A Novel Image Enhancement Technique based on Statistical Analysis of DCT coefficients for JPEG Compressed Images

Jaspreet Bhatia, Manish Okade
Department of Electronics and Communication Engineering,
National Institute of Technology, Rourkela, 769008, India.
Email: jasvir.bhatia@gmail.com, okadem@nitrkl.ac.in

***Abstract*—This paper investigates a novel image enhancement technique based on statistical analysis of DCT coefficients. The proposed method treats the DC coefficient and AC coefficients of a DCT block separately to arrive at two different scaling factors. Since the DC coefficient of a block being an average value concerns with illumination of the image, the coefficient of variation (c_v) is estimated which is used as the DC scaling factor. On the other hand, since the AC coefficients concern with the local contrast, these are analyzed diagonally forming bands followed by calculating entropy and contrast which are utilized to arrive at the AC scaling factor. The two scaling factors are used to compute the enhanced DCT block and the corresponding enhanced image. Our experimental results show that such statistical analysis is able to capture the behaviour of the DCT coefficients which is exploited to arrive at the scaling factors thereby making the proposed method independent of pre-defined enhancement functions like twicing function, S-function currently utilized by state-of-the-art methods. Extensive testing and comparative analysis of the proposed method clearly shows better results in comparison to an existing technique.**

I. Introduction

Image enhancement is the process of adjusting the brightness, contrast and color of an image for better visualization and rendering. Among the listed measures, the brightness and contrast have the maximum impact on the Human Visual System (HVS) and has been receiving research attention for several decades. The image enhancement task can be performed either in the pixel domain [1]–[4] also referred to as spatial domain or in the compressed domain [5]–[8] also referred to as the transform domain. The domains where the enhancement can be carried out i.e. pixel or compressed, pose their own advantages and shortcomings. Pixel domain offers superior enhancement quality at the cost of high computational complexity due to all the pixels being involved in the processing pipeline. Few among the state-of-the-art techniques in this domain are retinex theory [1], bilateral tone adjustment [3] etc. However, with the popularity of compression methods like JPEG and JPEG-2000 having reached significant maturity, more and more methods are currently being explored in the compressed domain.

Compressed domain methods are inspired from the motivation that if the image which is stored in the compressed form can be directly operated on then sufficient savings in computational power can be achieved since decompression and subsequent recompression's can be avoided. It also offers less storage space which is an added advantage. However, there is a caveat here in the form of artifacts which arise due to the compression pipeline, which significantly reduces the enhancement quality achieved over its pixel domain counterparts. This caveat is circumvented by savings in computational complexity which makes the compressed domain techniques very popular. Moreover, with the advent in the mobile phone technology and its popularity, increasingly images are now being stored in compressed form which calls for better techniques to be designed in the compressed domain which is the focus of the current paper. A brief review of the works which have been carried out for the image enhancement problem in the compressed domain are highlighted below.

Aghagolzadeh and Ersoy [9] were among the first to investigate utilizing compressed data by way of filtering the transform coefficients using alpha-rooting and unsharp masking followed by block artifact removal using overlap-save technique for image enhancement. Lee [8] investigated a novel image enhancement method by extending the retinex theory of pixel domain to compressed domain by non-uniform treatment of AC and DC coefficients. This was coupled by a noise reduction strategy to control the compression artifacts. Mukherjee and Mitra [5] proposed a novel technique referred as Contrast Enhancement by Scaling (CES) for color image enhancement by calculating a uniform scaling factor which was utilized to estimate the enhanced DCT blocks and the corresponding image. Their method was based on using pre-defined enhancement functions like twicing function, S-function for treating the DCT coefficients followed by estimation of the block scaling factor. Similar strategy was used by Tang et al. [7] where spectral bands were formed from the DCT blocks followed by utilizing the pre-defined functions for enhancement. Although the above listed techniques achieve good enhancement quality, yet their dependence on pre-defined functions makes them heuristic and application dependent. Motivated by these shortcomings in existing techniques, we investigate if DCT block statistics can be employed to carry out the enhancement operation. To this effect we model the DC and AC coefficients of a block separately. Our study presented in this paper shows that the statistical behaviour of

978-1-5090-2361-5/16/$31.00

DCT coefficients can be exploited to arrive at scaling factors which can achieve good enhancement quality. The proposed method shows superior enhancement results for all the tested images at comparable computational complexity as that of an existing method of Mukherjee and Mitra henceforth referred to as CES [5] throughout the paper.

II. Key Contributions

The DC coefficient and the AC coefficients of a DCT block have been analyzed separately [10]–[13] and two scaling factors have been estimated, the first for scaling the DC coefficient and the second for scaling the AC coefficients. Since the DC coefficients of an transformed image follows the gaussian distribution while the AC coefficients follows the laplacian distribution, we show that estimation of separate scaling factors offers an advantage in achieving better enhancement results. Such separate modeling is also beneficial since DC coefficients affects the illumination (i.e. brightness) while the AC coefficients affects the contrast of the image. The DC scaling factor has been calculated utilizing the coefficient of variation ($\frac{\sigma}{\mu}$) as a measure for checking the range of optimum brightness. The AC scaling factor has been calculated based on the entropy of a block by analyzing the AC coefficients diagonally and relating it to the contrast. Such statistical analysis makes the proposed method independent of any pre-defined external functions as used in CES work [5] and offers advantages since the image statistics itself is involved in the choice of the scaling factors in-place of pre-defined enhancement functions.

III. JPEG Compression Overview

JPEG compression pipeline consists of DCT, quantization by fixed tables followed by huffman encoding. The decompression does the inverse of each of these steps i.e. decode, de-quantize and Inverse DCT. The image is partitioned into 8 x 8 non-overlapping pixel blocks i.e. $f(x, y); 0 \leq x, y \leq 7$. The block wise DCT is calculated using,

$$d_{kl} = \alpha(k)\alpha(l)\sum_{x=0}^{7}\sum_{y=0}^{7} f(x,y)cos\left(\frac{(2x+1)k\pi}{16}\right)cos\left(\frac{(2y+1)l\pi}{16}\right) \tag{1}$$

$$\alpha(k) = \alpha(l) = \begin{cases} \sqrt{\frac{1}{N}} & k,l = 0; \\ \sqrt{\frac{2}{N}} & k,l = 1,2,\ldots 7; \end{cases}$$

The matrix d_{kl}, $k, l \in \{0, 1, 2, \ldots 7\}$ is then quantized using quantization matrix q_{kl} as,

$$D^q_{kl} = round\left(\frac{d_{kl}}{q_{kl}}\right) \tag{2}$$

Coefficients of D^q_{kl} are ordered using zig-zag scan and encoded using the Huffman encoder. Decompression is carried out by multiplying D^q_{kl} by q_{kl} (i.e. $d_{kl} = q_{kl} \times D^q_{kl}$) and taking IDCT followed by rounding the result and truncating to integer values in the range [0, 255]. i.e. $B = T(R(IDCT(d)))$ where T is the truncation operation and R is the rounding operation.

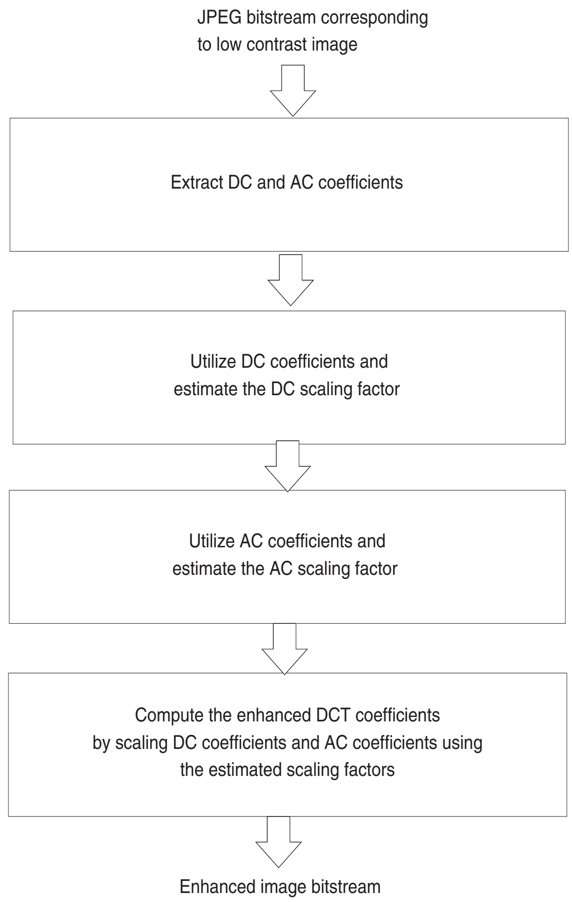

Fig. 1. Flowchart of the proposed method

IV. Proposed Method

Fig. 1. shows the flowchart of the proposed method. The proposed method utilizes the statistical behaviour of DCT coefficients extracted from the JPEG bitstream. Our idea is inspired from the fact that the DC coefficient and the AC coefficients of a DCT block follow different distributions and hence needs to be analyzed separately. The DC coefficients follows the gaussian distribution while the AC coefficients follows the laplacian distribution. We estimate two different scaling factors, one for DC coefficient and the other for AC coefficients followed by computing the enhanced DCT coefficients by scaling the DC and AC coefficients using the estimated scaling factors. Our experiments show superior qualitative and quantitative results in comparison to an existing state-of-the-art technique i.e. CES [5].

The detailed description is given in the following subsections. The flow of the proposed method is as follows: Estimation of DC scaling factor, estimation of AC scaling factor and finally computing the enhanced DCT block coefficients. In addition, we extract a single DCT block $d_{kl}, 0 \leq k, l \leq 7$ from the JPEG bitstream using equation (1) for explaining the statistical analysis and is shown below. Each DCT block contains 1 DC coefficient (i.e. first coefficient d_{00}) and 63 AC coefficients (i.e. $d_{kl}, 1 \leq k, l \leq 7$).

$$
\begin{array}{c}
\begin{array}{cccccccc} & E_1 & & & & & & E_{14} \end{array} \\
\begin{pmatrix}
d_{00} & d_{01} & d_{02} & d_{03} & d_{04} & d_{05} & d_{06} & d_{07} \\
d_{10} & d_{11} & d_{12} & d_{13} & d_{14} & d_{15} & d_{16} & d_{17} \\
d_{20} & d_{21} & d_{22} & d_{23} & d_{24} & d_{25} & d_{26} & d_{27} \\
d_{30} & d_{31} & d_{32} & d_{33} & d_{34} & d_{35} & d_{36} & d_{37} \\
d_{40} & d_{41} & d_{42} & d_{43} & d_{44} & d_{45} & d_{46} & d_{47} \\
d_{50} & d_{51} & d_{52} & d_{53} & d_{54} & d_{55} & d_{56} & d_{57} \\
d_{60} & d_{61} & d_{62} & d_{63} & d_{64} & d_{65} & d_{66} & d_{67} \\
d_{70} & d_{71} & d_{72} & d_{73} & d_{74} & d_{75} & d_{76} & \boxed{d_{77}}
\end{pmatrix}
\end{array}
$$

A. *Estimating DC scaling factor*

The first coefficient i.e. d_{00} of a DCT block is the DC coefficient. Suppose the compressed image under analysis has 'M' blocks, where $M = \frac{\text{Image Width} \times \text{Image Height}}{8 \times 8}$.

Let d_{00}^m represent the DC coefficient of m^{th} block, $m \in \{1, 2, \ldots, M\}$. We collect the DC coefficients from all 'M' blocks and form a DC matrix having 'p' rows and 'q' columns. This matrix is analyzed using 4 $\times$ 4 window and the ratio of maximum value to minimum value of DC coefficient for the 4 $\times$ 4 window is estimated using,

$$\Psi(i, j) = \frac{\max DC_{4\times4}(i, j)}{\min DC_{4\times4}(i, j)} \tag{3}$$

where $i = 1, 2, \ldots p/4$ and $j = 1, 2, \ldots q/4$. The Ψ matrix is further used for analysis by estimating the mean (μ) and variance (σ) of the Ψ matrix followed by calculating the coefficient of variation c_v using,

$$c_v = \frac{\sigma}{\mu} \tag{4}$$

The coefficient of variation (c_v) is chosen as the DC scaling factor and is denoted by λ i.e.

$$\lambda = c_v = \frac{\sigma}{\mu} \tag{5}$$

The DC scaling factor (λ) is used to scale the DC coefficients of all 'M' blocks.

B. *Estimating AC scaling factor*

In order to make the AC scaling factor independent of any pre-defined functions, we introduce the concept of calculating the entropy of AC coefficients. The entropy [14], [15] in this context is given by,

$$H = -\sum_{\forall j} p(x_j) \log p(x_j) \tag{6}$$

where, x_j is the j^{th} dct coefficient. The estimation of AC scaling factor for a DCT block is inspired and motivated from Tang et al.'s work [7] of analyzing AC coefficients diagonally forming bands. We adopt a modified version of it to suit our problem of calculating the AC scaling factor. The 63 AC coefficients of a block $d_{kl}, 1 \leq k, l \leq 7$, as shown earlier in the matrix form are grouped into 14 diagonal bands $E_1, E_2, \ldots, E_{14}$ (kindly refer the d_{kl} matrix). The AC coefficients of n^{th} band are composed of $n = k + l$ number of coefficients. The Contrast at the nth band i.e. C_n ($n \geq 1$) is defined as,

$$C_n = \frac{E_n}{\sum_{t=0}^{n-1} E_t} \tag{7}$$

where,

$$E_t = \frac{\sum_{k+l=t} E_t}{N}$$

$$N = \begin{cases} t + 1 & t < 8 \\ 14 - t + 1 & t \geq 8. \end{cases}$$

As reported by Tang et al. [7], such coefficient grouping leads to a band imposing a multi-scale structure which is utilized in our study to calculate the contrast values as follows:

1) For a DCT block, the 63 AC coefficients are grouped into 14 diagonal bands as explained above followed by calculating the contrast for each band ($n \geq 1$) using equation (7) which gives,

$$C = [C_1, C_2, \ldots, C_{14}]$$

2) On similar lines, for a DCT block, the 63 AC coefficients are grouped into 14 diagonal bands followed by calculating the entropy ratio $H_n^{'}$ for each band ($n \geq 1$) using,

$$H_n^{'} = \frac{H_n}{\sum_{t=0}^{n-1} H_t} \tag{8}$$

where,

$$H_t = \frac{\sum_{k+l=t} H_t}{N}$$

H_n= entropy of n^{th} band. Equation (8) gives,

$$H^{'} = [H_1^{'}, H_2^{'}, \ldots, H_{14}^{'}]$$

3) The element wise difference between $H^{'}$ and C arrays is calculated followed by choosing the largest element in the difference array as the AC scaling factor i.e.

$$\Phi = \max[H^{'} - C] \tag{9}$$

4) Steps 1) to 3) are repeated for rest of the DCT blocks i.e. 'M' blocks and Φ_m scaling factors are estimated, $m \in \{1, 2, \ldots, M\}$.

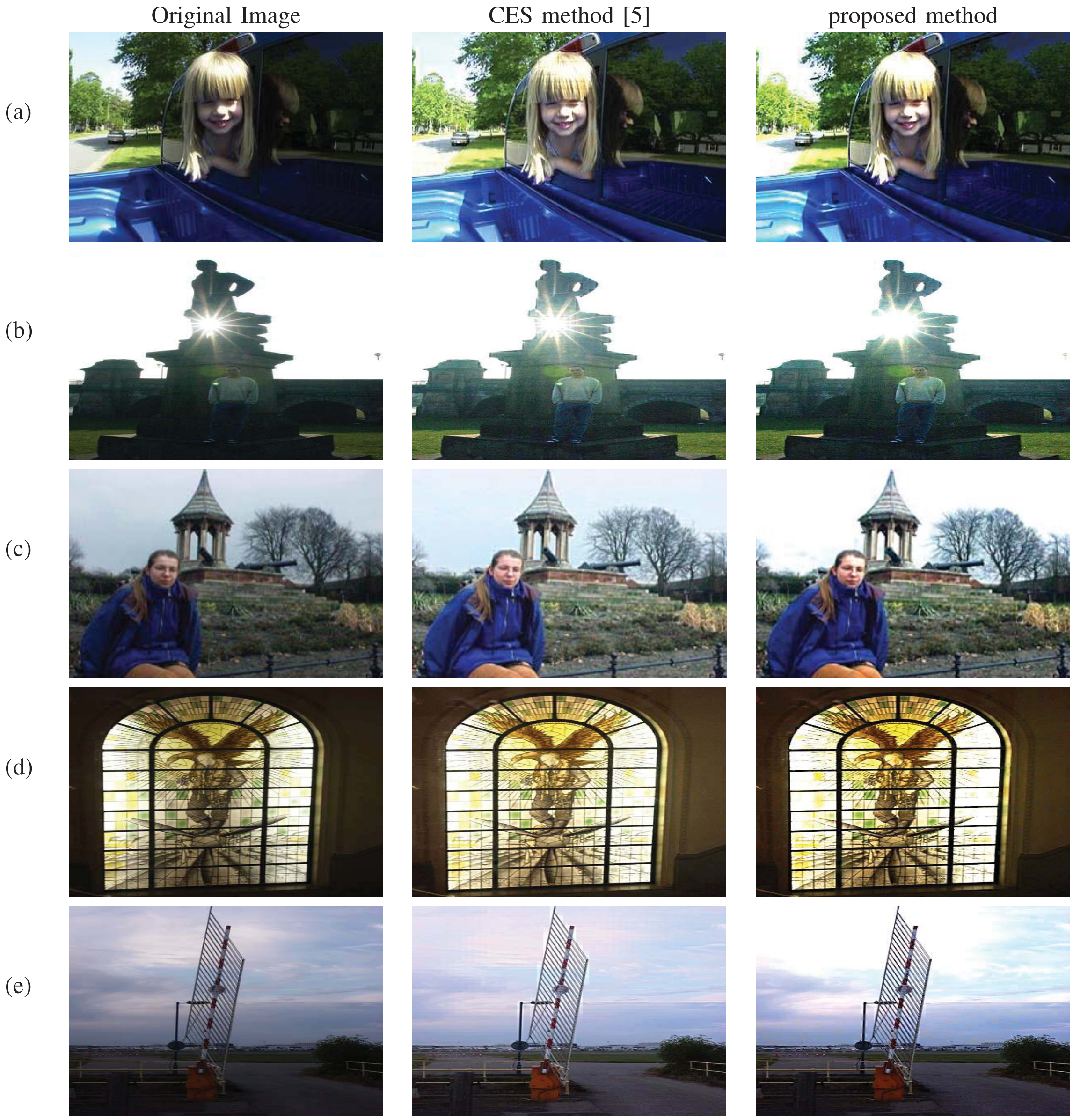

Fig. 2. Qualitative i.e. subjective comparative analysis for the proposed method: (a) Image16, (b) Ucid00146, (c) Ucid00196, (d) Ucid00470, (e) Ucid00607.

C. Computing Enhanced Block values

The final stage of the proposed method is to estimate the enhanced DCT blocks which is performed as follows:

1) The original DC value of all DCT block's are replaced to obtain the enhanced DC coefficients d_{00}^{enh} using,

$$d_{00}^{enh} = \lambda \times d_{00} \tag{10}$$

2) Since the AC scaling factor is non-uniform across blocks due to its dependence on entropy, the original AC values of a particular block is replaced to obtain the enhanced AC coefficients d_{kl}^{enh} using,

$$d_{k,l}^{enh} = \Phi_m \times d_{kl} \tag{11}$$

3) Recompose the DCT blocks using d_{00}^{enh} as the enhanced DC coefficient and d_{kl}^{enh} as the enhanced AC coefficients.

V. Results

Matlab 8.1 is used for experimentation. The proposed method is tested on images which have been earlier used in studies pertaining to image enhancement. In addition, we also show the enhancement results for few images taken from UCID v2 [16] dataset. Comparative analysis is carried out with a standard technique i.e. Contrast Enhancement by Scaling (CES) [5] since the proposed method is motivated from it. The research code, results as well as supplementary material is available at https://sites.google.com/site/manishokade/publications. The motivation for making the research results and implementation public is to encourage fellow researchers to carry forward our work.

As mentioned earlier the proposed method treats the DC coefficient and the AC coefficients separately to arrive at two different scaling factors which are independent of any pre-defined external enhancement functions like twicing function, S-function etc. as used in CES [5]. The scaling factors are further utilized to enhance the DCT coefficients to obtain the image enhancement. Such a treatment offers advantages as demonstrated in the following sections. We perform the qualitative as well as quantitative studies for the proposed method and compare with CES method [5] to validate the effectiveness of the proposed method.

A. Qualitative Evaluation

This section presents the qualitative i.e. subjective evaluation of the proposed method. Fig. 2. shows few images which have been tested in this study. For additional results and images readers are kindly referred to our web-page. As observed from Fig. 2., the proposed method is subjectively better in comparison with CES method [5] for most of the tested images. For image16, which shows the child seated in a vehicle and looking outside the window, it is observed that the proposed method achieves better results in areas like the child's reflection on the vehicle's glass window as well as on her hair where the sun's illumination appears more balanced in comparison to CES method [5]. Similar observations are made for the balancing of the sunlight on the road where the proposed method is better in comparison to CES method [5]. Comparative analysis with UCID images also shows some interesting observations. The proposed method preserves the subtle details as observed on the glass pane of Ucid00470 image where the green color of few panes below and above the eagle are more prominent as compared to CES work [5]. Such improvements have been observed for the other images as seen from Fig. 2 as well. This improvement in brightness and contrast is possible for the proposed method due to the fact that we utilize DCT block statistics in arriving at the scaling factors which are used for the enhancement. It is worth mentioning here again that we achieve comparable subjective results as that of CES [5] without using external enhancement functions as used in CES [5] which itself is a novel characteristic of the proposed method.

B. Quantitative Evaluation

This section presents the quantitative evaluation of the proposed method along with its comparative analysis with CES [5]. Prior to the quantitative analysis we show the behaviour of contrast (C_n) and entropy ratio ($H_n^{'}$) for a DCT block with respect to the diagonal bands. Fig. 3. shows the behaviour of contrast and entropy ratio (i.e. statistical properties) with respect to the 14 diagonal bands. The AC coefficients utilized for this analysis are extracted from DCT block number # 330 of Image 16.

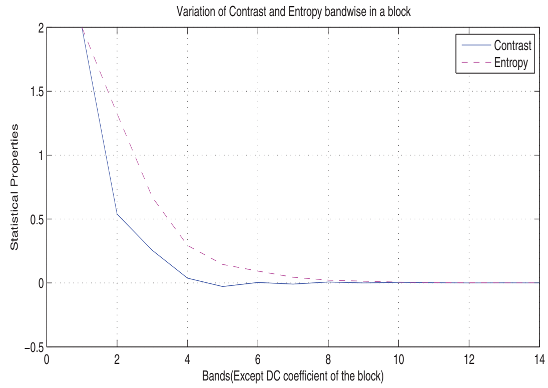

Fig. 3. Contrast and Entropy behaviour with respect to bands in one 8x8 DCT block. The DCT block chosen is # 330 from Image16.

As observed from Fig. 3. for the considered DCT block, the contrast closely follows entropy when diagonal band representation is utilized signifying that the maximum entropy and hence contrast is localized in the mid-range. This concept is exploited by us in choosing the AC scaling factor for a DCT block. This is also in-line with Tang et al. [7] interpretation of spectral bands having a multiscale structure. As mentioned earlier, this concept is exploited in the proposed method by taking the difference between $H_n^{'}$ and C_n followed by choosing the maximum value as a block scaling factor (Φ) for the AC coefficients.

We now present the quantitative evaluation of the proposed method. The Contrast Enhancement Factor (CEF) is chosen as a measurement metric for comparative analysis in order to maintain uniformity in comparison to CES work [5]. The Contrast Enhancement Factor is defined as below,

$$CEF = \frac{CM(I_{enhanced})}{CM(I_{original})} \tag{12}$$

where,

$$CM(I) = \sqrt{\sigma_\alpha^2 + \sigma_\beta^2} + 0.3\sqrt{\mu_\alpha^2 + \mu_\beta^2}$$

α and β are the channels which are estimated from the R, G and B components of the image, i.e. $\alpha = R - G$ and $\beta = ((R+G)/2) - B$. μ_α and σ_α are the mean and standard deviation of α channel, while μ_β and σ_β are the mean and standard deviation of β channel. As observed from Table I, the proposed method achieves higher CEF values as compared to CES work [5]. This is observed for all the tested images from CES [5] as well as UCID dataset. The improvement in CEF values has been possible due to utilization of the DCT block statistics in arriving at the scaling factor values. Although CES [5] achieves good results, yet our study shows that their choice of utilizing a single scaling factor for AC and DC coefficients combined with external enhancement function's is unable to capture the DCT block behaviour. On the contrary, the proposed method which although is inspired and motivated from their work, yet we adopt an altogether different strategy

TABLE I
CEF EVALUATION

IMAGE NAME	CES [5] method	proposed method
Image16	1.38	1.50
Image22	1.72	1.92
Image24	1.76	1.93
Ucid00196	1.46	1.69
Ucid00018	1.02	1.30
Ucid00095	1.40	1.78
Ucid00146	1.73	1.97
Ucid00470	1.42	1.76
Ucid00503	1.37	1.57
Ucid00564	1.38	1.49
Ucid00607	1.42	1.50
Ucid00609	1.58	1.86
Ucid00030	1.18	1.70
Ucid00155	1.74	1.92
Ucid01194	1.59	1.87

of capturing DCT block behaviour via modeling DC and AC coefficients separately and utilizing statistics of the DCT coefficients for selection of our scaling factors.

VI. Conclusion

This paper investigated a novel technique for image enhancement for JPEG compressed images. The presented method utilized statistical properties of DCT coefficients to estimate scaling factors which are utilized to calculate the enhanced image. The statistical analysis was carried out separately for DC coefficient and AC coefficients of a DCT block to arrive at two different scaling factors. Since the DC coefficient impacts the illumination, we choose coefficient of variation as a DC scaling factor while entropy of AC coefficients was utilized to arrive at an AC scaling factor. Experimental results show better results compared to an existing compressed domain technique which used uniform scaling factor for all coefficients along with using pre-defined external enhancement functions. Our future work is focused on utilizing the enhanced images for vision applications.

References

[1] D. Jobson, Z.-u. Rahman, and G. Woodell, "Properties and performance of a center/surround retinex," *IEEE Transactions on Image Processing*, vol. 6, no. 3, pp. 451–462, Mar 1997.

[2] H. Cheng and H. Xu, "A novel fuzzy logic approach to contrast enhancement," *Pattern Recognition*, vol. 33, no. 5, pp. 809 – 819, 2000.

[3] W.-M. Ke, C.-R. Chen, and C.-T. Chiu, "Bita/swce: Image enhancement with bilateral tone adjustment and saliency weighted contrast enhancement," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 21, no. 3, pp. 360–364, March 2011.

[4] T. Celik, "Spatial entropy-based global and local image contrast enhancement," *IEEE Transactions on Image Processing*, vol. 23, no. 12, pp. 5298–5308, Dec 2014.

[5] J. Mukherjee and S. Mitra, "Enhancement of color images by scaling the dct coefficients," *IEEE Transactions on Image Processing*, vol. 17, no. 10, pp. 1783–1794, Oct 2008.

[6] J. Tang, E. Peli, and S. Acton, "Image enhancement using a contrast measure in the compressed domain," *IEEE Signal Processing Letters*, vol. 10, no. 10, pp. 289–292, Oct 2003.

[7] J. Tang, J. Kim, and E. Peli, "Image enhancement in the jpeg domain for people with vision impairment," *IEEE Transactions on Biomedical Engineering*, vol. 51, no. 11, pp. 2013–2023, Nov 2004.

[8] S. Lee, "An efficient content-based image enhancement in the compressed domain using retinex theory," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 17, no. 2, pp. 199–213, Feb 2007.

[9] S. Aghagolzadeh and O. K. Ersoy, "Transform image enhancement," *Optical Engineering*, vol. 31, no. 3, pp. 614–626, 1992.

[10] J. Jiang and G. Feng, "The spatial relationship of dct coefficients between a block and its sub-blocks," *IEEE Transactions on Signal Processing*, vol. 50, no. 5, pp. 1160–1169, May 2002.

[11] R. Reininger and J. Gibson, "Distributions of the two-dimensional dct coefficients for images," *IEEE Transactions on Communications*, vol. 31, no. 6, pp. 835–839, Jun 1983.

[12] F. Muller, "Distribution shape of two-dimensional dct coefficients of natural images," *Electronics Letters*, vol. 29, no. 22, pp. 1935–1936, Oct 1993.

[13] E. Lam and J. Goodman, "A mathematical analysis of the dct coefficient distributions for images," *IEEE Transactions on Image Processing*, vol. 9, no. 10, pp. 1661–1666, Oct 2000.

[14] S. J. Sangwine and R. E. N. Horne, *The Colour Image Processing Handbook*. Horne, Eds. London, U.K.: Chapman & Hall, 1998.

[15] R. C. Gonzales and E. Woods, *Digital Image Processing*. Reading,MA: Addison-Wesley, 1992.

[16] G. Schaefer and M. Stich, "Ucid: an uncompressed color image database," in *Proc. SPIE*, vol. 5307, 2003, pp. 472–480.