Image Enhancement Using a Contrast Measure in the Compressed Domain

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Abstract

A new 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 proposed algorithm are: (1) The algorithm does not affect the compressibility of the original image because it enhances the images in the decompression stage. (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.

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1. Introduction

The goal of image enhancement is to improve the image quality so that the resultant image is better than the original image for a specific application or set of objectives. In the past, many researchers contributed to this field and many algorithms have been proposed. One of the most widely used algorithms is global histogram equalization [1], which adjusts the intensity histogram to conform to a uniform distribution. The main disadvantage of global histogram equalization is that the global image properties may not be appropriate in a local context. In fact, global histogram modification treats all regions of the image equally and often yields poor local performance. In response, several local image enhancement algorithms have been introduced to improve enhancement [2][3][4][5][6][7][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][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][5][6][7][8] are direct local contrast enhancement methods, because they establish a criterion of contrast measure and enhance the images by improving the contrast measurement directly.

The key step in the direct image enhancement approach is the establishment of a suitable image contrast measure. For simple patterns, two definitions of contrast measures have been proposed. One is the *Michelson contrast measure* [9]; the other is the *Weber contrast measure* [10]. *Michelson contrast* is used to measure a periodic pattern such as a sinusoidal grating, while the *Weber contrast* measure assumes a large background with a small test target. Both measures are unsuitable for measuring the contrast in complex images. Some contrast measures are also proposed for complex images [5][6][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. Derived from the definition in [6], another contrast measure based on a local analysis of edges is defined in [7].

We contend that because human contrast sensitivity is a function of spatial frequency; the spatial frequency contrast of an image should be considered in the definition of contrast. The contrast measure proposed in [10] satisfies this requirement. In [10], a definition of local band-limited contrast is proposed that assigns a contrast value to every point in the image as a function of the spatial frequency band. For each frequency, the contrast is defined as the ratio of the band-pass filtered image at that frequency to the low-pass filtered image to an octave below the same frequency. This contrast has multiscale structure and has found wide application especially in some image processing problems corresponding to human vision system [7] [10].

This paper provides a new contrast measure that can be used to measure the contrast of images in DCT domain. Similar to the contrast measure defined in [10], our measure contrast also has a multi-scale structure that corresponds 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 enhance 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. The proposed image enhancement algorithm is applicable to any DCT-based image compression standard, such as JPEG, MPEG 2 and H. 261**.**

The rest of the paper is organized as follows: Section 2 will focus on the definition of the new contrast measure and the associated image enhancement algorithm. Experimental results and discussion are given in Section 3. Finally, conclusions will be given in Section 4.

2. Image contrast enhancement in JPEG domain

2.1 Preliminaries

A JPEG system is composed of an encoder and a decoder. In the encoder, the image is first divided into non-overlapping 8×8 blocks. Then the two-dimensional DCT is computed for each 8×8 block. After the DCT coefficients are obtained, they are quantized using the specified quantization table. Quantization of the DCT coefficients is a lossy process, and in this step, many small AC coefficients are quantized to zeros. The zig-zag scan of the DCT matrix and entropy coding make use of this property to lower the bit rate required to encode the coefficients. In the decoder, the compressed image is decoded, dequantized by pointwise multiplication with the quantization table and inverse DCT transformed.

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

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

where k,l =0,1,…,7 and

$$c(k) = \begin{cases} \frac{1}{\sqrt{2}} & if \quad k=0 \\ 1 & otherwise \end{cases} \tag{2}$$

DCT has inverse transformation that can be expressed as

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

where i, j =0,1,…,7.

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

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

We first classify the coefficients into 15 different frequency bands. The n^{th} band is composed of the coefficients with $n = i + j$. These bands are similar in radial frequency but heterogeneous in orientation. Our local contrast measure is defined on each band. The contrast at the n^{th} band is defined as

$$C_n = \frac{E_n}{\sum_{i=0}^{n-1} E_i} \tag{4}$$

where

$$E_n = \frac{\sum_{i+j=n} \left| d_{i,j} \right|}{N} \tag{5}$$

is a spatial frequency band illustrated in Figure 1. and

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

The definition provides a local contrast measure for each band in DCT domain. The measure has a multi-scale structure similar to [5][10].

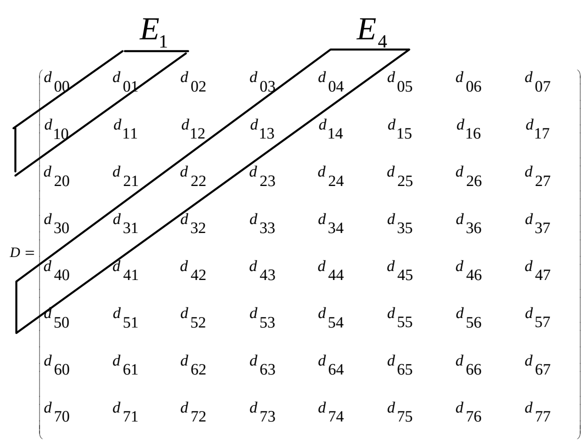


Figure 1. A DCT output block

2.2. Image enhancement in JPEG domain

There are usually three ways to enhance the JPEG compressed images. The first way is to enhance the image before compression. However, there are two disadvantages of this approach. One disadvantage is that enhancement will affect the compressibility of the original image; the other disadvantage of this approach is that it will affect all the receivers. The second way is to enhance the image after decompression. Because the post-compression approach does not affect the compressibility of the original image, it is often adopted. In the present paper, 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 requirement and computational expense as the majority of the coefficients in DCT domain are zeros after quantization.

The proposed image enhancement algorithm is based on the contrast measure proposed in Section 2.1. Let the contrast of the original block be $C=(c_1,c_2,...,c_{14})$, where c_i is the contrast at a specific frequency band E_i, and let the contrast of the enhanced block be denoted by $\overline{C}=(\overline{c}_1,\overline{c}_2,...,\overline{c}_{14})$. If, for example, one wishes to enhance the contrast uniformly for all frequencies, then

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

leading to

$$\frac{\overline{E}_n}{\sum_{k=0}^{n-1}\overline{E}_k}=\overline{c}_n=\lambda c_n=\frac{\lambda E_n}{\sum_{k=0}^{n-1}E_k} \tag{8}$$

(8) can be stated as

$$\overline{E}_n=\lambda H_n E_n \tag{9}$$

where

$$H_n=\frac{\sum_{i=0}^{n-1}\overline{E}_i}{\sum_{i=0}^{n-1}E_i}. \tag{10}$$

From (9), we can obtain the enhanced DCT coefficients $\overline{d}_{ij}$ as

$$\overline{d}_{ij}=\quad\lambda H_{i+j}d_{ij} \tag{11}$$

H_n can be obtained by recursion. The proposed algorithm can be summarized as follows:

<u>Step1</u>. Let *n*=0 and

$$\overline{E}_0=E_0=|d_{00}| \tag{12}$$

<u>Step 2</u>. Let *n*=*n*+1 and use (10) to compute H_n.

Step 3. Use (11) to obtain $\overline{d}_{ij}$ $(n = i + j)$.

Step 4. If n<15, use (5) to compute E_n and $\overline{E}_n$. Else, end.

Step 5 Return to Step 2.

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

3. 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 Figure 2. The input image had a gray resolution of eight bits. The size of the image was 256x256. It was a blurry image with complex features.

The enhanced images obtained by the histogram method and the proposed method are shown in Figures 3(a) and 3(b). Compared with the original image, both of the histogram method and the proposed method produced enhanced images. But the proposed method obtained an enhanced image with clearer details and better visual quality. With histogram equalization, some regions appear overly darkened and other overly lightened (see Figure 3(a)).

In addition to the comparison between histogram equalization and the proposed algorithm, we also compared the proposed algorithm with another enhancement method -- the alpha-rooting algorithm in DCT domain [13]. In this algorithm, the magnitude of each DCT coefficient is raised to a power α, where α is a positive real number. Let $d_{n,m}$ be the DCT coefficients, the modified DCT coefficient $d'_{n,m}$ is expressed as

$$d'_{n,m} = d(n,m)\left|d(n,m)\right|^{\alpha} \tag{13}$$

Figure 3(c) displays the enhanced image by the alpha-rooting algorithm. Comparing the resultant image from the proposed method with the alpha-rooting algorithm, we can find that the image computed from contrast measure based method has better visual quality than the resultant image with alpha-rooting algorithm. The alpha-rooting procedure yielded a “bleached” or over-whitened image in which brighter details are merged with the background and are thus effaced.

For quantitative comparison, we computed the average contrast in different bands in DCT domain of an image

$$\hat{c}_n = \frac{1}{N}\sum_{k=1}^{N} c_n^k \tag{14}$$

where n is the band number, N is the number of 8x8 blocks and c_n^k is the contrast of the n^{th} band of the k^{th} 8x8 block.

Figure 4 shows the average contrast of n bands of the decompressed images without enhancement and the enhanced images. Figure 4 shows that histogram equalization enhanced band 1, but did not enhance contrast in other bands. The performance measure explains why Figure 3(a) has improved brightness but not improved detail. From Figure 4, the alpha-rooting algorithm did not enhance contrast in any band.

4. Conclusion

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

References

[1] R. Hummel, "Histogram modification techniques", *Computer Graphics and Image Processing*, Vol. 4, pp. 209-224, 1975.

[2] J.A. Silva Centeno and V. Haertel, “An adaptive image enhancement algorithm”, *Pattern Recognition*, Vol.30, No.7,pp 1183-1189.

[3] A. Polesel, G. Ramponi and V.J. Mathews, “Image enhancement via Adaptive Unsharp Masking”, *IEEE Trans. Image Processing*, Vol. 9, No. 3, March 2000.

[4] H.D. Cheng and H. Xu, “A novel fuzzy logic approach to contrast enhancement”, *Pattern Recognition*, 33(2000), 809-819.

[5] A. Toet, "Multiscale contrast enhancement with applications to image fusion," *Optical Engineering*, Vol. 31, No.5 1992.

[6] *W. M. Morrow, R. B. Paranjape, R. M. Rangayyan, and J. E. L. Desautels,* “Region-based contrast Enhancement of Mammograms,” *IEEE Trans. On Medical Imaging*, vol.11(3), 1992.

[7] A. Beghcladi, and A. L. Negrate, “Contrast enhancement technique based on local detection of edges,” *Computer vision, Graphics, Image Processing*, vol. 46, 1989, pp.162-274.

[8] T. Zong, H. Lin, and T. Kao, “Adpative local contrast enhancement method for medical images displayed on a video monitor”, *Medical Engineering and Physics*, 22(2000) 79-87.

[9] A.A. Michelson, *Studies in Optics*, U. Chicago Press, Chicago, Ill., 1927.

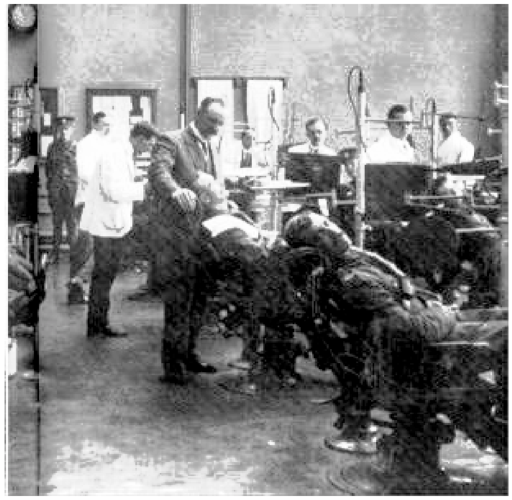
[10] E. Peli,"Contrast in complex images,". *J Optical Soc Am A*, 7:2032-2040, 1990.

[11] S.S. Agaian, K.P. Lentz, and A.M. Grigoryan, "A New Measure of Image Enhancement", *IASTED International Conference on Signal Processing & Communication*, Marbella, Spain, Sept. 2000.

[12] V. Bhaskara, K. Konstantides, *Image and Video Compression Standards: Algorithms and Architecture*, Kluwer Academic Publishers, 1995.

[13] H.C. Andrews, A. G. Tescher, and R. P. Kruger, “Image processing by digital computer”, IEEE Spectrum 9(7), 20-32 1972.

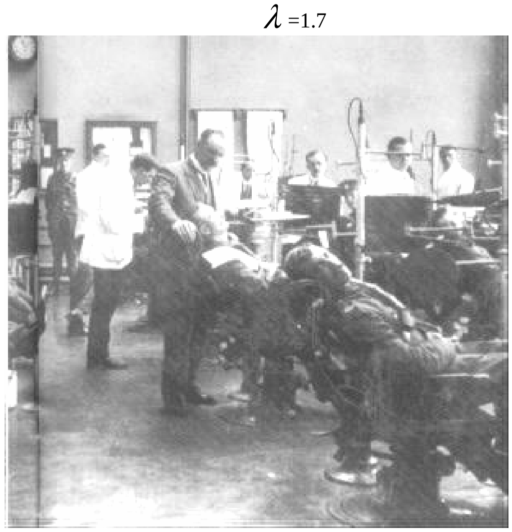
Figure 2. Decompressed JPEG image



(a) Histogram equalization

(b) The proposed contrast measure based method

λ =1.7



(c) Enhanced image using alpha-rooting algorithm

α **=0.5**

Figure 3. Enhanced images using three different algorithms

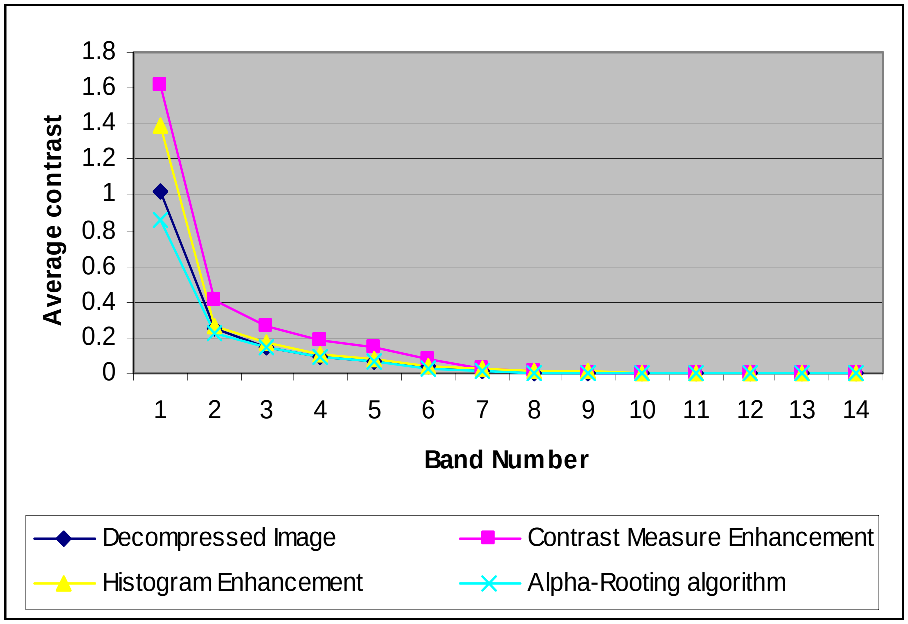


Figure 4. Comparison of average contrast for the decompressed image and enhancement results.