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Modified Pointwise Shape-Adaptive DCT for High Quality Deblocking of Compressed Color Images

C.S.Rawat, Rohan K. Shambharkar, Dr. Sukadev Meher

Abstract— Blocking artifact is one of the most annoying artifacts in image compression coding. In order to improve the quality of the reconstructed image several deblocking algorithms have been proposed. A high-quality modified image deblocking algorithm based on the shape-adaptive DCT (SA-DCT) is shown. The SA-DCT is a low-complexity transform which can be computed on a support of arbitrary shape. This transform has been adopted by the MPEG-4 standard and it is found implemented in modern video hardware. This approach has been used for the deblocking of block-DCT compressed images. In this paper we see modified pointwise SA-DCT method based on adaptive DCT threshold coefficient instead of constant DCT threshold coefficient used by the original pointwise SA-DCT method. Extensive simulation experiments attest the advanced performance of the proposed filtering method. The visual quality of the estimates is high, with sharp detail preservation, clean edges. Blocking artifacts are suppressed while salient image features are preserved. A structural constraint in luminance-chrominance space is shown to enable an accurate filtering of color images. Simulation experiments show the quality of the final estimate of our modified approach is better than the original method. The SA-DCT filtering used for the chrominance channels allows to faithfully reconstruct the missing structural information of the chrominances, thus correcting color-bleeding artifacts.

Index Terms— Anisotropic, Blocking Artifacts, Deblocking, Discrete cosine transform (DCT), JPEG, LPA-ICI, Shape adaptive.

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1 INTRODUCTION

The new JPEG-2000 image compression standard solved many of the drawbacks of its predecessor. The use of a wavelet transform computed globally on the whole image, as opposed to the localized block-DCT (B-DCT) (employed e.g. by the classic JPEG), does not introduce any blocking artifacts and allows it to achieve a very good image quality even at high compression rates. Unfortunately, this new standard has received so far only very limited endorsement from digital camera manufacturers and software developers. As a matter of fact, the classic JPEG still dominates the consumer market and the near-totality of pictures circulated on the internet is compressed using this old standard. Moreover, the B-DCT is the work-horse on which even the latest MPEG video coding standards rely upon. There are no convincing indicators suggesting that the current trend is about to change any time soon. All these facts, together with the ever growing consumer demand for high quality imaging, makes the development of advanced and efficient post-processing (deblocking) techniques a very actual and relevant application area.

In this paper a novel method for the restoration of B-DCT compressed color images is seen. It is based on the pointwise shape-adaptive DCT (SA-DCT) [4] approach and its characterized by a high quality of the filtered estimate.

The SA-DCT [1, 2] is a generalization of the usual separable block-DCT (B-DCT) which can be computed on a support of arbitrary shape. It is obtained by cascaded application of one-dimensional varying-length DCT transforms first on the columns and then on the rows that constitute the considered support. Thus, it retains the same computational complexity of the B-DCT. The SA-DCT has been originally developed for coding non-rectangular image patches near the border of image objects, in such a way to minimize the stored information and to avoid the ringing artifacts (Gibbs phenomenon) that would appear in correspondence with strong edges. Because of its low complexity, the near-optimal de-correlation and energy compaction properties (e.g. [1], [5]), and its backward compatibility with the B-DCT, the SA-DCT has been included in the MPEG-4 standard [3], where it is used for the coding of image segments that lie on the video-object's boundary. The recent availability of low-power hardware SA-DCT platforms (e.g. [2], [6]) makes this transform an appealing choice for many image-and video-processing tasks.

The first attempt to use of SA-DCT for image denoising was seen in [7]. The original version of the method has been adapted for image deblocking. These algorithms demonstrate a remarkable performance, typically outperforming the best methods known to the authors [14]. The SA-DCT estimates have also been shown to achieve one of the highest subjective visual quality [8].

The paper is organized as follows. In the next section a brief overview on the basic anisotropic LPA-ICI in conjunction with SA-DCT method is discussed [4,14]. Section 3 discusses the relation of quantization table and with the value of the variance to be used for the filtering process and the adaptation of the denoising algorithm to deblocking. The algorithm is

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- *Rohan K. Shambharkar is currently pursuing masters degree in electronics and telecommunication engineering in VESIT, Chembur, Mumai University, India,E-mail: rohanluke@rediffmail.com*
- *C.S.Rawt is pursuing Phd in ECE Dept., NIT Rourkela. E-mail: chandansrawat@gmail.com*
- *Dr.Sukadev Meher is currently working as Prof. and Head of ECE Dept, NIT Rourkela.*

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extended for color images with the “luminance-chrominance structural constraint” in Section 4. Section 5 discusses the proposed modified Pointwise SA-DCT algorithm. The final Section is devoted to extensive experimental results by considering several level of compression for color images.

2 ANISOTROPIC LPA-ICI-DRIVEN SA- DCT DENOISING

Here only a brief overview on the original method developed for image denoising is shown and refer the reader to [9] (and references therein) for a more formal, complete, and rigorous description.

Fig. 1. Details of the JPEG-compressed grayscale *Lena* (*Q*=6, *PSNR*=28.24dB) and Pointwise SA-DCT estimate (*PSNR*=29.8671dB) and of the corresponding modified Pointwise SA-DCT estimate (*PSNR*=29.8679dB). The estimated standard deviation for this highly compressed image is σ=17.6.

The use of a transform with a shape-adaptive support involves actually two separate problems: not only the transform should adapt to the shape (i.e. a shape-adaptive transform), but the shape itself must adapt to the image features (i.e. an adaptive shape). The first problem has found a very satisfactory solution in the SA-DCT transform [1, 2]. The second problem is essentially application-dependant. It must be noted that conventional segmentation (or local-segmentation) techniques which are employed for video processing (e.g. [10]) are not suitable for degraded (noisy, blurred, highly compressed, etc.) data. In this approach, the SA-DCT in conjunction with the anisotropic LPA-ICI technique [11, 12, 13] is used. By comparing varying-scale directional kernel estimates, the technique adaptively selects, for each point in the image, a set of directional adaptive-scales. The length of the support of the corresponding adaptive-scale kernels define the shape of the transforms support in a pointwise-adaptive manner. Examples of such neighborhoods are shown in Fig. 4.

For each one of these neighborhoods a SA-DCT is performed. The hard-thresholded SA-DCT coefficients are used to reconstruct a local estimate of the signal within the adaptive-shape support. By using the adaptive neighborhoods as support for the SA-DCT, it is ensured that data are represented sparsely in the transform domain, allowing to effectively separate signal from noise using hard thresholding. Since supports corresponding to different points are in general overlapping (and thus generate an overcomplete representation of the signal), the local estimates are averaged together using adaptive weights that depend on the local estimates’ statistics. In this way an adaptive estimate of the whole image is obtained.

Fig. 2. Details of the JPEG-compressed *Lena* (*Q*=15, *PSNR*=31.95dB) and Pointwise SA-DCT estimate (*PSNR*=33.2144dB) and of the corresponding modified Pointwise SA-DCT estimate (*PSNR*=33.2148dB). The estimated standard deviation for this compressed image is σ=9.7.

Once this global estimate is produced, it is used as reference estimate for an empirical Wiener filter in SA-DCT domain. Following the same adaptive averaging procedure as for hard-thresholding, we arrive to the final Anisotropic LPA-ICI-driven SA-DCT estimate. This procedure is called “*Pointwise SA-DCT*”.

3 POINTWISE SA-DCT FOR B-DCT ARTIFACTS REMOVAL [14]

More sophisticated models of B-DCT-domain quantization noise have been proposed by many authors, here we model this degradation as some additive Gaussian white noise. In this section we restrict our attention to the grayscale/single-channel case and thus assume the observation model

$$z = y + n \tag{3}$$

where y is the original (non-compressed) image, z its observation after quantization in B-DCT domain, and n is independent Gaussian with variance σ^2, $n(\cdot) \sim N(0,\sigma^2)$.

We estimate a suitable value for the variance σ^2 directly from the quantization table $\mathbf{Q} = [q_{i,j}]_{i,j=1,\dots,8}$ using the following empirical formula:

$$\sigma^2 = 0.69 \cdot \left(\frac{1}{9}\sum_{i,j=1}^{3} q_{i,j}\right)^{1.3} \tag{4}$$

This formula uses only the mean value of the nine table entries which correspond to the lowest-frequency DCT harmonics (including the DC-term) and has been experimentally verified to be quite robust for a wide range of different quantization tables and images. A higher compression obviously corresponds to a larger value for the variance.

The σ^2 which is calculated by (4) is *not* an estimate of the

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variance of compressed image, *nor* it is an estimate of the variance of the difference between original and compressed images. Instead, it is simply the variance of the white Gaussian noise n in the observation model (3). It is the variance of some hypothetical noise which, if added to the original image y, would require - in order to be removed - the same level of adaptive smoothing which is necessary to suppress the artifacts generated by the B-DCT quantization with the table **Q**.

Fig. 1 and Fig. 2 shows the JPEG compressed grayscale *Lena* image obtained for two different compression levels (JPEG quality Q=6 and Q=15) and the corresponding SA-DCT filtered estimates and our modified estimates. For these two cases the estimated standard deviations are σ=17.6 and σ=9.7.

4 COLOR IMAGE PROCESSING WITH STRUCTURAL CONSTRAINT IN LUMINANCE CHROMINANCE SPACE

When compressing color images or video, the standard approach (e.g. in the JPEG and MPEG), is to first perform the *YUV* color transformation - which decomposes the signal in one luminance and two chrominance channels - and then process the resulting three channels separately. According to the modeling in the previous section, it is assumed that the original (non-compressed) image
$y = [y_R, y_G, y_B]$ in the *RGB* color space is represented, after B-DCT quantization in *YUV* space as

$$z_C = y_C + n_C,\ C = Y, U, V$$

where, y_Y, y_U and y_V are the luminance and chrominance channels of y, z_Y, z_U and z_V are the corresponding channels after quantization in B-DCT domain, and $n = [n_y, n_u, n_V]$ is independent Gaussian noise,

$$n_C(\cdot) \sim N(0, \sigma_C^2)$$

The estimate of the variances σ^2_Y, σ^2_U and σ^2_V from the corresponding quantization tables for the luminance and chrominance channels is done, using formula (4). However, the chrominance channels are downsampled, then the estimated variances for the chrominances need to be further multiplied by 2, in order to take into account for the coarser sampling.

Usually, the quantization tables $\mathbf{Q}U$ and $\mathbf{Q}V$ used for the two chrominances coincide, $\mathbf{Q}U = \mathbf{Q}V = \mathbf{Q}UV$. Following established models of the human visual system, a higher compression is performed on the chrominances than on the luminance. Thus, it is typical that the estimated variances are such that $2\sigma^2_Y < \sigma^2_U = \sigma^2_V$.

A first example of the original method for color images in Figure 3. In this example, the values of σ_Y and $\sigma_U = \sigma_V$ calculated according to formula (2) are 12.6 and 27.1, respectively.

As proposed in [16] for color image denoising, we approach color data in a channel-by-channel manner imposing a unique structural contraint among the three channels. This allows to filter the chrominance channels restoring the structural information which went lost because of quantization and coarse sampling. The peculiarity of this approach [14] is easily explained and demonstrated through this first example.

Even at relatively high bit-rates, the compression of the chrominance channels is usually quite aggressive. The typical scenario is illustrated in Figure 3. It can be seen that only very few AC-terms of the chrominance blocks survive to quantization, and the resulting chrominance channels end up with the vast majority of blocks represented by the DC-term only. It results in unpleasant color-bleeding artifacts along edges between differently colored objects. At the same time, on smoother areas the uneven hue due to quantization becomes particularly noticeable.

Fig. 3. Fragments of the JPEG-compressed (Q=20, $PSNR$=29.83dB), and restored *Lena* image using Pointwise SA-DCT ($PSNR$=30.9985dB) and Modified Pointwise SA-DCT ($PSNR$=30.9994dB). Top to bottom row: *RGB* color, luminance *Y*, and chrominance *U* and *V* channels.

Ideally, the *Y*, *U*, and *V* channels are considered as independent. Therefore, the common approach is to filter the three channels separately and independently one from the other.

However, when considering natural images, the different color channels typically share some common features which are inherited from the structures and from the objects depicted in the original image. In particular, it can be observed that along the objects' boundaries all color channels of the original image usually exhibit some simultaneous discontinuities or sharp transitions.

This kind of structural correlation is exploited by imposing

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that the three transform's supports which are used for the filtering of the Y, U, and V channels at a particular location have the same adaptive shape. The adaptive neighborhoods defined by the anisotropic LPA-ICI for the Y channel are used by all the three channels, because it is in the luminance that the structural information is usually better preserved after compression.

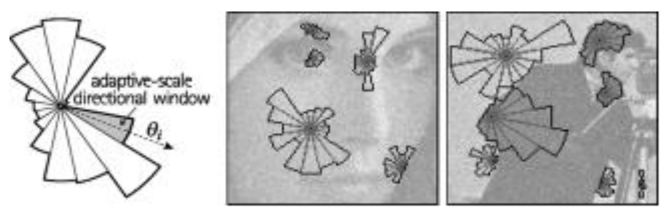

Fig. 4. Anisotropic LPA-ICI. From left to right: Sectorial structure of the anisotropic neighborhood achieved by combining a number of adaptive-scale directional windows; some of these windows selected by the ICI for the noisy Lena and Cameraman images [14].

Such a constraint make so that whenever some structure is detected (by the LPA-ICI), it is taken into account (and thus preserved) for the filtering of all three channels. Restricted to the adaptive supports, however, the channels are assumed as independent, and thus the transform-domain filtering is still performed for each channel independently from the others.

5 PROPOSED MODIFIED POINTWISE SADCT ALGORITHM

Here the fact is to be emphasized that the PSNR value can be improved by using adaptive DCT threshold coefficient 'DCTthrCOEF' parameter in the algorithm. The DCTthrCOEF parameter in original algorithm has been fixed to value 0.925. However after extensive analysis it can be effectively concluded that if DCTthrCOEF parameter is kept selective instead of constant there is improvement in PSNR value. For this a look-up has been created. The look up table is as shown in Table 1.

The look up table gives improvement in PSNR values. Thus we can verify the results which shows that the values of PSNR can be improved by not keeping DCT threshold coefficient 'DCTthrCOEF' fixed as suggested by base paper [14] but keeping it adaptive improves results.

TABLE 1
LOOKUP TABLE

Look up table										
1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
1.9	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	0.925
1.9	1.9	0.985	0.965	0.94	0.903	0.925	0.804	0.784	0.784	0.784
0.985	0.905	0.9	0.895	0.935	0.925	0.928	0.685	0.625	0.555	0.355

6 EXPERIMENTAL RESULTS

Extensive simulation experiments were carried out. Consequently, we present numerical results in tabulated form. The table is dedicated to experiments with JPEG compression of color images.

In Table 2 we show results for the Pointwise SA-DCT filtering of JPEG-compressed color images, from very high (Q=4) to very low (Q=50) compression levels. It can be seen that the improvement is significant especially for very high and moderate compression levels. For very low compression levels - for which the compression artifacts are barely visible and thus there is typically no need for postprocessing - the improvement is still substantial for those images which present some structures or edges.

For the simulations in Table 2, the baseline IJG JPEG implementation is used. For a JPEG-quality parameter Q=50, the quantization tables [17] for the luminance and chrominance channels are shown below, and the corresponding estimated standard deviations according to (4) are σ_Y = 4.4 and $\sigma_U = \sigma_V$ = 9.7.

Figure 3 shows that the original method effectively attenuates blocking artifacts, faithfully preserving the structures and the salient feature in the image. Moreover, it demonstrates its ability of reconstructing the missing structural information in the chrominance channels. The obtained color estimate is then quite sharp, with well-defined edges, and the color-bleeding artifacts - obviously visible in the JPEG-compressed image - are accurately corrected. Also we compare our modified pointwise SA-DCT method with the original pointwise SA-DCT method. In this comparison, our modified Pointwise SA-DCT method is found to be better than the original method. Figure 5 shows the graph of the comparison between the PSNR values of JPEG, original SA-DCT method and our proposed modified SA-DCT method versus Quality of Lena, Peppers, Baboon and House images.

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The *Luminance Quantization Table* $\mathbf{Q}Y_{Q=50}$

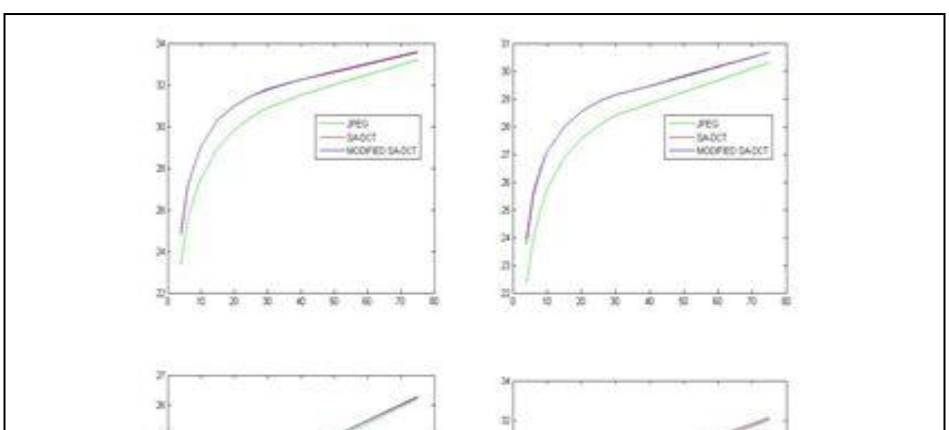
16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

The *Chrominance Quantization Table* $\mathbf{Q}UV_{Q=50}$

17	18	24	47	99	99	99	99
18	21	26	66	99	99	99	99
24	26	56	99	99	99	99	99
47	66	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99

TABLE 2
PSNR (dB) RESULTS FOR THE POINTWISE SA-DCT FILTERING OF JPEG-COMPRESSED COLOR IMAGES. IT SHOWS THE COMPARISON OF THE ORIGINAL SA-DCT METHOD [14] AND OUR PROPOSED MODIFIED SA-DCT METHOD.

Qual	Color Lena 512×512×24			Color Peppers 512×512×24			Color Baboon 512×512×24			Color House 256×256×24		
	JPEG	SA-DCT	Modified SA-DCT	JPEG	SA-DCT	Modified SA-DCT	JPEG	SA-DCT	Modified SA-DCT	JPEG	SA-DCT	Modified SA-DCT
4	23.34	24.7912	24.9347	22.32	23.7741	23.9676	19.28	19.9975	20.0002	22.63	23.756	23.9985
6	25.52	27.0954	27.132	23.99	25.5359	25.6268	20.38	21.0501	21.0503	24.41	25.6571	25.7025
8	26.64	28.1627	28.1675	24.99	26.3987	26.4576	21.12	21.709	21.7093	25.16	26.4105	26.5997
10	27.53	29.0607	29.0638	25.77	27.1096	27.1154	21.63	22.1306	22.131	26.25	27.5384	27.5491
15	28.97	30.3279	30.3282	26.88	27.9859	27.9981	22.49	22.8784	22.8785	27.52	28.6585	28.8751
20	29.83	30.9985	30.9994	27.57	28.5328	28.5441	23.07	23.3724	23.3724	27.87	28.7496	28.9254
25	30.44	31.4555	31.4555	28.04	28.8963	28.9203	23.50	23.7552	23.7552	28.55	29.4371	29.6184
30	30.91	31.7876	31.7925	28.40	29.134	29.1495	23.85	24.0649	24.0683	28.96	29.7648	29.9244
40	31.54	32.2595	32.2661	28.83	29.4535	29.4606	24.40	24.5617	24.5705	29.51	30.2005	30.4096
50	32.02	32.6258	32.6379	29.25	29.8136	29.8351	24.85	24.9702	24.9849	29.80	30.3972	30.5647
75	33.21	33.5602	33.5853	30.29	30.6666	30.6667	26.21	26.2522	26.2826	31.44	32.0033	32.1244



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7 CONCLUSION

We proposed a new method of selecting DCT threshold coefficient instead of taking it constant as in original SA-DCT. Our modified SA-DCT approach with adaptive DCT threshold coefficient gives better result than the original SA-DCT method with constant DCT threshold coefficient. Thus we can verify the results which show that the values of PSNR can be improved by not keeping DCT threshold coefficient fixed as suggested by base paper but keeping it adaptive improves results.

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