Image Enhancement Using a Contrast Measure in the Compressed Domain

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***Abstract*—An image enhancement algorithm for images compressed using the JPEG standard is presented. The algorithm is based on a contrast measure defined within the discrete cosine transform (DCT) domain. The advantages of the psychophysically motivated algorithm are 1) the algorithm does not affect the compressibility of the original image because it enhances the images in the decompression stage and 2) the approach is characterized by low computational complexity. The proposed algorithm is applicable to any DCT-based image compression standard, such as JPEG, MPEG 2, and H. 261.**

***Index Terms*—Compressed domain, contrast measure, discrete cosine transform (DCT), human vision system, image enhancement, JPEG/MPEG.**

I. Introduction

THE GOAL of image enhancement is to improve the image quality so that the processed image is better than the original image for a specific application or set of objectives [1]. Many image enhancement algorithms have been proposed. One of the most widely used algorithms is global histogram equalization [1], which adjusts the intensity histogram to approximate a uniform distribution. The main disadvantage of global histogram equalization is that the global image properties may not be appropriately applied in a local context [2]. In fact, global histogram modification treats all regions of the image equally and, thus, often yields poor local performance in terms of detail preservation. Therefore, several local image enhancement algorithms have been introduced to improve enhancement [2]–[8]. Each of these algorithms can be classified into two types of image enhancement methods [4]: indirect image enhancement methods and direct image enhancement methods. The algorithms described in [2] and [3] belong to the class of indirect image contrast enhancement methods, since they enhance the image without measuring the contrast. The algorithms described in [4]–[8] are called direct local contrast enhancement methods because they establish a criterion of contrast measure and enhance the images by improving the contrast measurement directly.

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A key step in the direct image enhancement approach is the establishment of a suitable image contrast measure. For simple patterns, two definitions of contrast measure have been frequently used. One is the *Michelson contrast measure* [9]; the other is the *Weber contrast measure* (see [10]). The Michelson contrast measure is used to measure the contrast of a periodic pattern such as a sinusoidal grating, while the Weber contrast measure assumes a large uniform luminance background with a small test target. Both measures are therefore unsuitable for measuring the contrast in complex images. A number of contrast measures were proposed for complex images [5]–[7], [10], [11]. A local contrast measure is proposed in [6], where the contrast is measured using the mean gray values in two rectangular windows centered on a given pixel. Another contrast measure based on a local analysis of edges is defined in [7] and is derived from the definition in [6].

Because human contrast sensitivity is a function of spatial frequency, an image's spatial frequency content should be considered in the definition of contrast. The contrast measure proposed in [10] explicitly satisfies this requirement. That definition of local bandlimited contrast assigns a contrast value to every point in the image for each spatial frequency band. For each frequency band, contrast is defined as the ratio of the bandpass-filtered image at that frequency to the image lowpass-filtered to an octave below the same frequency. This multiscale contrast structure has found wide applications especially in image processing problems related to the human vision system [8], [10].

This letter provides a new contrast measure that can be used to measure the contrast of images in the DCT domain. The contrast measure is defined as the ratio of high-frequency content and low-frequency content in the bands of the DCT matrix. Like the contrast measure defined in [10], our contrast measure also has a multiscale structure that corresponds with the human vision system. Based on this contrast measure, an image enhancement algorithm for direct application to the compressed domain is developed. The basic idea of our algorithm is to filter the image by manipulating the DCT coefficients according to the contrast measure defined. The proposed algorithm has the following advantages: 1) the algorithm does not affect the compressibility of the original image; 2) given a majority of zero-valued DCT coefficients (after quantization), the algorithm expense is relatively low; and 3) the proposed image enhancement algorithm is applicable to any DCT-based image compression standard, such as JPEG, MPEG 2, and H. 261.

II. Image Contrast Enhancement in JPEG Domain

A. Preliminaries

A JPEG system is composed of an encoder and a decoder. In the encoder, the image is first divided into nonoverlapping

8×8 blocks. Then, the two-dimensional DCT is computed for each 8×8 block. Once the DCT coefficients are obtained, they are quantized using a specified quantization table. Quantization of the DCT coefficients is a lossy process, and in this step, many small coefficients (usually high frequency) are quantized to zeros. The zig-zag scan of the DCT matrix followed by entropy coding makes use of this property to lower the bit rate required to encode the coefficients. In the decoder, the compressed image is decoded and then dequantized by pointwise multiplication with the quantization table and inverse-DCT-transformed.

Let $\{x_{i,j}\}$ be an 8×8 block in the original image, and the DCT transform of it is $\{d_{k,l}\}$. The 2-DCT transformation is expressed as

$$d_{k,l} = \frac{c(k)c(l)}{4} \sum_{i=0}^{7} \sum_{j=0}^{7} x_{i,j} \cos\left(\frac{(2i+1)k\pi}{16}\right) \cos\left(\frac{(2j+1)l\pi}{16}\right) \tag{1}$$

where $k,\, l = 0, 1, \ldots, 7$, and

$$c(k) = \begin{cases} 1/\sqrt{2}, & \text{if } k = 0 \\ 1, & \text{otherwise.} \end{cases} \tag{2}$$

The DCT inverse transformation can be expressed as

$$x_{i,j} = \sum_{k=0}^{7} \sum_{l=0}^{7} \frac{c(k)c(l)}{4} d_{k,l} \cos\left(\frac{(2i+1)k\pi}{16}\right) \cos\left(\frac{(2j+1)l\pi}{16}\right) \tag{3}$$

where $i,\, j = 0, 1, \ldots, 7$.

From (3), we see that each $d_{k,l}$ represents the contribution corresponding to the klth waveform [12] and the coefficients $d_{k,l}$ in the output DCT block are arranged left to right, and top to bottom in order of increasing spatial frequencies in the horizontal and vertical spatial dimensions, respectively.

The spatial frequency properties of the DCT coefficients provide a natural way to define a contrast measure in the DCT domain. It is known that the human visual detection depends on the ratio between high-frequency and low-frequency content [10]. Thus, the contrast measure can be defined as the ratio of high- and low-frequency content in the bands of the DCT matrix.

We first classify the coefficients into 15 different frequency bands. The nth band is composed of the coefficients with $n = k + l$. A band defined by $n = k + l$ gives a diamond-shaped approximation to a circle and, thus, selects approximately equal radial frequencies. Therefore, the image block generated using (3) by retaining only one band can be thought of as the bandpass version of the original image block. As the band number increases, the frequency content of the bandpass image block corresponds with higher frequencies and, thus, creates a primitive multiscale structure. Our local contrast measure is defined on each band with band number more than 0. The contrast at the nth band ($n \geq 1$) is defined as

$$c_n = \frac{E_n}{\sum_{t=0}^{n-1} E_t} \tag{4}$$

where

$$E_t = \frac{\sum_{k+l=t} |d_{k,l}|}{N} \tag{5}$$

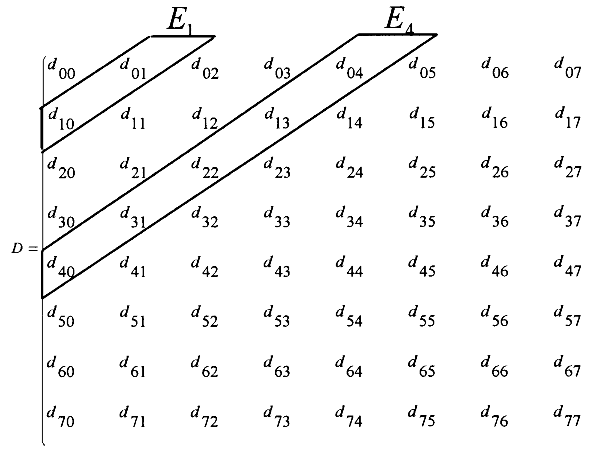


Fig. 1. DCT output block.

is the average amplitude over a spectral band. Fig. 1 illustrates the first and fourth bands and

$$N = \begin{cases} t + 1, & t < 8 \\ 14 - t + 1, & t \geq 8. \end{cases} \tag{6}$$

Here, for the sake of simplicity, we assume that visual acuity is isotropic.

The definition provides a local contrast measure for each band ($n \geq 1$) in the DCT domain. The contrast measure c_n in the nth band is the ratio of the frequency content of the bandpass image block obtained by the nth band and the frequency content of the lowpass image block that can be generated using (3) by retaining all of the bands in which the band numbers are less than n. Thus, the definition of our contrast measure has a multiscale structure similar to [5] and [10] in a primitive sense.

B. Image Enhancement in JPEG Domain

There are three ways to enhance the JPEG compressed images. The first is to enhance the image before compression. However, there are two disadvantages of this approach. One is that enhancement will reduce the compressibility of the original image; the other is that it will affect all the receivers. The second way is to enhance the image after decompression. Because the postcompression approach does not affect the compressibility of the original image, it is often adopted. In this letter, we consider direct enhancement in the compressed domain. The basic idea of this method is to enhance the image by manipulating the DCT coefficients. Compared with the image enhancement in the spatial domain, this method can reduce storage requirements and computational expense as the majority of the coefficients in the DCT domain are zeros after quantization.

The proposed image enhancement algorithm is based on the contrast measure proposed in Section II-A. Let the contrast of the original block be $C = (c_1, c_2, \ldots, c_{14})$, where c_n is the contrast at a specific frequency band corresponding to E_n and let the contrast of the enhanced block be denoted by $\bar{C} = (\bar{c}_1, \bar{c}_2, \ldots, \bar{c}_{14})$. If, for example, one wishes to enhance the contrast uniformly for all frequencies, then

$$\bar{c}_n = \lambda c_n \tag{7}$$

Fig. 2. Enhanced images using different algorithms. (a) Decompressed JPEG image. (b) Global histogram equalization. (c) Local histogram equalization [2]. (d) The proposed contrast-measure-based method with $\lambda = 1.95$.

leading to

$$\frac{\bar{E}_n}{\sum_{t=0}^{n-1} \bar{E}_t} = \bar{c}_n = \lambda c_n = \frac{\lambda E_n}{\sum_{t=0}^{n-1} E_t}. \qquad (8)$$

Equation (8) can be stated as

$$\bar{E}_n = \lambda H_n E_n, \qquad n \geq 1 \qquad (9)$$

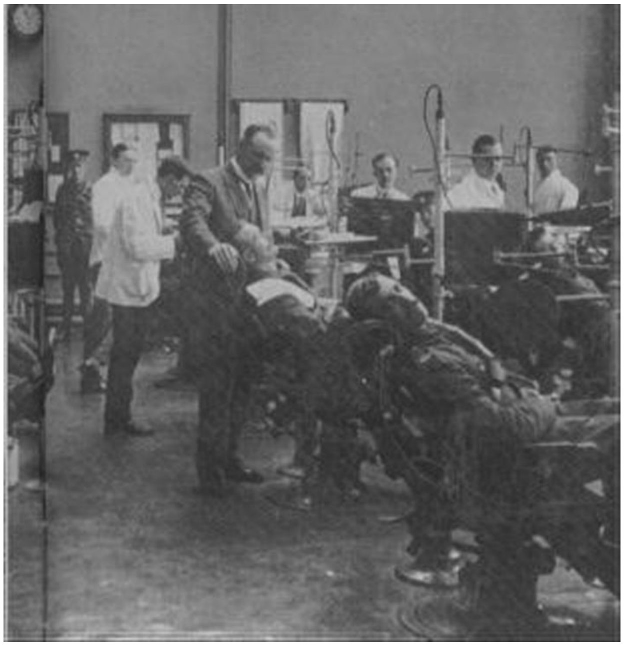
where

$$H_n = \frac{\sum_{t=0}^{n-1} \bar{E}_t}{\sum_{t=0}^{n-1} E_t}, \qquad n \geq 1. \qquad (10)$$

From (9), we can obtain the enhanced DCT coefficients $\bar{d}_{k,l}$ as

$$\bar{d}_{k,l} = \lambda H_{k+l} d_{k,l}, \qquad \mathrm{k} + l \geq 1. \qquad (11)$$

H_n $(n = 1, 2, \ldots, 14)$ can be obtained by recursion. The proposed algorithm can be summarized as follows.



(e)

Fig. 2. *(Continued)* Enhanced images using different algorithms. (e) Enhanced image using alpha-rooting algorithm with $\alpha = 0.98$.

Step 1. Let $n = 0$, $\bar{d}_{00} = d_{00}$ and

$$\bar{E}_0 = E_0 = |d_{00}|. \quad (12)$$

Step 2. Let $n = n + 1$ and use **(10)** to compute H_n.
Step 3. Use **(11)** to obtain $\bar{d}_{k,l}$ $(k + l = n)$.
Step 4. If $n < 14$, use **(5)** and **(9)** to compute E_n and $\bar{E}_n$, respectively. Else, end.
Step 5. Return to Step 2.

Here λ is an image enhancement control factor that is chosen by the user. When $\lambda > 1$, the image will be enhanced. When $\lambda < 1$, the image will be softened.

III. Experimental Results and Discussion

In the experiments provided here, a JPEG compressed image was used to evaluate the performance of the proposed algorithm. The decompressed image without enhancement is shown in Fig. 2(a). The input image has a gray resolution of eight bits. The size of the image is 256×256.

The enhanced images obtained by global histogram equalization, local histogram equalization [2] (with a window size of 30×30), and the proposed method are shown in Fig. 2(b)–(d), respectively. In Fig. 2(d), the value of enhancement factor λ $(= 1.95)$ was decided by a subjective test. When compared with the original image, the histogram equalization methods and the proposed method produced moderately enhanced images. However, in our judgment, the proposed method obtained an enhanced image with improved visual quality compared to both of the histogram equalization methods. With histogram equalizations, some regions appear overly darkened and others overly lightened [see Fig. 2(b) and (c)]. The visual quality of the enhanced image obtained by global histogram equalization is superior to that obtained by local histogram equalization as the local enhancement artificially overemphasizes local details.

In addition to the comparison between histogram equalization methods and the proposed algorithm, we also compared the proposed algorithm with another DCT-based enhancement method: the alpha-rooting algorithm [13], [14]. In this algorithm, the magnitude of each DCT coefficient is raised to a power α (α is a positive real number). Let $d_{k,l}$ be the DCT coefficients; the modified DCT coefficient $d'_{k,l}$ is expressed as [14]

$$d'_{k,l} = d_{k,l} \left| d_{k,l} \right|^{\alpha - 1}. \quad (13)$$

Fig. 2(e) displays the enhanced image by the alpha-rooting algorithm. The value of α used in our experiments is 0.98, which was obtained by a subjective test. Comparing the resultant image from the proposed method with the alpha-rooting algorithm, one can see that the image obtained with the contrast-measure-based method retains more detail than the image obtained with the alpha-rooting algorithm. The image obtained by the alpha-rooting algorithm is darker than the original image when observed on the screen; however, the printed version differs (the difference between the screen view and the printed version is due to the nonlinear gamma response of the monitor).

IV. Conclusion

In this letter, we have described an image contrast enhancement algorithm that is based on a contrast measure defined in the DCT domain. The comparative analysis between the proposed algorithm and two existing algorithms has shown the merit of the contrast measure-based approach.

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