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Reduction of Blocking Artifact in JPEG Images with Orthogonal Polynomials

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Abstract: A deblocking scheme with orthogonal polynomials transform coefficients that reduces the blocking artifact in JPEG compressed images is presented in this paper. The proposed deblocking scheme first measures the amount of artifact present in the blocks with step function and image gradient and produces an artifact measurement factor. The proposed artifact reduction scheme aims to reduce the artifact by converting the step function into a ramp function adaptively. Consecutive blocks of the image are considered and applied with orthogonal polynomials transformation and independently two identity matrices are considered and subjected to orthogonal polynomials transformation and combined with consecutive blocks to produce a shifted block. This shifted block is processed with the proposed blocking artifact reduction technique with linearization into ramp function and updated block is obtained with reduced blocking artifacts. The proposed deblocking technique is experimented with standard bench mark images and performance is measured with standard PSNR. The results are encouraging.

Keywords: Artifact Measurement Factor, Blocking Artifact, Linearization, Orthogonal Polynomials.

1 Introduction

Image data compression has been an active area of research in the past two decades. The aim of data compression is to achieve saving in the storage, or in other words, to reduce the number of bits required to store the image. In general, data compression can be classified as either lossless or lossy. In lossless coding, the exact original image is reproduced, but with less compression ratio. On the other hand, lossy compression intents to produce an approximation to original, but with higher compression ratio. In lossy compression, transform coding technique is found to be popular due to energy preserving property of the transform [1], and hence used in many international standards such as JPEG [2] MPEG video coding standard [3] ITU-T H.261 [4], and H.263 [28] recommendation. There are two major steps involved in any transform coding technique: (*i*) conversion of original correlated image data into a decorrelated domain, with any unitary transformation and (*ii*) entropy coding of transform coefficients, obtained in the previous stage, with quantization. Among different unitary transforms, Discrete Cosine Transform (*DCT*) is found to be most popular in many transform coding techniques as it exhibits good energy preservation, and decorrelation. DCT is also proved to be asymptotic approximation to the Karhunen-Loeve Transform (*KLT*) when it is approximated with first order Markov-model [6] and be computed effectively like Forward Fourier Transform (*FFT*), with fast algorithm. Hence the international standard JPEG and MPEG used DCT to compress still and sequence of motion images respectively. During the application of DCT, the entire image under consideration is first partitioned into blocks of size (8×8) and then applied with DCT to decorrelate the original pixel values. Inspite of easy implementation and energy compaction property, DCT based transform coding technique produces visible annoying artifact at block boundaries in the reconstructed picture. This is called blocking artifact. Blocking artifacts occur due to signal discontinuities at block boundaries [26]. There have been tremendous research efforts to suppress this annoying blocking artifact in the past two decades. In this paper, a simple gradient based adaptive blocking artifact removal scheme in orthogonal polynomials transformation domain is presented.

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2 Literature Survey

In this section, literature survey related to the proposed artifact reduction scheme is presented. In order to reduce the blocking artifacts, Reeve and Lim used a low pass filtering on boundary pixels [7]. Another low pass filtering with non linear space variant approach that reduces the blocking artifact was reported in [8]. But simple space invariant filters cannot take into account the varying characteristics of image data and hence use of zero masking is reported in [9]. An adaptive separable median filter was introduced as an extension of low-pass filtering scheme by Yuh-Feng Hsu and Yung-Chang Chen in [10]. All these low-pass filtering approaches aim to reduce high frequency components, near block boundary, but at the same time produce unnecessary blurring.

The JPEG [5] reported the use of difference pulse code modulation of DC coefficients of DCT to efficiently code the transform coefficients, with less bits. This requires synchronization between coder and decoder and could not reduce the blocking effect significantly. Kou Hu Tzou [11] reported an approach with anisotropic low pass filtering on boundary pixels to remove high frequency part of visible edges caused by blocking effects. But this low cut-off low-pass filter introduces excessive blurring at few places where local characteristics of the image are not properly considered.

Shigenobu Minami and Avideh Zakhor [12], reported an optimization approach for removing blocking artifacts, based on Mean Squared Difference of Slope (*MSDS*) between slope across two adjacent blocks, with a quadratic programming approach. Rourke and Stevenson [13] suggested a method for producing higher quality reconstructed image based on stochastic model for image data. Here the image estimation scheme is integrated with convex constrained optimization problem that can be solved by iteration. Another iterative approach that formulates the blocking artifacts reduction as an image recovery problem has been reported by Zakhor [14]. But Stanley J. Reeves et al. showed that the method reported by Zakhor minimized high frequency information and hence blurring at edge portions occur at low bit rates [15]. Also it took minimum of 3 to 5 iterations for the algorithm to converge, where both DCT and IDCT were needed for each iteration, thereby accounting for higher computation cost.

Projection Onto Convex Sets (*MSDS*) based recovery schemes have been reported for reducing blocking artifacts in [16] and [17]. But POCS based schemes suffer from higher computational cost. Yang et al [18] introduced two schemes to reduce blocking artifacts: one based on POCS and another based on constrained least square. But both the schemes failed to produce remarkable restoration as it makes less sense to minimize the distance to the defective blocky image. Yang et al [19] suggested another approach to remove the blocking artifacts using POCS with line-processing model.

As an alternative to POCS and iterative schemes, non-iterative, spatially adaptive post-filtering schemes are reported by S.D. Kim et al. [20] and J. Chos et al. [21]. But these filters could not completely eliminate blocking artifacts [22] By defining block boundary discontinuity measure, as a sum of squared differences of pixels values along the block boundary, Byeungwoo Jeon and Jechang Jeong [23] reported the reduction of blocking artifacts. This post-processing approach aims to achieve minimum discontinuity of pixels values over block boundaries by compensating the loss of coefficients accuracy in transform domain. In an another work, adaptive post-processing algorithm for low bit rate video signal was suggested by T.S. Lie and N.S Jayant [24]. A post-processing algorithm that can reduce blocking artifacts in DCT coded images is reported in [25], wherein artifacts are analysed as noise component residing across two neighbouring blocks. Chen et al. suggested a post-filtering scheme in [26] to reduce blocking artifacts. It makes use of shifted blocks and local activity of each block. But its computational cost is higher as it requires 24 shifted blocks for smooth block region. In [27], Shizhong Liu and Bovik introduced a DCT domain algorithm for measuring and reducing blocking artifacts, by constructing shifted block across any two adjacent blocks and making use of properties of Human Vision Systems (*HVS*). In order to reduce the blockiness in the decoded picture, H.263 Annex Q [28,29,30] included an optional Reduced Resolution Update (*RRU*) coding where each block of prediction error residuals is downsampled and interpolated without using any data from outside the block. Comer[32] introduced a technique called RRU+ where down-sampling and interpolation filters are utilized with residuals from neighbouring blocks so as to prevent the blockiness that was obtained in their previous work [31].

Based on the probability distribution of original unquantized DCT coefficients, Jim Chou et al. [33], designed a filtering strategy with an estimation of quantization error for removal of blocking artifacts. But later it is realized, that a good estimate of probability distribution of DCT coefficients of each frequency is difficult [26]. By separating the regions to be smooth or texture or edge, Ying Luo and Rabab K. Ward [34] suggested an adaptive approach for reducing blockiness in both DCT and Spatial domain. Followed by a low-pass filtering, a predictor based on broken line regression model was introduced by Kiryung Lee et al.[35] for reduction of blocking artifacts in JPEG compressed images.

Jongho Kim and Chun Bo-Sim [36] reported an algorithm for blocking artifact removal based on Signal Adaptive Weighted Sum (*SANS*) technique. Here the deblocking process is interpreted as a spatial smoothing process with weighted average of block boundary pixels. Application to detection and removal of blocking artifacts was also reported in the literature for digital photography and skin images for forensic analysis respectively in [37] and [38].

Besides spatial domain techniques for blocking artifact reduction, researchers have also investigated the use of transforms such as wavelets [39,40,41]. In this respect Hsung et al. introduced deblocking methods with wavelet transform modules maxima for block transform compressed image [42]. Law and Siu reported an approach for suppression of blocking artifacts with successive structural analysis using Wavelet transform [43]. With least minimum mean square error filtering on selected sub-bands in wavelet domain, Hyuk Choi and Taejeong kim reported the reduction of blocking artifacts in block-coded images [44,45]. Taking into account the statistical characteristic of block discontinuities along with behaviour of wavelet coefficients across scales for different image features, Liew and Hong Yan described a blocking artifact suppression scheme in [44]. Alan W.C. Liew and Hong Yan designed two algorithms to obtain filter to reduce reconstruction error near block boundaries in wavelet-based image compression, based on boundary filter bank and polyphase structure. With Fast Fourier Transform (*FFT*), Jorge I. Marn-Hurtado and David V. Anderson, introduced artifacts and distoration free convolution based on extension of impulse responce in [46]. Foi et al. have introduced a pointwise shape-adaptive DCT for high quality denoising and deblocking of grayscale and colour images in [47]. Based on fields of experts prior, Sun and Charm [48] introduced a postprocessing scheme for reduction of blocking artifacts in low bit-rate block DCT coded images. D.T.Vo et al. reported the design of fuzzy filter for artifact reduction in compressed images and videos in [49]. Design of architecture for deblocking filter in the standard H.264/AVC [50] is introduced in [51,52]. X.Zhang et al. [53] reported a scheme based on overlapped block transform coefficient estimation from non-local blocks. Later, to overcome the loss of edge detail, a DCT-domain blind measurement [24,25,26,33] is adopted by replacing 2-D step function with linear function.

Most of the schemes reported in the literature make use of human vision system to compute the visibility of blocking artifacts. In this paper, an adaptive scheme, based on gradient measurement with 2-D step function is introduced to measure the artifact in spatial domain. In the deblocking process, orthogonal polynomials transformation coefficients are utilized in the shifted block and a linearization stage is introduced with the same orthogonal polynomials domain.

The rest of the paper is organized as follows. Section 3, deals with on the orthogonal polynomials model. Section 4, describes the proposed architecture. The proposed artifact measurement scheme is presented in Section 5. Section 6 describes in detail the proposed blocking artifact reduction scheme. The performance measure is presented in Section 7. Experiments and results of the proposed blocking artifact reduction scheme are presented in Section 8. and conclusions are drawn in Section 9.

3 Mathematical Preliminary on Orthogonal Polynomials

The orthogonal polynomials transformation that has already been established to extract edge [55] is utilised in the proposed work to design a deblocking technique. A brief overview of the same is presented in this section. A linear 2-D image formation system for the purpose of proposing a deblocking technique, is considered around a Cartesian coordinate separable, blurring, point-spread operator in which the image I results in the superposition of the point source of the impulse weighted by the value of the object function f. Expressing the object function f in terms of derivatives of the image function I relative to its Cartesian coordinates is very useful for analysing the image. The point-spread function $M(x,y)$ can be considered a real valued function defined for $(x,y) \in X \times Y$, where X and Y are ordered subsets of real values. In the case of grey-level image of size $(n \times n)$ where X (rows) consists of a finite set, which can be labelled $\{0, 1, \ldots, \text{n-1}\}$ for convenience, the function M(x, y) reduces to a sequence of functions.

$$M(i,t) = \mu_i, i,t = 0,1,\ldots,n-1 \quad (1)$$

The linear 2-D transformation can be defined using point-spread operator $M(x,y)(M(i,t) = u_i(t))$ as shown in equation (*2*).

$$\beta'(\zeta,\eta) = \int_{x\in X}\int_{y\in Y} M(\zeta,x)\,M(\eta,y)\,I(x,y)\,dxdy \quad (2)$$

Considering both X and Y to be finite set of values $\{0,1,2,\ldots,n-1\}$, equation (*2*), can be written in matrix notation as follows:

$$\left|\beta'_{ij}\right| = (|M| \otimes |M|)^t\,|I| \quad (3)$$

where $\otimes$ is the outer product, $\left|\beta'_{ij}\right|$ be n^2 matrices arranged in dictionary sequence, |I| is the image, $\left|\beta'_{ij}\right|$ be the coefficients of transformation and the point-spread operator |M| is

$$|\mathrm{M}| = \begin{vmatrix} u_0\ (t_0) & u_1\ (t_0) & \cdots & u_{n-1}\ (t_0) \\ u_0\ (t_1) & u_1\ (t_1) & \cdots & u_{n-1}\ (t_1) \\ & & \vdots & \\ u_0\ (t_{n-1}) & u_1\ (t_{n-1}) & \cdots & u_{n-1}\,(t_{n-1}) \end{vmatrix} \quad (4)$$

We consider a set of orthogonal polynomials $u_0(t), u_1(t), \ldots, u_{n-1}(t)$ of degrees 0,1,2,...,n-1, respectively, to construct polynomial operators of different sizes from equation (4) for $n \geq 2$ and $t_i = i+1$. The generating formula for the polynomials is as follows:

$$u_{i+1}(t) = (t-\mu)u_i(t) - b_i(n)u_{i-1}(t) \text{ for } i \geq 1, \quad u_1(t) = t-\mu, \text{ and } u_0(t) = 1, \tag{5}$$

where $b_i(n) = \frac{\langle u_i, u_i \rangle}{\langle u_{i-1}, u_{i-1} \rangle} = \frac{\sum_{t=1}^{n} u_i^2(t)}{\sum_{t=1}^{n} u_{i-1}^2(t)}$ and $\mu = \frac{1}{n}\sum_{t=1}^{n} t$

Considering the range of values of t to be $t_i = i, i = 1, 2, 3, ..., n$, we obtain

$$b_i(n) = \frac{i^2\left(n^2 - i^2\right)}{4\left(4i^2 - 1\right)}, \qquad \mu = \frac{1}{n}\sum_{t=1}^{n} t = \frac{n+1}{2}$$

We can construct the point-spread operators $|M|$ of different sizes from equation (4) using the above orthogonal polynomials for n $\geq$ 2 and $t_{i=}$i+1. To make point-spread operations more convenient, the elements of $|M|$ are scaled to integer values. Extensive explanation of OPT operators can be obtained from [56, 57]. The basis operators are presented in the next subsection.

3.1 Orthogonal Polynomials Basis

For the sake of computational simplicity, the finite Cartesian coordinate set X, Y is labelled as $\{1, 2, 3\}$. The point-spread operator in equation (3) that defines the linear orthogonal transformation for image coding can be obtained as $|M| \otimes |M|$, where $|M|$ can be computed and scaled from equation (4) as follows:

$$|M| = \begin{vmatrix} u_0(t_0) & u_1(t_0) & u_2(t_0) \\ u_0(t_1) & u_1(t_1) & u_2(t_1) \\ u_0(t_2) & u_1(t_2) & u_2(t_2) \end{vmatrix} = \begin{vmatrix} 1 & -1 & 1 \\ 1 & 0 & -2 \\ 1 & 1 & 1 \end{vmatrix} \tag{6}$$

(6)

The set of polynomial basis operators $O_{ij}{}^{n}$($0 \leq$ i, j $\leq$ n-1) can be computed as

$O_{ij}{}^{n} = \hat{u}_i \otimes \hat{u}_j$

where $\hat{u}_i$ is the (i + 1) st column vector of $|M|$.

The complete set of basis operators of size (3×3) that are used in this proposed deblocking scheme is given below.

$$\left[O_{00}^{3}\right] = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}, \left[O_{01}^{3}\right] = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix},$$

$$\left[O_{02}^{3}\right] = \begin{bmatrix} 1 & -2 & 1 \\ 1 & -2 & 1 \\ 1 & -2 & 1 \end{bmatrix}, \left[O_{10}^{3}\right] = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix},$$

$$\left[O_{11}^{3}\right] = \begin{bmatrix} 1 & 0 & -1 \\ 0 & 0 & 0 \\ -1 & 0 & 1 \end{bmatrix}, \left[O_{12}^{3}\right] = \begin{bmatrix} -1 & 2 & -1 \\ 0 & 0 & 0 \\ 1 & -2 & 1 \end{bmatrix},$$

$$\left[O_{20}^{3}\right] = \begin{bmatrix} 1 & 1 & 1 \\ -2 & -2 & -2 \\ 1 & 1 & 1 \end{bmatrix}, \left[O_{21}^{3}\right] = \begin{bmatrix} -1 & 0 & 1 \\ 2 & 0 & -2 \\ -1 & 0 & 1 \end{bmatrix}, \left[O_{22}^{3}\right] = \begin{bmatrix} 1 & -2 & 1 \\ -2 & 4 & -2 \\ 1 & -2 & 1 \end{bmatrix}$$

Having outlined the transformation, we present the proposed blocking artifact reduction architecture in the next section.

4 Proposed Architecture

The architecture of the proposed blocking artifact reduction technique, with orthogonal polynomials model coefficients is presented in this section. The steps involved in the proposed architecture are presented in Fig.1. It contains three major steps:

(i) Artifact Measurement

(ii) Linearization into ramp function and

(iii) Artifact reduction.

Since the proposed technique aims to reduce the block boundary appearing due to independent processing of blocks of image in the compression, we consider the same set of blocks here. Hence the image under analysis is partitioned into blocks of equal size. The proposed scheme then computes a measure of artifact by modeling the block boundary with 2-D step function in horizontal and vertical directions and hence a gradient measure is calculated. In the second stage, the proposed work aims to convert the block boundary into a ramp functions with an adaptive Artifact Reduction Factor, obtained in the previously calculated gradient measure. The orthogonal polynomials model is then applied to both the step and ramp function and the difference δ is computed for use in artifact reduction scheme. Independently, the proposed technique obtains orthogonal polynomials transform coefficients of consecutive blocks of image under analysis and are used to obtain a shifted block $B_s$with orthogonal polynomials transform coefficients of two identity matrices that model the block boundary as a step function. The shifted block thus obtained is subjected to the proposed artifact reduction technique with δ and μ, the sum of elements of R and produces the corresponding artifact reduced block, called updated shifted block $B_{u.}$The proposed scheme repeats the above steps for all the blocks of the image and obtains corresponding updated shifted blocks. These blocks are then synthesized to produce the blocking artifact reduced image. The stages involved in the proposed blocking artifact reduction technique are described in detail in the subsequent sections.

5 Measure of Artifact

In this section, detection and measurement of blocking artifact, present in the given input image, based on

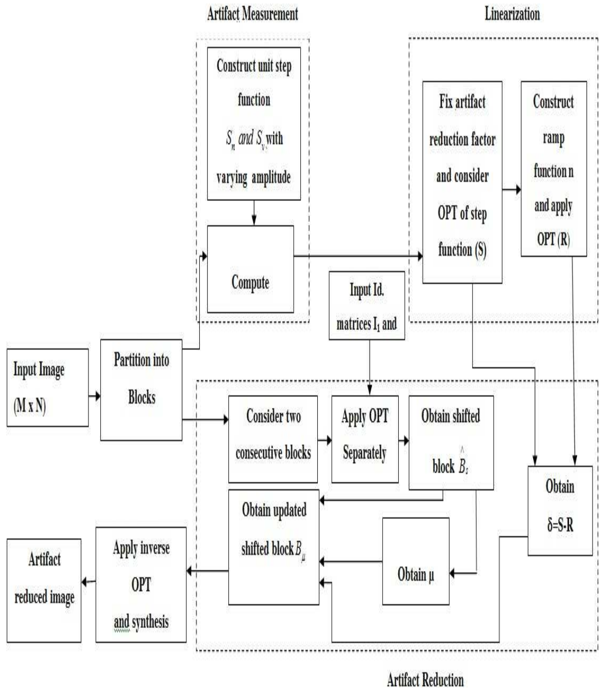


Fig. 1: Architecture of Proposed Blocking Artifact Reduction Technique.

gradient measure with unit step function is proposed. The proposed technique first identifies, and measures the blocking artifact and represents the artifact for the purpose of designing an adaptive deblocking scheme.

In this proposed work, block boundary is modeled according to their intensity profile in terms of defining step function, whose intensity changes abruptly from one value, present in one side of discontinuity to a different value on the other side. The cause for this discontinuity attributes to the block-based compression scheme. As stated in [40,54], this discontinuity generally occurs between two regions having almost similar or constant but different gray levels. To facilitate the measure of this blocking artifact, the proposed work partitions the image into blocks so as to extract the large difference in their intensity profile and aims to compensate by computing one dimensional unit step function u(t), defined mathematically, as

$$u(t) = \begin{cases} 1 & t > 0 \\ 0 & t < 0 \\ 0.5 & t = 0 \end{cases} \tag{7}$$

The amplitude values 0, 1, and 0.5 are defined to be constant values for different values of t. The step function u(t) represents the region of discontinuity at t. It can be observed that in amplitude scaling the quadrative axis values are alone changed, representing change in the magnitude of the signal, simultaneously having no change in the periodicity of signal. Hence one-dimensional step function u(t) can be defined, with signal processing properties, as

$$s(t) = \alpha.u(t) \tag{8}$$

where α represents the varying amplitude of the step function at the point of discontinuity. In a similar fashion, two dimensional step function x and y coordinate, s(x, y) is defined as

$$s(x,\ y) = \begin{matrix} \alpha u(t) & for\ x = 0,1,2,3;\ y = 0,1,...,n-1 \\ -\alpha u(t) & for\ x = 4,5,6,7;\ y = 0,1,...,n-1 \end{matrix} \tag{9}$$

where u(t) shall have the value 0.5 at the point of discontinuity, as defined in equation (7), α takes the value as defined in equation (8) and (n×n) represents the size of the block under analysis. The proposed technique measures the blocking artifact in terms of edge profile, using 2-D step function s(x, y). The 2-D step function is modeled to represent positive values on one side of the block boundary and negative values on the other. Since gradient represents intensity which points in the direction of greatest change, the step function is computed in both horizontal and vertical directions. The rate of change of intensity in both these directions, for the above computed step function is measured, by convolving the divided blocks of size (n x n) of the image with 2-D step function $s_h(x,\ y)$ and $s_v(x,\ y)$:

$$s_h(x,\ y) = \begin{cases} \alpha.u(t) & for\ x = 0,1,2,3;\ y = 0,1,...,n-1 \\ -\alpha.u(t) & for\ x = 4,5,6,7;\ y = 0,1,...,n-1 \end{cases} \tag{10}$$

$$s_v(x,\ y) = \begin{cases} \alpha.u(t) & for\ x = 0,1,2,3;\ y = 0,1,...,n-1 \\ -\alpha.u(t) & for\ x = 4,5,6,7;\ y = 0,1,...,n-1 \end{cases} \tag{11}$$

The rates of change of intensity in horizontal and vertical directions are represented as g_h and g_v. The proposed work then computes the gradient measure, G_b as:

$$G_b = \sqrt{g_h^2 + g_v^2} \tag{12}$$

The proposed technique then judges the visibility of blocking artifact and optimizes the relevance and suitability of step function in terms of α, called Artifact Reduction Factor (ARF). This is achieved by conducting experiments with varying amplitude values α. Thus the proposed work fixes the artifact reduction factor with reduced gradient measure value G for the purpose of deblocking. The use of Artifact Reduction Factor (ARF), thus obtained, is highlighted to propose a linearization and hence to reduce the blocking artifact adaptively; it is presented in the next section.

Having identified the gradient present in between the blocks, by varying α, the proposed work obtains Artifact

Reduction Factor, with reduced gradient magnitude measure G_b. The utilization of artifact measurement scheme is highlighted for proposing an effective artifact reduction scheme and it is presented in the next section.

6 Blocking Artifact Reduction

In this section, a new blocking artifact reduction technique, making use of orthogonal polynomials model coefficients of blocks of the input image, with linearization of step function is presented. Since blocking artifacts appear at block boundaries, the proposed work considers a shifted block to reduce the blocking artifact as carried out by few other researchers.

The formation of shifted block, in this proposed artifact reduction technique is carried out in the orthogonal polynomials domain. For this purpose, the input image is partitioned into blocks of size (n $\times$ n) and applied with orthogonal polynomials as described in section 3. Let us consider two blocks a_1 and a_2 and their corresponding transformed blocks obtained after applying orthogonal polynomials transformation be represented as A_1 and A_2. Two identity matrices of order (n $\times$ n) are also separately taken and subjected to orthogonal polynomials transformation and represented as I_1 and I_2. Now, a shifted block B_s is obtained using the relation:

$$B_s = \frac{1}{2}\left(A^s I^s + A^d I^d\right) \tag{13}$$

where A^s is the sum of orthogonal polynomials transform coefficients of A_1 and A_2 , A^d is the difference of orthogonal polynomials transform coefficients of A_1 and A_2 , I^s is the sum of orthogonal polynomials transform coefficients of I_1 and I_2 and I^d is the difference of orthogonal polynomials transform coefficients of I_1 and I_2.

Having obtained the shifted block, the proposed blocking artifact removal technique aims to update the coefficients of B_s, so that the real blocking artifact is reduced. For this purpose the proposed technique linearises the block boundary, of course in tune with the amount of blocking artifact measured in terms of artifact removal factor. Initially, a ramp function is considered as the ratio between the coordinate position x and slope of shifted block B_s. A linear block of size (n x n) is then obtained by repeating the row x=0,1,....n-1, y=0,1,..,n-1 and magnitude of 2-D step function is constant in the vertical direction and anti-symmetric in horizontal direction. Thus a linear block r of size (n x n), corresponding to the step function s, is further applied with orthogonal polynomials transform and represented as R. This process is called linearization, as mentioned in the architecture (Fig.1).

To estimate the value of coefficients of updated shifted block B_u, the proposed orthogonal polynomials based bloking artifact removal scheme updates the orthogonal polynomials transform coefficients of shifted block B_s with corresponding difference coefficients of step and ramp functions. The proposed technique utilizes only a subject of coefficients of shifted block B_s that need to be corrected for effective reduction of blocking artifact. Sum of such coefficients is denoted as μ. Thus the orthogonal polynomials transformation coefficients of updated shifted block B_u,corresponding to the shifted block B_s is obtained as

$$B_u = B_s(x,y) + \mu.\delta \tag{14}$$

where $\mu = \sum_{k=0}^{n-1} B_s(0,k)$

and δ is the difference between step and ramp functions. The updated shifted blocks thus obtained are subjected to inverse orthogonal polynomials transform as described in subsection 3.1 and synthesized to produce the blocking artifact reduced image. The performance of the proposed blocking artifact removal technique is computed with standard performance measure.

7 Performance Measure

In this section, the performance of proposed image blocking artifact reduction scheme is evaluated with the use of existing standard measure, Peak Signal to Noise Ratio (PSNR), as the same is widely used as quality measurement unit in the field of image restoration, that measures the objective quality between the original and restored images. It is defined as:

$$PSNR = 10\log_{10}\left[\frac{255^2}{\sqrt{MSE}}\right](dB) \tag{15}$$

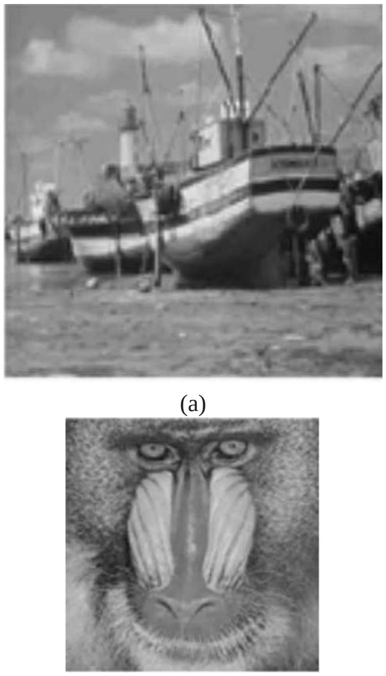
where the Mean Square Error, MSE is given as,

$$MSE = \frac{1}{m\times n}\sum_{i=1}^{m}\sum_{j=1}^{n}\left[I(i,j) - I^{'}(i,j)\right]^2 \tag{16}$$

where m and n represent the size of images. I represents the original image and $I^{'}$represents the resulting artifact reduced image. To evaluate the performance of proposed deblocking technique, experiments are conducted and they are presented in the next section.

8 Experiments and Results

The proposed gradient-based measurement of blocking artifacts is tested over hundred JPEG compressed images at varying bits per pixel from standard benchmark database. Two sample, representative images Boat and Baboon both of size (256×256) with pixel values in the range 0-255 are presented in Figures 2(a) and 2(b) respectively. The input images are partitioned into non-overlapping blocks of size (8×8) and the resulting blocks are subjected to the proposed blocking artifact measurement scheme as described in section 5, with 2-D step functions along horizontal and vertical directions. The artifacts reduction factor is then obtained, followed



(a)

(b)

Fig. 2: Sample Input Images (a) Boat and (b) Baboon

by considering the ramp function R, as described in linearization stage. Two consecutive blocks of image under analysis are considered and subjected to Orthogonal Polynomials Transformation. Simultaneously two identity matrices are taken and are applied with orthogonal polynomials transformation. From the orthogonal polynomials coefficients of consecutive blocks of image and identity matrices I_1 and I_2, shifted block B_s is formed. The proposed gradient measurement with step function is now linearized to a ramp function and updated shifted block B_u is then computed as described in section 6. The resulting shifted blocks are synthesized and the reconstructed image with reduced artifacts is obtained. The results of proposed deblocking scheme, corresponding to the original images shown in Figure 2 are presented Figure 3 correspondingly when artifact reduction factor is 0.125. The performance of the proposed blocking artifact reduction technique is measured with PSNR as described in section 7. For the Boat and Baboon images shown in Figure 2, the proposed deblocking scheme could produce PSNR values of 34.90 dB and 30.02 dB respectively when the input images are present with a Bpp of 0.2. These results are presented in Table 1.

Table 1: PSNR values obtained for Sample Images with Proposed Deblocking Technique and Comparison with other Existing Techniques

Image	Bit Rate *PerPixel*	Proposed *Method*	Lie et al.	Tang et al.
Boat	0.1	34.90	33.74	31.95
	0.2	35.85	33.98	30.89
	0.3	32.50	29.72	28.42
Baboon	0.1	30.02	29.93	29.99
	0.2	32.20	32.09	32.18
	0.3	33.05	32.76	32.50
camera *man*	0.1	27.99	27.74	27.44
	0.2	30.65	30.25	30.40
	0.3	30.95	30.85	30.15
pepper	0.1	27.79	27.68	27.00
	0.2	30.18	29.89	29.65
	0.3	31.09	30.25	30.12
Lena	0.1	34.63	32.54	28.00
	0.2	31.05	30.13	29.15
	0.3	31.75	31.08	29.98

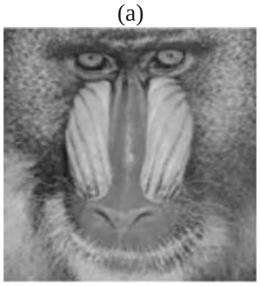
The experiments are conducted for different BPP values of input images of Boat and Baboon and the results are incorporated in Table 1. The results obtained with the proposed scheme on other representative images with different Bits per Pixel are also incorporated in Table 1. The performance of the proposed blocking artifact reduction technique is also compared with two existing schemes viz. Lie et al. [24] and Tang et al. [38] methods and the results of blocking artifact reduction by these schemes, corresponding to the original images shown in Figure 2 are presented in Figure 4 and Figure 5 correspondingly. The experiments are repeated for different standard representative images of varying BPP and the results obtained with both the proposed and existing schemes are incorporated in Table 1.

The performance of the existing schemes is also measured with PSNR and these results are incorporated in Table 1 for all the representative input images. It is evident from Table 1 that the proposed blocking artifact reduction technique with orthogonal polynomials model coefficients could perform well in terms of reducing the blocking artifacts.

9 Conclusion

In this paper, an attempt has been made to reduce the blocking artifacts that appear in block boundaries of

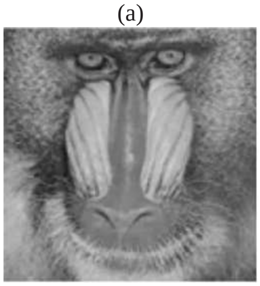
(a)



(b)

Fig. 3: Results of Proposed Blocking Artifact Reduction Technique.

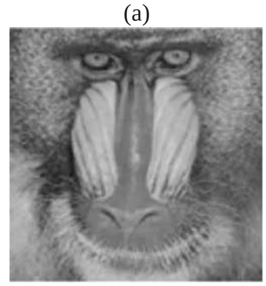
(a)



(b)

Fig. 4: Results of Blocking Artifact Reduction Technique With Lie et al. method

(a)



(b)

Fig. 5: Results of Blocking Artifact Reduction Technique With Tang et al. Method

JPEG compressed images. The proposed deblocking scheme introduces an adaptive scheme to measure the appearance of artifact in terms of step function and gradient measure. A linearization scheme that converts the block gradient into ramp function in the shifted blocks of the image is introduced in the orthogonal polynomials domain. Standard PSNR measure is used to evaluate the performance of the proposed deblocking technique. The results are also compared with exiting schemes. The proposed technique is found not only to suppress the blocking artifacts, but also preserves the true edges of the image, besides selection of adaptive step function.

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