ON THE USE OF COLOR APPEARANCE MODELING FOR EFFICIENT COMPRESSED-DOMAIN IMAGE ENHANCEMENT

Maria Chatzigiorgaki and Athanassios N. Skodras

School of Science and Technology, Hellenic Open University, 26222 Patras, Greece
mhatzi@ieee.org, skodras@ieee.org

ABSTRACT

In this paper we propose a compressed-domain image enhancement algorithm based on color appearance modeling. We aim at providing an efficient high-quality JPEG color image enhancement algorithm, in terms of color boosting and low computational cost. For that purpose, the high-performance recently proposed iCAM06 model has been adopted, where a wide range of color appearance phenomena are predicted in an efficient manner. In order to reduce the computational complexity, a pseudo-pixel extraction algorithm is applied to the four low-frequency DCT coefficients of each block, resulting in a scaled RGB version of the input image (directly in the DCT domain), where the iCAM06 model is then applied. To cope with the problem of inadequate information of small-sized images, as only 6.25% of the DCT coefficients are used, a 2-fold upsampling is performed at a preprocessing stage. The proposed algorithm outperforms relevant methods, as it is validated by the comparative results.

Index Terms— Compressed-domain enhancement, DCT, color appearance modeling, JPEG, image resizing, quality metrics

1. INTRODUCTION

Enhancement constitutes a fundamental process of image processing that aims at improving image's visual appearance [1]. Many image/video content analysis applications incorporate image enhancement at initial level, in order to improve their performance. Image segmentation is such an application, where enhancement as a preprocessing stage is common practice.

Generally, image enhancement methods can be categorized into *spatial-domain* methods, operating in the pixel domain and *frequency-domain* methods, where images are processed in the transform domain. As JPEG dominates the world market of imaging technology, the development of techniques regarding manipulation of images directly in their compressed form is an imperative need. To this direction, several compressed-domain enhancement methods have been proposed. Among them, those operating in the Discrete Cosine Transform (DCT) domain are of increased popularity, as DCT is the basis of JPEG and MPEG compression standards.

A first attempt to enhance images in the transform domain is reported in [2], where a simple method formally known as *alpha-rooting* is proposed. In this technique, the magnitude of each DCT coefficient is raised to a power α ($0.5 < \alpha < 0.99$). A *contrast measure* based approach used to measure the contrast of an image in the DCT domain was proposed by Tang *et al* [3]. The DCT coefficients of each 8x8 block are divided into 15 different frequency bands and a contrast value is calculated for each band. The contrast enhancement is accomplished by multiplying the coefficients of each band by the corresponding contrast value. It should be noted that both of the aforementioned methods have been designated for contrast enhancement of grayscale images and, more importantly, they do not modify the DC coefficients. A dynamic range compression and contrast enhancement algorithm was proposed by Lee in [4]. DC coefficients (representing illumination) are used for dynamic range compression, while AC coefficients (representing reflectance) are modified according to a spectral content measure of the image for contrast enhancement. Recently, Mukherjee *et al* [5] deal with the problem of compressed-domain image enhancement not only in terms of contrast and brightness, but also in terms of color preservation. Contrary to existing methods, the DCT coefficients of both luminance (Y) and chrominance (Cb, Cr) components are exploited, resulting in enhanced images of improved perceptual quality.

(a) Input image (b) Output image

Fig. 1. Illustrative example of an image rendered using iCAM06

The underlying idea of all the aforementioned methods is that the DCT coefficients of each 8x8 block are scaled by a particular *scale factor* (or enhancement factor). Mapping functions have been effectively used in [4] and [5] for the calculation of the appropriate scale factor(s). However, the performance of compressed-domain image enhancement methods is still not comparable to those of spatial-domain, mainly due to the difficulty in extracting contrast, brightness and especially color information, directly in the DCT domain. Despite the progress in the field, manipulation of information in its compressed form remains a great challenge.

Color appearance models [6] allow for the description of important attributes such as lightness, brightness, colorfulness, chroma, and hue. Image appearance models extend upon this to also predict attributes as sharpness, graininess, contrast, and resolution. The iCAM06 *image Color Appearance Model* [7] developed for High-Dynamic Range rendering provides a unified framework, where a wide range of color appearance phenomena are predicted in an

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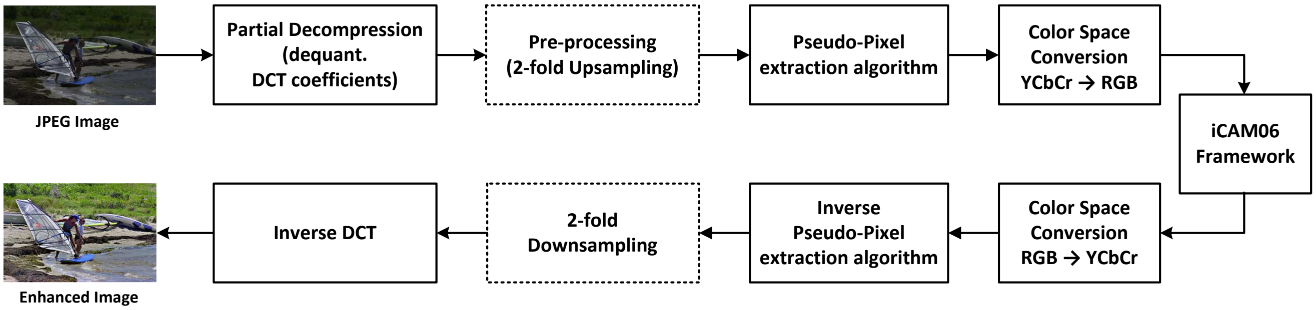


Fig. 2. Block diagram of the proposed compressed-domain color image enhancement method

efficient manner. An example of image rendering using iCAM06 model[1] is illustrated in figure 1.

Motivated by the high-quality performance enhancement of iCAM06, we propose a new method for color image enhancement directly in the DCT domain. The iCAM06 model is the basis for the proposed method, as enhancement is performed on a scaled RGB approximation of an input image, constructed from the low-frequency DCT coefficients of each block, as it is described in the following sections. Due to space limitations, the iCAM06 model is not described in this paper and the reader should refer to [7], while [6] constitutes a valuable resource of information regarding color appearance models.

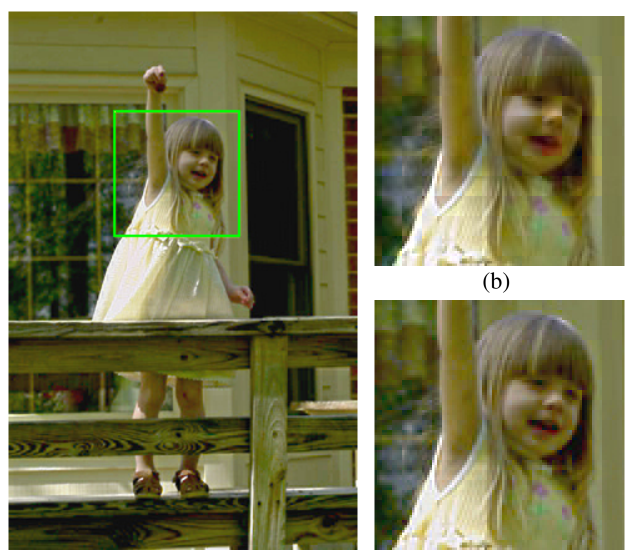
2. THE PROPOSED METHOD

The proposed method for compressed-domain enhancement consists of three major parts, namely the pre-processing stage of 2-fold image resizing directly in the block-DCT domain, the pseudo-pixel extraction algorithm and the iCAM06 framework.

Initially, a distorted JPEG image is partially decoded up to the stage of dequantization, where the dequantized DCT coefficients of the luminance Y and the chromaticity components Cb and Cr are derived, lying in the interval $[-1024, +1023]$. Next, the DC and the three (3) low-frequency AC coefficients in zig-zag order of each 8x8 block are exploited by a pseudo-pixel extraction algorithm [8], resulting in a four-times downsized version of the input image. By applying $YCbCr$ to RGB color conversion on the pseudo-pixel image, an RGB approximation image is derived directly in the frequency domain, using only the 6.25% of the DCT coefficients, while avoiding the time consuming inverse DCT. The actual enhancement is then performed at the final stage by application of the iCAM06 framework on the RGB approximation image. The inverse procedure is then followed, in order to get the enhanced image in its original size. A block diagram summarizing the proposed method is illustrated in figure 2.

Contrary to relevant methods, the size of the input image is an important factor in the proposed framework. Thus, small and large images are treated differently. Large images are usually distortion-free after applying a compressed-domain enhancement algorithm, due to the fact that the majority of the DCT blocks are uniform. Small images on the other hand are sensitive to many kinds of visual distortions (i.e discontinuities between neighboring blocks and visibility of blocking artifacts when contrast enhancement is performed), as each 8x8 block is processed independently to its adjacent ones. As the visibility of blocking artifacts has great impact on the perceptual quality of the enhanced images, a blocking artifacts suppression module is incorporated in the state-of-the-art algorithms in the field. Blocking artifacts suppression involves either smoothing of the DC enhancement factor of a block over four of its neighboring blocks [4], or sub-block decomposition of each 8x8 block [5] if the standard deviation σ of a block exceeds a predefined threshold value, where the enhancement algorithm is then applied on each 4x4 sub-block.

As only the four low-frequency DCT coefficients of each block are exploited by the proposed method, visual distortions appear in the resulting images due to inadequate (for the enhancement) amount of information conveyed in these coefficients. To cope with this problem, a pre-processing stage is incorporated in the proposed methodology, where images are 2-fold up-sampled directly in the DCT-domain, prior to the application of the pseudo-pixel algorithm. In this way the available information in the RGB approximation image is 4x increased, as well as elimination of blocking artifacts is achieved, leading to significantly improved enhanced images as it is illustrated in figure 3. In the case of large-sized images the pre-processing stage is bypassed.



(a) (b) (c)

Fig. 3. The effect of DCT-domain image resizing on the perceptual quality of **image15**: a) Enhanced image obtained by application the proposed method and a zoomed-in fragment of it obtained b) without 2-fold upsampling and c) with 2-fold upsampling

[1] MATLAB code available at: http://www.cis.rit.edu/mcsl/icam06/

2.1. Image resizing in the DCT domain

In the direction of retaining the computational cost in low levels, the *L/M-fold resizing* algorithm [9] was selected, due to the fact that no inverse DCT is needed. The main characteristic of the image resizing algorithm is the exploitation of the multiplication-convolution property of DCT, resulting in high-quality up/down-sized images. The symmetric-convolution filters $W_0(k)_{16}$ and $W_1(k)_{16}$ for the 2-fold up/down sampling used in our method, are reported in detail in [9].

2.2. Pseudo-pixel extraction algorithm

The pseudo-pixel extraction algorithm, originally proposed by Jiang *et al* [8], aims at providing a solution to the problem of color representation directly in the DCT domain. As it was already mentioned, an approximation RGB image can be extracted by exploiting only the DC and the three low-frequency AC coefficients of each 8x8 block. Due to space limitations, only the equations for the calculation of the 4 pseudo-pixel P values are presented (eq. 1), as well as those for the inverse procedure (eq. 2).

$$\begin{aligned} P_{00} &= (C_{00} + C_{10} + C_{01} + C_{11})/8 \\ P_{10} &= (C_{00} - C_{10} + C_{01} - C_{11})/8 \\ P_{01} &= (C_{00} + C_{10} - C_{01} - C_{11})/8 \\ P_{11} &= (C_{00} - C_{10} - C_{01} + C_{11})/8 \end{aligned} \tag{1}$$

$$\begin{aligned} C_{00} &= 2 * (P_{00} + P_{01} + P_{10} + P_{11}) \\ C_{01} &= 2 * (P_{00} - P_{01} + P_{10} - P_{11}) \\ C_{10} &= 2 * (P_{00} + P_{01} - P_{10} - P_{11}) \\ C_{11} &= 2 * (P_{00} - P_{01} - P_{10} + P_{11}) \end{aligned} \tag{2}$$

3. EXPERIMENTAL RESULTS

For the evaluation of the proposed method against several relevant methods in the field, a test JPEG image dataset from NASA Langley Research Center[2] was used. Ground truth set is also provided, containing the corresponding images processed by NASA using multi-scale Retinex with color restoration technology. These were served as reference images in our experiments. Additional to the original large image dataset, their small versions are available as well (distorted and reference images respectively). Following the same methodology as in [5], 21 JPEG color images of quality factor 100 and 4:4:4 sampling format from the small image dataset were selected for performance evaluation.

The performance of the proposed method was compared to that of three existing DCT-domain image enhancement algorithms, namely the *alpha-Rooting* [2], the *Contrast Measure*-based enhancement [3] and the *Color Enhancement by Scaling* (CES) [5] algorithm. Three variations of the latter are derived depending on the mapping function used, namely the TW-CES, DRC-CES and SF-CES algorithms, corresponding to $\tau(x)$, $\eta(x)$ and $\psi(x)$, respectively.

In the case of alpha-Rooting, the enhancement factor α was set equal to 0.98 and the image enhancement control factor λ of Contrast Measure-based technique was set equal to 1.95 according to [3]. As far as it concerns the CES algorithm, the baseline algorithm was implemented, i.e. without blocking artifacts suppression. The algorithm was tested using the three aforementioned mapping functions

[2]http://dragon.larc.nasa.gov/retinex/pao/news/

Table 1. Average Performance on SMALL IMAGES DATASET

METHOD	UQI [10]	SSIM [11]	JPQM [12]
alpha-Rooting [2]	0.8227	0.6922	**9.4107**
Contrast Measure [3]	0.6976	0.6752	7.5439
DRC-CES ($\eta(x)$) [5]	0.8710	0.7609	8.6905
SF-CES ($\psi(x)$) [5]	0.8773	0.7769	8.4310
TW-CES ($\tau(x)$) [5]	0.8974	0.8061	8.2024
Proposed method	**0.9435**	**0.8361**	7.8283
Spatial iCAM06	0.9445	0.8515	8.3807

(corresponding to TW-CES, DRC-CES and SF-CES) and the parameters were set equal to those reported in [5]. Finally, for the implementation of the proposed method, the parameters of iCAM06 were set as follows: $L_{max} = 20000$ (maximum luminance(cd/m^2)), $p = 0.9$ (overall contrast) and $\gamma = 1.5$.

Three state-of-the-art quality indices were used for perceptual quality evaluation, namely the *Universal Quality Index* (UQI) [10], the widely used *Structural SIMilarity* (SSIM) index [11] and the *JPEG Quality Metric* (JPQM) [12]. MATLAB implementations of the quality indices JPQM and UQI[3], as well as SSIM[4] are freely available. As the luminance component Y contributes the most information to the image and also constitutes on its own the grayscale representation of a color image, it was selected for performance evaluation. In particular, the Y component was obtained by the following pixel-wise transformation:

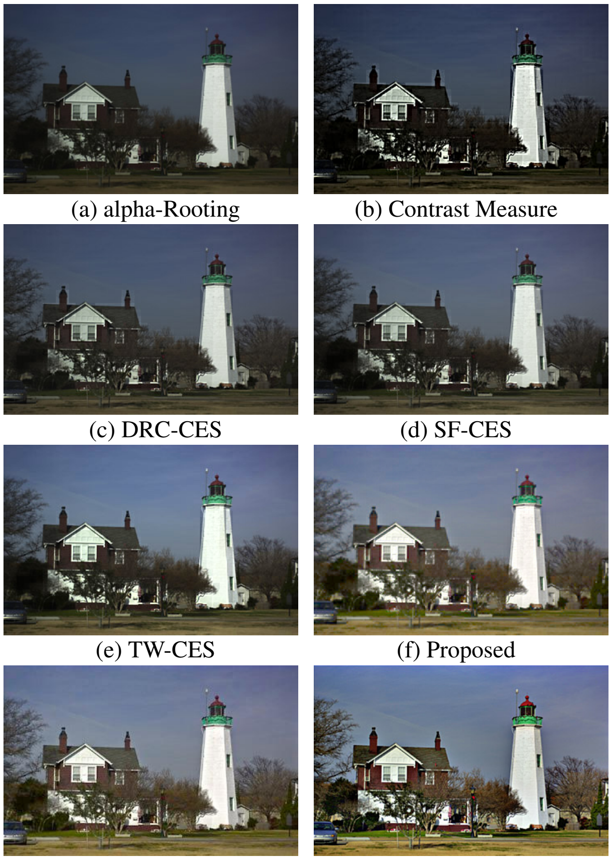
$$Y = 0.299R + 0.587G + 0.114B \tag{3}$$

The comparative results for the small-sized images are listed in table 1, where the average performance on the whole small images dataset for every quality index is presented. The comparative results reveal that the proposed method outperforms relevant ones in terms of UQI and SSIM indices. Surprisingly, poor performance is denoted in terms of JPQM metric, as our method performs only better than the Contrast Measure-based technique.

Additionally, as the key idea of the proposed method is the application of iCAM06 directly in the block DCT-domain, it would be interesting to be evaluated against the original (spatial-domain) iCAM06. The corresponding average values of the three indices are listed in the last row of table 1. Although the original iCAM06 outperforms our method as it was expected, however the quality indices indicate slight improvement (in terms of UQI and SSIM) by application of iCAM06 in the spatial domain.

An illustrative example for qualitative evaluation is provided in figure 4. It is observed that not only the proposed method results in perceptually better and more colorful images in comparison to existing methods, but also both spatial and DCT-domain iCAM06 result in visually very similar images, hard to distinguish. In figure 5, a more helpful in judgment, regarding the perceptual evaluation, illustrative example is presented. Two observations can be made. Firstly, due to the modification of only the 4 lowest-frequency DCT coefficients of each block by the proposed method, the visibility of blocking artifacts is poor. This can be explained by the fact that only the modification of higher frequency DCT coefficients (as happens with the methods compared to ours), expressing the details - textural

[3]JPQM and UQI: http://www.cns.nyu.edu/~zwang/
[4]SSIM: http://www.cns.nyu.edu/~lcv/ssim/



(a) alpha-Rooting (b) Contrast Measure

(c) DRC-CES (d) SF-CES

(e) TW-CES (f) Proposed

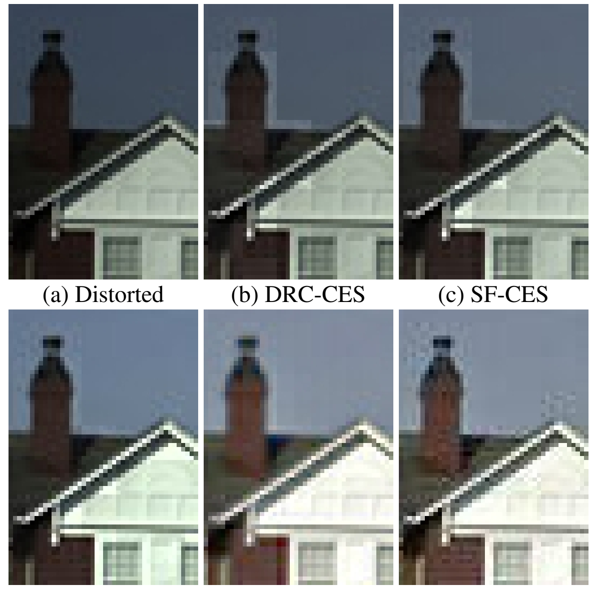
(g) Spatial iCAM06 (h) Reference

Fig. 4. Resulting images by application of various compressed-domain enhancement algorithms on the **image22**. Enhancement using: a) alpha-Rooting [2], b) Contrast Measure [3], c) DRC-CES ($\eta(x)$) [5], d) SF-CES ($\psi(x)$) [5], e) TW-CES ($\tau(x)$) [5], f) Proposed method and g) spatial-domain iCAM06, compared to the h) Reference image

information of a block, increases the visibility of blocking artifacts. Secondly, contrary to the proposed method, spatial-domain iCAM06 appears to have increased visibility of blocking artifacts, which is its major drawback. However, it should be noted that images of perfect quality (no blocking artifacts) are derived, in the case of large-sized dataset, by application of spatial-domain iCAM06.

4. CONCLUSIONS

In this paper we have presented an efficient compressed-domain image enhancement method, based on color appearance modeling. The recently proposed iCAM06 framework developed for HDR image rendering was incorporated in the proposed scheme due to its remarkable performance. By applying a pseudo-pixel extraction algorithm to the four low-frequency DCT coefficients of each block, a 4x down-scaled version of the original image is derived, where the iCAM06 framework is applied. The visual distortion in the resulting images, when the proposed method is applied to small-sized images, is eliminated by performing a 2-fold up-sampling, directly in the DCT domain, as a pre-processing stage. In this way, high-quality colorful enhanced images are derived, as it is validated by the comparative results with the state-of-the-art methods in the field.



(a) Distorted (b) DRC-CES (c) SF-CES

(d) TW-CES (e) Proposed (f) spatial iCAM06

Fig. 5. A zoomed-in fragment of **image22** enhanced by the methods in [5] (b)-(d), the proposed method (e) and the original (spatial-domain) iCAM06 (f)

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