Dynamic Stochastic Resonance Based Blocking Artifacts Removal from Compressed Images in DCT Domain

Rajib Kumar Jha, Onkar Krishna, Saurabh Kumar Pandey, Sumit Kumar and Vivek Singh Verma

May 3, 2019

Dynamic Stochastic Resonance Based Blocking Artifacts Removal from Compressed in DCT Domain

Rajib Kumar Jha[1], Onkar Krishna[2], Saurabh Kumar Pandey[1], Sumit Kumar[1], Vivek Singh Verma[2]
[1]*Indian Institute of Technology Patna,* [2]*PDPM IIITDM Jabalpur*
(jharajib, saurabh)@iitp.ac.in, (onkarkris, sumitphd13, viveksv10)@gmail.com

***Abstract*—In this paper, we have introduced a dynamic stochastic resonance (DSR)-based blocking artifacts removal of compressed images in DCT domain. Blockiness in DCT based compressed images after reconstruction are a very challenging problem. In the proposed technique it has been observed that blockiness is coming due to a few DCT coefficient of the first row of each block, so we focused only on target coefficient and modified them with a weighted average of neighboring block coefficients. To improve the performance of the blocking artifacts reduction methods, we have used the dynamic stochastic resonance (DSR) by exploiting the clamor or decadence introduced during the quantization procedure. DSR is an iterative process which modulates the quantized factors so that the impact of the quantization procedure is compressed and image information is enhanced. To find a better outcome and minimize the computational complexity, an adaptive optimization method has been taken for selection of bistable parameters. The main advantage of the proposed method is, it overcomes the blocking artifacts introduced during the DCT based compression. The qualitative and quantitative results are also shown.**

***Index Terms*—Dynamic Stochastic Resonance (DSR); Discrete cosine transform (DCT); Stochastic Resonance (SR).**

I. INTRODUCTION

Benzi *et al.* [1] was the first author who has introduced the term stochastic resonance (SR) in the context of noise enhanced signal processing in 1981; wherein they addressed the problem of periodic recurrence of Earth ice ages. SR phenomenon was also reported by Fauve *et al.* [2] in 1983. They studied the noise dependence of the spectral line of an acdriven Schmitt trigger circuit. Besides that, SR is widely used in the image processing applications like image enhancement [3], watermarking [4], signal detection [5]–[8], and segmentation [9] *etc.*

In 2003, Qinghua *et al.* [10] used the SR phenomenon for line detection from noisy images based on Radon transform. In 2006, Guangchun *et al.* [11] investigated the novel watermarking scheme, which is based on the stochastic resonance. Jha *et al.* used the concept of stochastic resonance in different fields of image and signal processing such as image denoising [12], image segmentation [13], image watermarking [14], contrast enhancement [15]. In these methods, authors utilize the inner noise, which is already present in the input image, as well as they, introduced the external noise to improve the executions.

Image compression is an essential requirement in several areas of communication. The main objective of compression is to reduce the image size for efficient storage and transmission purposes. Numerous of efficient compression methods are used for several applications. From them, a discrete cosine transform (DCT) was adopted in the international standard of JPEG, MPEG, and H.261. The reformed images from JPEG compression produce annoying blocking artifacts near block boundaries, for highly compressed images. The degradation mentioned above is a direct outcome of the coarse quantization of the DCT coefficients and also due to independent processing of the blocks, except the dc coefficients of blocks.

Several techniques have been proposed by researchers; both in spatial and frequency domains for the reduction of blocking artifacts with varying degree of success. Some methods working in the frequency domain are proposed by different authors [16]–[18]. A new index to measure the blocking effects namely the mean squared difference of slope (MSDS) is introduced in [16]. It is shown that the expected value of the MSDS increased with an increase in the quantization of the DCT coefficients. There approaches remove the blocking effect by minimizing the MSDS, while imposing linear constraints corresponding to quantization bounds. Liu et al. [17] proposed a DCT domain method for blind measurement of blocking artifacts, by modeling the artifacts as 2-D step functions in shifted blocks. Zeng [18] proposed another DCT domain method for blocking artifact reduction by applying a zero masking to the DCT coefficients of some shifted image blocks.

Main objective of our algorithm is to maximally reduce the extraneous noise introduced by the quantization process without sacrificing the image quality. For this purpose, we used the concept of dynamic stochastic resonance (DSR). DSR is a phenomenon where a controlled amount of random noise is used for signal and image improvement. Here in this work, we have used internal quantization noise present in the compressed image for blocky artifacts removal.

II. OVERVIEW OF DYNAMIC STOCHASTIC RESONANCE

It has been observed in one-dimensional signals that at an optimum resonant value of noise, the signals cross the threshold and transits into another (enhanced state)) [15]. To establish the principles of SR in applications of image processing, the discrete image pixels are incisively treated as discrete particles, whereby the gray value of an image pixel corresponds to a specific kinetic parameter of a physical particle in Brownian motion. The mathematical formulation of the theory of dynamic stochastic resonance can be found in [15]. In this paper, we used DSR technique for blocky artifacts removal purposes. At optimum intrinsic noise density (or the optimum number of oscillations) the particle makes a transition into the other well. In the proposed analogy, this optimum amount of noise is reached with maximization of PSNR by tuning the quantized DCT coefficients using discrete iterative Eq. 1.

$$x(n+1) = x(n) + \Delta t[ax(n) - bx^3(n+1) + Input] \quad (1)$$

Here n is iteration count; $\triangle\, t$ is the sampling time, taken as 0.015 experimentally. $Input = B\sin(\omega t) + \sqrt{D}\xi(t)$ denotes the sequence of input signal and noise. This denotation can be done keeping in view images affected with blocking artifacts can be viewed as signal consisting of transformed image coefficient and noise corresponding to quantization of the coefficients.

In the paper [15], an analogy to Benzi's double-well model for the global climate, in the context of blocking artifacts reduction has been developed. The model shows the physical relationship between the proposed work and the stochastic resonance concept. The position of the particle in a double well system is analogous to the state of DCT coefficients responsible for blocking artifacts. A weak periodic forcing is constituted by the DCT coefficients, while the noise is constituted by the noise introduced during the quantization process. Each of the two stable states is represented by a noisy state and enhanced state respectively. The iterative process is used for tuning the DCT coefficients, after a certain number of iterations; coefficients change their state from a weak state to enhanced state. Selection of bistable system parameters is based on the maximization of SNR [15].

III. REPRESENTATION OF BLOCK DISCONTINUITY IN DCT DOMAIN AND PREPROCESSING

We examine two horizontally adjacent blocks A and B each of size $8x8$ shown in Fig. 1. Assume block A has a constant gray value a and block B has a constant gray value b, $a \neq b$, for vertically adjacent blocks, the same assumptions are made. Let the right half of block A and the left half of block B form a block denoted as block C. Block C is an 8×8 block which contains the boundary pixels of blocks A and B. Let, $F_a(u, v)$ $F_b(u, v)$ and $F_c(u, v)$ be the DCT coefficients of blocks A, B and C respectively. Since the pixels of blocks A and B have constant intensity values, so for $F_a(u, v)$ and $F_b(u, v)$ has only one nonzero value at $u = v = 0$ and all others are zero. Block C has discontinuity in its middle due to boundary, the same can be observed from the DCT coefficients of block C, which is $F_c(u, v) = 0$ for $v = 2, 4, 6$ and $u = 0$ and $F_c(u, v) \neq 0$ for $v = 0,\ 1, 3, 5, 7$ in $u = 0$. It implies that the horizontal boundary discontinuity in block C can be represented only in a few DCT coefficients of the first row. It also can be easily deduced that the heavier the block discontinuity, the larger the ripples in these nonzero values.

We have targeted coefficients responsible for blocky artifacts of an image. As the coefficient adapts to the local information content of the image, altering the values of these coefficients without taking into consideration, the information about the

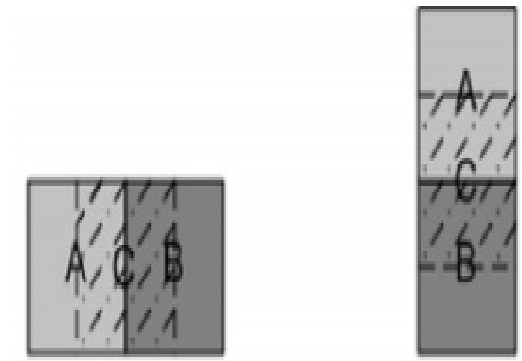


Fig. 1: Horizontally and vertically adjacent blocks

nature of the image pixels in its neighborhood might result in artifacts. This is especially the case for high bit rate applications. Therefore before such filtering is performed, one has to ensure that the edge appearance between blocks A and B is not due to a genuine horizontal change in the grey levels of the pictures at that position. Conditions that should be met before modifying the blockiness responsible for blockiness appearance of the smooth regions are in the paper [19].

Now we perform our preprocessing step of blocky artifacts reduction in the DCT domain by modifying the five relevant coefficients of $F_c(u, v)$. The first row of the DCT coefficient matrix of block C is modified by the weighted average of the first row of DCT coefficients of blocks A, B, and C. The advantage of using the weighted average of adjacent block coefficients is that it is much adaptive to image contents instead of simply adjusting the value of DCT coefficient of block C. Detailed description of this can be found in the paper [19].

IV. DSR BASED BLOCKING ARTIFACT REMOVAL

Now we apply the DSR concept on pre-processed blocks. We derived the DSR iterative equation as discussed in Section II and calculated double well system parameters by maximization of signal-to-noise ratio (SNR). DSR tries to suppress the noise effect introduced due to quantization error by tuning this internal noise at the different number of iterations, after certain iteration, we get the results in which simultaneously artifacts are invisible and information content enhanced. Therefore, the peak signal-to-noise ratio (PSNR) reached its maximum value. The average number of iterations in our experiment is found to be three. The following algorithm steps using DSR for vertical discontinuities is given below.

(a) From the pre-processed DCT coefficients block, we try to get a new matrix T of size smaller than the original one. To do so, we remove first and last four columns of the original matrix, and then select various rows leaving eight rows between selected rows as shown in Fig. 2, this is to collect all vertical discontinuity together. σ_0 is the standard deviation of noisy or target coefficients.

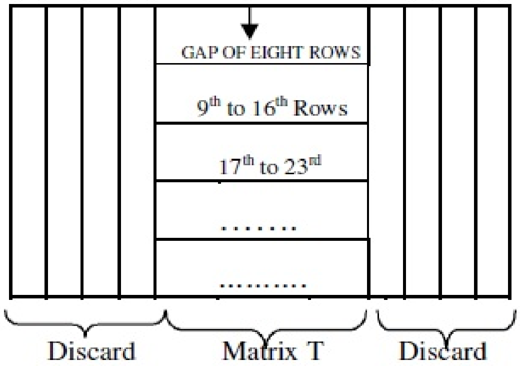


Fig. 2: Matrix Used in DSR iteration

(b) Using iterative equation given in Eq. 1, compute tuned set of coefficients of matrix T. Here, $x(n+1)$ is the DSR enhanced DCT coefficient in $(n+1)^{th}$ iteration number a, b and $\triangle\ t$ are the bistable system parameters. T is input matrix of DCT coefficient.

(c) We repeat the iteration till as PSNR gets maximized, due to which artifact gets invisible, the PSNR maximization is because of stochastic resonance process discussed inSection II.

(d) Finally, replace original coefficients with enhanced coefficients obtained after 3-4 DSR iteration.

V. RESULTS AND DISCUSSION

Our experiments are shown on different test images. To justify our results we used PSNR as a quantitative measure. We calculated PSNR value of highly compressed images test images, at different quality factors two of them shown in Fig.3 and Fig. 4. We also tried to compare our algorithm with two exiting techniques shown in Table II and results after blocky artifacts removal by the proposed algorithm shown in Table I. We tested our proposed algorithm for highly compressed images at different quality factors.

The basic mechanism of DSR for improvement of robustness is attributed to the way DSR modifies the distribution of selected DCT coefficient (only those coefficient which is responsible for blockiness) of blocky image. It is observed that the distribution of DCT coefficients after certain iteration count n which maximizes PSNR value is approximately the same as the distribution of DCT coefficients of the original image. Since the nature of the density function of the coefficients become same after a certain number of iterations using DSR operation. Therefore, it gives the best result at the particular value of iteration.

VI. CONCLUSIONS

A noise-induced dynamic SR-based technique is investigated in this paper. The iterative process on the noisy (DCT) coefficients enhances the image energy. We have applied DSR at the selected DCT coefficient of blocky image. DSR suppress the effect of artifacts by tuning the double well parameters. Our method takes advantage of prior existing techniques of blocking artifacts removal. It can efficiently eliminate blockiness for images coded at different bit rates without producing noticeable artifacts smoothes out the undesired block edges while retaining the sharpness of the decoded image to a noticeable degree. It can highly preserve the high-frequency components while smoothing out the blocking artifacts. This is because only the DCT coefficients related to the blocking artifact are modified while other frequency components remain the same. The most striking feature of our proposed DSR based algorithm is that it reduces the blockiness without producing any other considerable artifacts on the original image.

TABLE I: PSNR for different images at different compression level. (QF-Quality factor)

Test Image	QF-8	QF-10	QF-12	QF-14	QF-16
Lena	41.24	38.79	37.05	34.94	32.33
Barbara	39.32	38.09	35.89	33.21	31.08
Cameraman	36.74	34.72	33.01	31.72	29.43

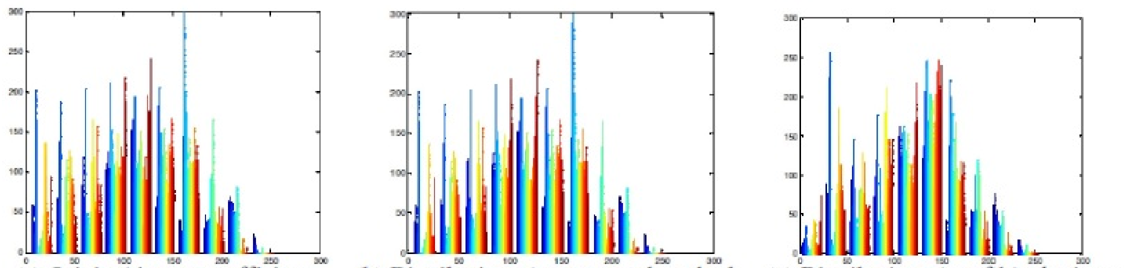
TABLE II: Comparison of our proposed DSR based technique with two existing techniques

Techniques	Lena			Barbara			Cameraman		
	QF (12)	QF (14)	QF (16)	QF (12)	QF (14)	QF (16)	QF (12)	QF (14)	QF (16)
Proposed Method	37.05	34.94	32.33	35.89	33.21	31.08	33.01	31.72	29.43
Y Luo [13]	33.80	29.05	24.01	30.43	27.70	23.44	29.04	22.89	19.78
S Liu [11]	30.41	26.90	19.06	27.01	23.89	17.32	23.90	18.28	13.71

ACKNOWLEDGEMENTS

This publication is an outcome of the R & D work undertaken in the project under the Visvesvaraya Ph.D. Scheme of Ministry of Electronics & Information Technology, Government of India, being implemented by Digital India Corporation (Formerly Media Lab Asia) (Grant No. U72900MH2001NPL133410).

Fig. 3: Upper row is reconstructed Lena image using DCT based compression. Below is blocky artifacts reduction using proposed DCT and DSR based technique



(a) Original image coefficient (b) Distribution plot proposed method (c) Distribution plot of blocky image

Fig. 4: DCT coefficient distribution (Histogram plot of DCT coefficients) of (a) original image, (b) Blocky artifact removal image and (c) blocky image of quality factor 10.

REFERENCES

[1] R. Benzi, A. Sutera, and A. Vulpiani, "The mechanism of stochastic resonance," *Journal of Physics A: mathematical and general*, vol. 14, no. 11, p. L453, 1981.

[2] S. Fauve and F. Heslot, "Stochastic resonance in a bistable system," *Physics Letters A*, vol. 97, no. 1-2, pp. 5–7, 1983.

[3] S. Kumar and R. K. Jha, "Enhancement of high dynamic range images using variational calculus regularizer with stochastic resonance," in *Proceedings of the Tenth Indian Conference on Computer Vision, Graphics and Image Processing*. ACM, 2016, p. 38.

[4] S. Kumar, R. K. Jha *et al.*, "Characterization of supra-threshold stochastic resonance for uniform distributed signal with laplacian and gaussian noise," in *Noise and Fluctuations (ICNF), 2017 International Conference on*. IEEE, 2017, pp. 1–4.

[5] S. Kumar and R. K. Jha, "Weak signal detection from noisy signal using stochastic resonance with particle swarm optimization technique," in *Noise and Fluctuations (ICNF), 2017 International Conference on*. IEEE, 2017, pp. 1–4.

[6] ——, "Noise-induced resonance and particle swarm optimization-based weak signal detection," *Circuits, Systems, and Signal Processing*, pp. 1–26, 2018.

[7] S. Kumar, A. Kumar, and R. K. Jha, "A novel noise-enhanced back-propagation technique for weak signal detection in neyman–pearson framework," *Neural Processing Letters*, pp. 1–18, 2019.

[8] S. Kumar and R. K. Jha, "Weak signal detection using stochastic resonance with approximated fractional integrator," *Circuits, Systems, and Signal Processing*, vol. 38, no. 3, pp. 1157–1178, 2019.

[9] S. Kumar and A. K. R. K. Jha, "Performance analysis of segmentation using ssr under different noise conditions," in *Noise and Fluctuations (ICNF), 2017 International Conference on*. IEEE, 2017, pp. 1–4.

[10] Q. Ye, R. Huang, X. He, and C. Zhang, "A sr-based radon transform to extract weak lines from noise images," in *Proceedings 2003 International Conference on Image Processing (Cat. No. 03CH37429)*, vol. 1. IEEE, 2003, pp. I–849.

[11] G. Wu and Z. Qiu, "A novel watermarking scheme based on stochastic resonance," in *2006 8th international Conference on Signal Processing*, vol. 2. IEEE, 2006.

[12] R. K. Jha, P. Biswas, and B. Chatterji, "Image denoising using stochastic resonance," in *Proceedings of International Conference on Cognition and Recognition*, 2005.

[13] ——, "Image segmentation using suprathreshold stochastic resonance," *World Academy of Science, Engineering and Technology, International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering*, vol. 4, no. 12, pp. 1861–1875, 2010.

[14] R. Chouhan, R. K. Jha, A. Chaturvedi, T. Yamasaki, and K. Aizawa, "Robust watermark extraction using svd-based dynamic stochastic resonance," in *2011 18th IEEE International Conference on Image Processing*. IEEE, 2011, pp. 2745–2748.

[15] R. K. Jha, P. Biswas, and B. Chatterji, "Contrast enhancement of dark images using stochastic resonance," *IET image processing*, vol. 6, no. 3, pp. 230–237, 2012.

[16] S. Minami and A. Zakhor, "An optimization approach for removing blocking effects in transform coding," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 5, no. 2, pp. 74–82, 1995.

[17] S. Liu and A. C. Bovik, "Efficient dct-domain blind measurement and reduction of blocking artifacts," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 12, no. 12, pp. 1139–1149, 2002.

[18] B. Zeng, "Reduction of blocking effect in dct-coded images using zero-masking techniques," *Signal processing*, vol. 79, no. 2, pp. 205–211, 1999.

[19] Y. Luo and R. K. Ward, "Removing the blocking artifacts of block-based dct compressed images," *IEEE transactions on Image Processing*, vol. 12, no. 7, pp. 838–842, 2003.