conference on Systems and Informatics*, pp. 936-941, 2016.

[15] C. Ledig, L. Theis, F. Huszar and J. Caballero, "Photo-Realistic Single Image Super-Resolution using a Generative Adversarial Network", *Proceedings of IEEE Conference on Computer Vision and Pattern Recognition*, pp. 4681-4690, 2017.

[16] B. Lim, S. Son, H. Kim, S. Nah and K. Mu Lee, "Enhanced Deep Residual Networks for Single Image Super-Resolution", *Proceedings of IEEE Conference on Computer Vision and Pattern Recognition Workshops*, pp. 136-144, 2017.

[17] J. Yu, Y. Fan, J. Yang, N. Xu, Z. Wang, X. Wang and T. Huang, "Wide Activation for Efficient and Accurate Image Super-Resolution", *Proceedings of IEEE Conference on Computer Vision and Pattern Recognition Workshops*, pp. 1-13, 2018.

[18] M. Sandler, A. Howard, M. Zhu, A. Zhmoginov and L.C. Chen, "Mobilenetv2: Inverted Residuals and Linear Bottlenecks", *Proceedings of IEEE Conference on Computer Vision and Pattern Recognition*, pp. 4510-4520, 2018.

[19] Y. Fan, J. Yu and T.S. Huang, "Wide-Activated Deep Residual Networks based Restoration for BPG-Compressed Images", *Proceedings of IEEE Conference on Computer Vision and Pattern Recognition Workshops*, pp. 2621-2624, 2018.

[20] E. Agustsson and R. Timofte , "Challenge on Single Image Super-Resolution: Dataset and Study", *Proceedings of IEEE Conference on Computer Vision and Pattern Recognition Workshops*, pp. 126-135, 2017.

[21] D. Martin, C. Fowlkes, D. Tal and J. Malik, "A Database of Human Segmented Natural Images and Its Application to Evaluating Segmentation Algorithms and Measuring Ecological Statistics", *Proceedings of the IEEE*

International Conference on Computer Vision, pp. 416-423, 2001.

[22] M. Bevilacqua, A. Roumy, C. Guillemot and M.L. Alberi-Morel, "Low-Complexity Single-Image Super-Resolution based on Nonnegative Neighbor Embedding", *Proceedings of the British Conference on Machine Vision*, pp. 1-12, 2012.

[23] A. Paszke, S. Gross, S. Chintala, G. Chanan, E. Yang, Z. De Vito, Z. Lin, L. Antiga and A. Lerer, "Automatic Differentiation in PYTORCH", Available at https://openreview.net/forum?id=BJJsrmfCZ, Accessed at 2021.

[24] H. Zhao, O. Gallo, I. Frosio and J. Kautz, "Loss Functions for Image Restoration with Neural Networks", *IEEE Transactions on Computational Imaging*, Vol. 3, No. 1, pp. 47-57, 2017.

[25] D.P. Kingma and J. Ba, "Adam: A Method for Stochastic Optimization", *Proceedings of International Conference on Learning Representations*, pp. 1-14, 2015.

[26] C. Yim and A.C. Bovik, "Quality Assessment of Deblocked Images", *IEEE Transactions on Image Processing*, Vol. 20, No. 1, pp. 88-98, 2011.

[27] J. Zhang, R. Xiong, C. Zhao, Y. Zhang, S. Ma and W. Gao, "Concolor: Constrained Non-Convex Low-Rank Model for Image Deblocking", *IEEE Transactions on Image Processing*, Vol. 25, No. 3, pp. 1246-1259, 2016.

[28] X. Liu, X. Wu, J. Zhou and D. Zhao, "Data-Driven Soft Decoding of Compressed Images in Dual Transform-Pixel Domain", *IEEE Transactions on Image Processing*, Vol. 25, No. 4, pp. 1649-1659, 2016.

[29] J. Zhang, S. Ma, X. Fan, Y. Zhang and W. Gao, "Reducing Image Compression Artifacts by Structural Sparse Representation and Quantization Constraint Prior", *IEEE Transactions on Circuits and Systems for Video Technology*, Vol. 27, No. 10, pp. 2057-2071, 2017.

[30] C. Chen, Z. Xiong, X. Tian and F. Wu, "Deep Boosting for Image Denoising", *Proceedings of the European Conference on Computer Vision*, pp. 3-18, 2018.