Reduction of Ringing Artifacts in Frequency Domain with Modified Overshoot Ripple Filter and Exponential Filter

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ABSTRACT 

At low and medium bit rates, the image compression in JPEG domain introduces Ringing artifacts especially near edges. As it causes annoying effects, we need to reduce the ringing artifacts and preserve the edge details without blurring. In this paper, we propose a new ringing artifact reduction method in Block Discrete Cosine Transform (BDCT) coding. The proposed method utilizes Modified Overshoot Ripple filter and Exponential filter in JPEG coded images which operate in frequency space with DCT. The Modified Overshoot Ripple filter and the Exponential filter reduce ripples on smooth region and overshoots near edges. The performance of the proposed method is measured in terms of Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR) and is compared with existing methods.

INTRODUCTION

JPEG is (Pennebaker, W. and J. Mitchell, 1993; Wallace, G.K., 1991) currently the most popular method for compressing digital images. It is used for storing and transmitting the information over the internet. Image compression is the process of reducing the amount of data needed to represent the digital image. It is classified into two types: Lossy and Lossless (Jain, A.K., 1981). Lossless compression is the error free compression. The steps involved in this type of compression are Predictor and Entropy Encoder. It removes the coding redundancy and the reconstructed image produces exactly the same as the original image. And hence, it is preferred for archival purpose in medical image processing, technical drawings, clip art etc. Lossy compression reduces the accuracy of the reconstructed images. The steps involved in this type of compression include applying DCT, Quantization, Prediction and Entropy Encoding. DCT converts correlated pixels to uncorrelated coefficients and it converts the data into the summation of a series of cosine waves oscillating at different frequencies. For compression, DCT is much more efficient when compared to other transforms because of the use of cosine functions and real coefficients. Quantization converts a sequence of floating numbers w to a sequence of integer’s q. Thus, it produces some artifacts and hence quality of the reconstructed image is not good. As a result of coarse quantization, the low and medium bit rate reconstructed images severely suffer from blocking and ringing artifacts. The continuity of image object such as flat and edge region are not properly restored because of minimizing the boundary difference of adjacent blocks. Hence, the motivation of the work proposed in this paper is to reduce such artifacts and produce the image as similar to the original.

Blocking artifacts occur when there are signal discontinuities at block boundaries (Chen, T. and B. Qiu, 2009). It appears as an artificial block boundary between adjacent blocks. Ringing artifacts occur due to the loss of high frequencies when quantizing the DCT coefficients with a quantization step (Hantao Liu, 2010; Mylene, C.Q. Farias, 2007). Ringing artifacts are similar to the Gibbs phenomenon and it generally appears near sharp edges. Some of the Ringing artifact reduction techniques use Kalman filter, Gaussian filter and Maximum Likelihood parameter estimation. All these methods work on spatial domain and it produces blurring and hence could not remove the ringing artifacts efficiently (Hyungjun Lim and Hyun Wook Park, 2011).

There has been a tremendous research effort of suppressing ringing artifacts in the past several
decades with their hardware implementation (Bernacchia, G. and S. Marsi, 1998; Ismaiel and Rabab Word, 2003). In literature, there are two main classes of methods to suppress the artifacts of JPEG decompressed images, namely, image enhancement methods and image restoration methods. Image enhancement method is a heuristic approach to improve the quality of perceptual sense. The image restoration approaches are based on the optimization of certain objective criteria with constraints to recover the original input image. Some of image restoration methods include Projection onto Convex Sets (POCS), the stochastic methods as Maximum a Posterior (MAP), and energy based methods. Literature survey of various developments to suppress ringing artifacts has been made and is presented here.

Y.Feng Hsu and Y.Chang Chen (1993) reported an adaptive median filter to suppress the blocking and ringing artifacts. The median filter is used to preserve the edges and eliminates the salt and pepper noise in images. But this filter is not efficient to suppress the blocking and ringing artifacts. A.Murat Tekalp (Murat Tekalp, A., 1989) designed a Linear Space Variant (LSI) edge based Kalman filter to suppress the ringing artifact. In this method, a Maximum posterior probability decision approach is used and it provides a better match to local edge orientation. It has the effect of smoothing along edges in images.

N. Ponomarenko et al (2007) described a discrete cosine transform based image compression method. First, the image is divided into blocks with a rate distortion based modified horizontal-vertical partition scheme. Statistical redundancy of quantized DCT coefficients of each image block is analyzed and reduced by a bit-plane dynamical arithmetical coding with a sophisticated context modeling. This method aims to give better compression than other JPEG domain methods. Hyungjun Lim et al (2011) reported a DCT domain filtering and image domain post processing. To reduce ripples on smooth region and overshoot near strong edges, they used Overshoot Ripple (OR) filter. It has three criteria with a parameter α. If α increases, this filter reduces ripples and if α decreases it reduces the overshoot. This filter reduces the ringing artifact without blurring and could not effectively eliminate the overshoots in and around edges.

Popovici and Douglas (2007) suggested a method for locating edges in JPEG-coded images which operate in frequency space of DCT coefficients. Custom built moments approach is used to detect the edges. This custom built moments approach is applied to the quantized DCT coefficient of each block to detect edges and Multiply Gaussian filter and then dequantizes and transforms the coefficients to pixel values. This method suppresses the ringing artifacts only in edges and could not effectively remove the ringing artifacts in smooth regions.

Henrique S. Malvar (1998) designed a lapped transform to reduce the blocking and ringing artifacts. Here Biorthogonal Lapped Transform (LBT) and Nonuniform Lapped Transform (NLT) are used. The LOT has two properties. One of the property is that it is longer than the block size and the other is that LOT decays smoothly to zero near at their boundaries. The LBT increases the coding gain and reduces the blocking artifact but it has more ringing artifacts. An efficient way to reduce the ringing artifact is to start with an LBT of half the desired block size and the two blocks are combined with hierarchical structure is a Nonuniform Lapped Transform. The optimal LBT does not take fast computational algorithm.

A Maximum likelihood approach is described by Senungjoon Yang et al (2001), to alleviate the ringing artifact removal problem. This parameter estimation method is based on the K-means algorithm with the number of clusters determined by a cluster separation measure. Average local variance is calculated for finding the ringing artifact measure in image edge regions. An edge map is generated by the Sobel operator. After the edge map is cleaned by de-noising, the edge map is dilated to indicate the region around the major edges and it takes less computational complexity.

Ci Wang et al (2006) reported a method for reducing the blocking and ringing artifacts in the DCT domain. It decomposes a low frequency (LF) sub-bands and high frequency (HF) sub-bands in the DCT domain. To reduce the blocking artifact, LF components are smoothened in the adjacent LF blocks and invalid HF components are discarded. HF vectors are reduced by bilateral filter. This filter alleviates the ringing artifacts and preserves the edges.

Dung T.Vo et al (2009) used an edge based Directional Fuzzy filter to suppress the ringing artifacts. Directional Fuzzy filter calculates the maximum and the minimum standard deviation of non edge pixels. To detect the edge region the Sobel operator is used and in edge region the isotropic fuzzy filter is used to reduce the ringing artifact.

Stuart W.A Bergen et al (2004) used ultraspherical window coefficients for designing a digital filter. Two methods are used to compute ultra spherical window coefficients. The first method is Streits method and the second is a new method that involves ultra spherical coefficients in the frequency domain to represent in Fourier series. The ultra spherical window has three parameters \((\mu, x_\nu, N)\) for controlling its properties and to design adjustable window coefficients.

From these literatures, it can be concluded that reduction of artifacts is necessary to get back the original images and the same can be effectively handled in frequency domain. In this paper, we study...
the effect of applying few filters that can reduce different forms of ringing artifacts with DCT transform coefficients. While we aim to reduce the ringing artifacts, we also have shown interest on eliminating blurring effect caused by low and medium bit rate decoded images.

This paper is organized as follows. The Architecture of the proposed ringing artifact reduction technique is presented in Section 2. The proposed ringing artifact reduction technique is described in detail in Section 3. Performance measure for the proposed scheme is presented in section 4. Section 5 provides the experimental results of proposed ringing artifact reduction scheme with standard test images. In Section 6, conclusions are drawn.

2. Architecture of the proposed scheme:

The architecture of the proposed reduction of ringing artifacts scheme is presented in Figure 1.

![Fig. 1: Architecture of the Proposed Ringing Artifact Reduction Method.](image)

In this proposed work, the input artifact image under the analysis of size \((M \times N)\) is split into \((n \times n)\) sub blocks where \(n<M, N\). The measure of ringing artifact is computed by using local variance. Based on that, the proposed algorithm decides whether to proceed with reduction algorithm or not. If it is less than a threshold value, then reduction algorithm is not needed. Now the block under consideration is classified as either edge block or non edge block with sobel operator. If edge block, we apply a Modified Overshoot Ripple filter to the DCT coefficients. This filter will reduce overshoot near strong edges. If non edge block, exponential filter is applied to the transform coefficients with DCT. This filter reduces ripples on smooth region. Now combine both edge and non edge block and apply Inverse DCT. These blocks are merged so as to get the reconstructed image. The reconstructed image reduces the ringing artifact near edges without blurring.

3. Proposed Ringing Artifacts Reduction Technique:

The proposed ringing artifact reduction technique has five stages. They are (i) Measurement of ringing artifacts, (ii) Edge detection, (iii) Discrete Cosine Transform, (iv) Modified Overshoot Ripple filter, and (v) Exponential filter. These are explained in the following subsections in detail.

3.1 Measurement of Ringing Artifacts:

The local visible ringing measure is aimed to calculate how much ringing is present in the decoded image near edge regions. It is an objective distortion measure for ringing artifacts and the average local variance is calculated on a small size window in the vicinity of major edges as reported in (Rick Archibald and Anne Gelb, 2002). Ringing artifact prone regions are detected by a series of morphological operations. Variation of grayscale values inside the detected region is due to the oscillations introduced by the ringing artifacts. Therefore, the average variance of the pixel value in this region can be used to quantify the degradation. The local behavior can be reasonably described as the intensity variance of pixels in the neighborhood. This denoted as \(LV(i, j)\) and is

\[
LV(i, j) = \frac{1}{9} \sum_{k=-1}^{1} \sum_{l=-1}^{1} \left[ I(k, l) - \frac{1}{9} \sum_{k=-1}^{1} \sum_{l=-1}^{1} I(k, l) \right]^2
\]

where \(I(k, l)\) is the decoded image.

3.2 Edge Detection:

The real images have more complicated edges, so in this proposed work, a strong filtering is applied to the direction perpendicular to the edge. A digital gradient is computed by convolving two windows with the image. One window yields the x component \(M_x\) and the other yields y component \(M_y\). This operation can be described by the following equations

\[
M_x(i, j) = \text{Mask}_x \ast I(i, j)
\]

\[
M_y(i, j) = \text{Mask}_y \ast I(i, j)
\]

where
and \( l(i, j) \) indicates some neighborhood of the pixel \((i, j)\) and * denotes convolution. The input artifact image is convolved with \((3 \times 3)\) mask weight to measure the difference in intensity along horizontal and vertical directions. Based on the Sobel operator with horizontal and vertical derivative approximation of the gradient, the edges are detected, by using the gradient magnitude \( M = \sqrt{M_x^2 + M_y^2} \). Its corresponding direction is determined by 
\[
\theta = \arctan \left( \frac{M_y}{M_x} \right) \tag{3.3.1}
\]

The formula for \( DCT(i, j) \) is given as below,
\[
DCT(i, j) = \frac{1}{\sqrt{2N}} c(i)c(j) \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} p(x, y) \cos \left( \frac{(2x+1)i\pi}{2N} \right) \cos \left( \frac{(2y+1)j\pi}{2N} \right) \tag{3.3.2}
\]

The formula for inverse DCT is given as below,
\[
p(x, y) = \frac{1}{\sqrt{2N}} c(i)c(j) \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} DCT(i, j) \cos \left( \frac{(2i+1)x\pi}{2N} \right) \cos \left( \frac{(2j+1)y\pi}{2N} \right) \tag{3.3.3}
\]

where \( i=0, 1, \ldots, N-1 \);
\( j=0, 1, \ldots, N-1; \)
\( p(x, y) \) is the \((8 \times 8)\) blocks of input image.
\( c(i) = \frac{1}{\sqrt{2}} \) if \( i = 0 \), else \( 1 \) if \( i > 0 \)

The transformed array of \( DCT(i, j) \) is obtained through equation (5) and of size \((N \times N)\), same as that of the original image block. It should be noted here that the transform-domain indices \( i \) and \( j \) indicate the spatial frequencies in the directions of \( x \) and \( y \) respectively. \( i = j = 0 \) corresponds to the average value or DC component and all the remaining ones are AC components.

### 3.4 Modified Overshoot Ripple Filter:

Modified Overshoot ripple filter is a low pass filter. It eliminates ripples on smooth region. The properties of MOR filter is that, the overshoot, which is the first ripple, can be reduced by applying a filter which has a smaller energy on the first side lobe and the other is that the ripples, except for the overshoot can be reduced by applying a filter that has most energy on the first side lobe rather than the other side lobes. The Modified Overshoot Ripple filter has two parameters. They are \( N \) and \( \alpha \), where \( N \) is the filter length and \( \alpha \) alters the side lobe pattern. MOR filter satisfies the required condition on the impulse response, can be derived by utilizing ultra spherical window functions whose characteristics are adjustable by parameters of \( \mu \) and \( x_\mu \)

The main lobe width of MOR filter is same as that of the Rectangular filter to preserve the details and edges on the reconstructed images. The side lobes of the MOR filter is changed by the parameter \( \alpha \), where \( \alpha \) is the relative rate of ripple ratio. The first and the other side lobes of the MOR filter are adjusted to reduce the overshoots and ripples. If \( \alpha > 1 \), it reduces ripples and at the same time it increases the overshoot. If \( \alpha < 1 \), it reduces overshoot and at the same time it increases the ripples. The ripple ratio is formulated as
\[
\text{Ripple ratio} = \frac{\text{mainlobeamplitude}}{\text{maximumsidelobeamplitude}} \tag{6.1}
\]

where main lobe amplitude is 1 and the maximum side lobe amplitude is \( \alpha \).

The MOR filter values are derived by ultra spherical window coefficients. The formula for filtered coefficients is given as below,
\[
y_{\alpha \beta}(k, l) = \mu_{\text{OR},DCT}(k, l)x_{\text{DCT}}(k, l)
\tag{7}
\]

where \( k=0, \ldots, N-1 \)
\( l=0 \ldots N-1 \)
\( \mu_{\text{OR},DCT}(k, l) \) is the filter function and the \( DCT(k, l) \) is the DCT coefficients.

\[
H_{\text{OR},DCT}(k, l) = \mu^{N} \left( \sum_{m=0}^{N-1} \sum_{n=0}^{N-1} c_{\mu}^{(m)} c_{\mu}^{(n)} \cos \left( \frac{\pi m}{N} \right) \cos \left( \frac{\pi n}{N} \right) \right)
\tag{8}
\]
where $C_{N}^{\theta} x_{\mu}$ is the ultra spherical polynomial which can be calculated by using recurrence relationship [11]. In this Modified OR filter with parameter $\alpha$ is derived by utilizing the formula is given as below
$$\alpha = \left\{\begin{array}{ll}
0.76609(R - 13.26)^{0.4}, & 13.26 \leq R \leq 60 \\
n0.12438(R + 6.3), & 60 \leq R \leq 120
\end{array}\right.$$  \hspace{1cm} (9)

where $R$ is frequency of the side lobe pattern. In this paper, we modify the OR filter to set $R=15.3$ db and then $\alpha$ gives 1.05, as described in equation (9). So that $\mu = 2$, $x_{\mu} = 1.0001$ are proposed in this modified overshoot ripple filter. In the spatial domain, the modified overshoot ripple filter are convoluted by an input artifact image pixel and it is replaced by the center pixel, a small size of the window is taken as the input artifact image to suppress the ringing artifacts.

3.5 Exponential Filter:

The exponential filter is derived by utilizing exponential window. This exponential window increases exponentially towards the center of the window and decreases exponentially in the second half and it never reaches zero. The exponential filter has high accuracy, robustness and simplicity. This exponential filter is multiplied by the DCT coefficients of the Non edge block so as to reduce the ringing artifacts. The formula for exponential filter, used in this proposed work is given as:
$$f_{\theta}^{\alpha}(x, y) = \sum_{k=0}^{N-1} \sum_{l=0}^{N-1} \theta_{\theta} \cdot DCT(k, l)$$  \hspace{1cm} (9)

Here $\theta_{\theta} = \theta \left(\frac{|k|}{N}\right)$ is the exponential filter and can be given by the notation
$$\theta_{\theta} \left(\frac{|k|}{N}\right) = e^{-\alpha \left(\frac{|k|}{N}\right)^{\gamma}}$$

where $p$ represents the order of the filter, $e$ is Euler’s number and $\alpha$ measures the strength of the filter. The exponential filter gives same proportional change. In the spatial domain, the filter mask is derived from the exponential window and a small size of the window as taken as the image to filter the values and it replaces in center pixel.

3.6 Algorithm:

The algorithm of the proposed ringing artifact reduction technique is presented below

Input image: Image containing ringing artifacts
Output image: Ringing artifact reduced image.
Begin
Step-1: Read the input artifact image
Step-2: Partition the input image into (3x3) blocks for determining Local visible Ringing measure as described in section 3.1.
Step-3: Apply Sobel operator to the input image, as mentioned in section 3.2.
Step-4: If it is an edge block of the input image then do the following:
I: Apply DCT to the input image, as described in section 3.3.
II: Multiply MOR filter values with DCT coefficients, as given in section 3.4.
Step-5: if it is a Non edge block of the input image then do the following:
I: Apply DCT to the non edge block of the image, as mentioned in section 3.3.
II: Multiply exponential filter coefficients to the DCT coefficients of non edge block of input image, as mentioned in the equation 3.5.
Step-6: Apply Inverse DCT to the results of Step-5 and Step-6, as mentioned in the equation (5).
Step-7: Obtain a Ringing artifact reduced image.
End

4. Performance Measure:

In order to evaluate the performance of the Ringing artifact reduction coding, it is necessary to define a measure that can estimate the difference between the original image and the ringing artifact reduction image. Two common measurements that are used to measure are the Mean square Error (MSE) and the Peak Signal to Noise Ratio (PSNR).

$$PSNR = 10 \log_{10} \left( \frac{255^2}{\epsilon_{mse}^2} \right)$$  \hspace{1cm} (10)

where the average mean square error $\epsilon_{mse}^2$

$$\epsilon_{mse}^2 = \frac{1}{NM} \sum_{i=0}^{N-1} \sum_{j=0}^{M-1} E[R(i, j) - \tilde{R}(i, j)]^2$$  \hspace{1cm} (11)

Here $R(i, j)$ is the (N x M) input artifact image and $\tilde{R}(i, j)$ is the (N x M) artifact removed image.

5. Experimental Results:

The proposed ringing artifact reduction algorithm is experimented with good number of standard benchmark images. Three sample images viz. pepper, baboon, text images and girl images, which are of size (256 x 256) with pixel values in the range (0-255), compressed with quality factors (q=10) are shown in the Figures 2 (a), (b), (c) and (d) respectively. Different input artifact image with quality factor (q=15) are shown in Figure 3 (a), (b), (c) and (d). We then partition these images into (3 x 3) and apply the measure of artifacts as described in section 3.1. Then Sobel operator is applied to each of these blocks of input images and classifies the blocks as either edge or non edge. MOR filter is applied to edge blocks as explained in the section 3.4 and Exponential filter is applied for non edge blocks as described in section 3.5. Finally, the artifact reduced image is produced by applying IDCT. The reconstructed images with the proposed artifacts reduction technique with quality factor (q=10), corresponding to the original images shown in Figure
2 (a), (b), (c) and (d) are presented in Figure 4 (a), (b), (c) and (d) respectively and the reconstructed images with the proposed artifact reduction technique with quality factor (q=15), corresponding to the original images shown in Figure 3 (a), (b), (c) and (d) are presented in Figure 5 (a), (b), (c) and (d) respectively. The proposed artifact reduction technique with modified OR filter and Exponential filter has been experimented with more than 100 image of different types and the quality of the ringing artifact reduced image is measured using PSNR, as described in section 4.

The PSNR value obtained with proposed ringing artifact reduction is 51.73db for pepper image, 47.34db for baboon image, 47.94db for text image, 46.17db for girl image, 53.589db for parrot image, 49.23db for barbara image and 34.03db for cameraman image. The proposed artifact reduction technique is also compared with existing techniques. The Popovici method gives a PSNR of 52.035db for pepper image, 47.71db for baboon image, 48.71db for text image, 47.56db for house image, 36.90db for lena image, 46.27db for girl image, 49.34db for Barbara image, 53.72db for parrot image and 34.02db for cameraman image. With the Hyungjun Lim method a PSNR values of 51.77db for pepper image, 47.72db for baboon image, 48.94db for text image, 47.43db for house image, 36.83db for lena image, 46.23db for girl image, 49.27db for Barbara image, 53.560db for parrot image and 34.4db for cameraman image is obtained. Results obtained for eight images with the proposed technique and their counterparts with existing techniques are summarized in table 1. From the results, it is evident that the proposed technique has lower PSNR values and hence its performance is good.

![Fig. 2: Input Artifact Image with quality factor q=10, (a) Baboon image, (b) Pepper image, (c) Text image, (d) Girl image.](image1)

![Fig. 3: Input Artifact Image with quality factor=15, (a) Parrot image, (b) Cameraman image, (c) Barbara image and (d) Lena image.](image2)

![Fig. 4: Results of the proposed ringing artifact reduction images (q=10), (a) Baboon image, (b) pepper image, (c) text image, (d) girl image.](image3)
6. Conclusion:

In this paper, a new ringing artifact reduction method is introduced to reduce the ringing artifacts in DCT domain, with Modified OR filter and Exponential filter. The proposed method reduces the ringing artifact more effectively than previous methods, as the method calculates the ringing measure initially and preserves the edge details without blurring.

REFERENCES


Table 1: PSNR values obtained with proposed and existing techniques.

<table>
<thead>
<tr>
<th>Input artifact images</th>
<th>Proposed method (db)</th>
<th>Popovici method (db)</th>
<th>Hyungjun Lim method (db)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pepper</td>
<td>51.70</td>
<td>52.035</td>
<td>51.77</td>
</tr>
<tr>
<td>Baboon</td>
<td>47.34</td>
<td>47.71</td>
<td>47.72</td>
</tr>
<tr>
<td>Text</td>
<td>47.944</td>
<td>48.71</td>
<td>48.194</td>
</tr>
<tr>
<td>House</td>
<td>47.84</td>
<td>47.56</td>
<td>47.43</td>
</tr>
<tr>
<td>Lena</td>
<td>36.78</td>
<td>36.90</td>
<td>36.83</td>
</tr>
<tr>
<td>Girl</td>
<td>46.17</td>
<td>46.27</td>
<td>46.23</td>
</tr>
<tr>
<td>Barbara</td>
<td>49.23</td>
<td>49.34</td>
<td>49.27</td>
</tr>
<tr>
<td>Parrot</td>
<td>53.589</td>
<td>53.72</td>
<td>53.560</td>
</tr>
<tr>
<td>Cameraman</td>
<td>34.03</td>
<td>34.02</td>
<td>34.4</td>
</tr>
</tbody>
</table>

Fig. 5: Results of the proposed ringing artifact reduction images (q=15). (a) Parrot image, (b) Cameraman image, (c) Barbara image, (d) Lena image.


