33.2: Image Enhancement in JPEG Domain for Low-Vision Patients

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Abstract

An image enhancement algorithm for low-vision television viewing was developed. The algorithm enhances the images in the JPEG/MPEG domain by weighting the quantization table. The advantages of our algorithm are threefold: (1) Low computation (only a change of the 8×8 quantization table in the decoding stage); (2) Suitable for real–time application; and (3) easily manipulated by individual users, because the enhancement level can be controlled at the receiver.

1. Introduction

Millions of Americans are visually impaired, and the number is expected to grow rapidly [1]. People with reduced visual acuity have difficulties reading small print, watching TV, etc. With the increasing importance of TV as a source of information and entertainment the need for image enhancement as a low vision aid is growing.

Previous work on image enhancement for low-vision was carried out in an uncompressed domain [2-4]. Images, including TV images, are frequently stored and transmitted in compressed format. Thus it's necessary to deal with decompressed images when applying image enhancement. Application of standard enhancement methods to decompressed images results in significant increase in block and other artifacts. This paper describes an enhancement concept for low vision applied directly in the compression domain. The proposed enhancement is based on using aspects of the JPEG protocol for image compression that are also applied in the MPEG protocol for moving images.

To enhance images compressed by JPEG, in the receiver we modify the Quantization Matrix sent with the images in ways that result in a desired spatial frequency filtering. This can be done by multiplying the entries in the quantization matrix received with images, point by point, with a new filter array. This results in the enhancement of the corresponding spatial frequency components during the decoding. This technique only requires access to the quantization matrix being received and the ability to modify it.

2. Enhancement in the JPEG Domain

2.1 General framework of the algorithm

In JPEG image compression [5][6], the image is divided into non-overlapping 8×8 image blocks. A two-dimensional DCT is computed for each block. The 8×8 DCT coefficients are quantized using a quantization table, Q, then losslessly coded and transmitted. In the receiver (Fig. 1) the compressed image is decoded and dequantized, using the quantization table Q that is transmitted with the compressed image, and then inverse DCT transformed to obtain the reconstructed block. The n-th output block of the dequantizer is denoted by Y^n and the n-th output block of the lossless decoder is denoted by Z^n.

The image enhancement algorithm operates in the decompression stage by weighting the quantization table Q with a pre-designed array to obtain a new quantization table Q' which includes the enhancement function.

2.2. Weighting of Quantization Table

2.2.1 Contrast measure of images in DCT domain

Image enhancement implies contrast modification and thus requires a measure of contrast. A contrast measure can be used to determine the parameters in an image enhancement algorithm [7] and an effective image enhancement algorithm can be obtained based on it [8].

For simple patterns, the Michelson and the Weber contrast measures have been used. These measures are only useful for measuring the contrast of simple patterns. Neither measure is suitable for measuring the contrast in complex images. Other contrast measures have been proposed for complex images [7][8][9][10]. A local contrast measure was proposed in [9], where the contrast was measured by the mean gray values in two rectangular windows centered on a pixel. Derived from the definition in [9], another contrast measure based on a local analysis of the edge gray level in the images was proposed in [8]. Human contrast sensitivity varies as a function of spatial frequency; therefore the spatial frequency content of an image should be considered in the definition of contrast. The contrast measures proposed in [10] and [11] satisfy this requirement. Peli [10] proposed a definition of local band-limited contrast in images 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 bandpass-filtered image at that frequency to the low-pass image filtered to an octave below the same frequency.

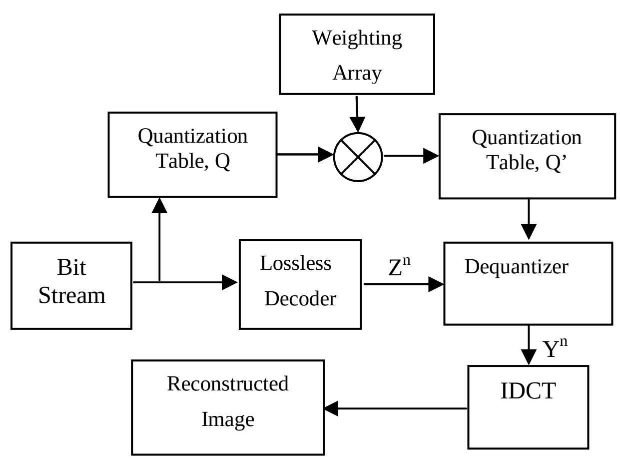

Figure 1. JPEG Decoder with image enhancement function Note ⊗ is a point-by-point multiplication.

Let D be an 8×8 block which is composed of DCT coefficients [5][6]

$$E_1 \qquad E_4$$

$$D = \begin{pmatrix} d_{00} & d_{01} & d_{02} & d_{03} & d_{04} & d_{05} & d_{06} & d_{07} \\ d_{10} & d_{11} & d_{12} & d_{13} & d_{14} & d_{15} & d_{16} & d_{17} \\ d_{20} & d_{21} & d_{22} & d_{23} & d_{24} & d_{25} & d_{26} & d_{27} \\ d_{30} & d_{31} & d_{32} & d_{33} & d_{34} & d_{35} & d_{36} & d_{37} \\ d_{40} & d_{41} & d_{42} & d_{43} & d_{44} & d_{45} & d_{46} & d_{47} \\ d_{50} & d_{51} & d_{52} & d_{53} & d_{54} & d_{55} & d_{56} & d_{57} \\ d_{60} & d_{61} & d_{62} & d_{63} & d_{64} & d_{65} & d_{66} & d_{67} \\ d_{70} & d_{71} & d_{72} & d_{73} & d_{74} & d_{75} & d_{76} & d_{77} \end{pmatrix} \tag{1}$$

where the $d_{i,j}$ are DCT coefficients. A corresponding local band-limited image contrast can be defined, following Peli [10], as

$$C_n = \frac{E_n}{\sum_{i=0}^{n-1} E_i} \qquad (1 \le n \le 14) \tag{2}$$

or following Toet [11] as

$$C_n = \frac{\sum_{i=0}^{n} E_i}{\sum_{i=0}^{n-1} E_i} \tag{3}$$

where

$$E_n = \frac{1}{N} \sum_{i+j=n} \left| d_{i,j} \right| \tag{4}$$

is a spatial frequency band illustrated in equation (1).

and

$$N = \begin{cases} n+1 & n < 8 \\ 14 - n + 1 & n \ge 8 \end{cases} \tag{5}$$

Here, for simplicity, we define a related contrast measure by

$$C_n = \frac{E_n}{E_{n-1}} \tag{6}$$

We adopted (6) as the definition of contrast measure, because, as shown below, it results in a very simple form of the function for uniform enhancement.

2.2.2 Contrast enhancement in the DCT domain

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 $\overline{C} = (\overline{c}_1, \overline{c}_2, ..., \overline{c}_{14})$. If for example one wishes to enhance the contrast uniformly for all frequencies, then

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

leading to

$$\frac{\overline{E}_n}{\overline{E}_{n-1}} = \overline{c}_n = \lambda c_n = \frac{\lambda E_n}{E_{n-1}} \tag{8}$$

which when rearranged, yields

$$\begin{aligned} \overline{E}_n &= \frac{\lambda E_n}{E_{n-1}} \overline{E}_{n-1} = \frac{\lambda E_n}{E_{n-1}} \frac{\lambda E_{n-1}}{E_{n-2}} \overline{E}_{n-2} \\ &= \lambda^2 \frac{E_n}{E_{n-2}} \overline{E}_{n-2} = \lambda^n \frac{E_n}{E_0} E_0 = \lambda^n E_n \end{aligned} \tag{9}$$

Thus the enhanced DCT coefficients $\overline{d}_{ij}$ are

$$\overline{d}_{ij} = \lambda^{i+j} d_{ij} \tag{10}$$

The above processing can be realized by weighting the quantization table Q.

$$\overline{q}_{ij} = \lambda^{i+j} q_{ij} \tag{11}$$

where q_{ij} are the elements of Q and $\overline{q}_{ij}$ are the elements of the modified quantization table Q'. Thus, the above processing requires only 64 multiplications [12] and can be implemented with a single parameter control.

2.3 Preliminary implementation

Initial experiments were performed on still frames of images obtained by digitizing directly and randomly from cable TV. The color NTSC images were digitized losslessly and were then compressed by a standard JPEG. Fig. 2a shows a sample of a compressed image used in our experiments. The PSNR of the image is 35.5 dB.

The images were enhanced by using the method described in section 2.2. The digital images were converted back to NTSC interlaced video format and were displayed on a TV monitor. The enhancement effects were evaluated visually. The level of enhancement was controlled by the factor λ. Examples of the enhanced images with two different λ values are shown in Figure 2 b and c.

Figure 2 illustrates how the enhancement can be adjusted by controlling a single parameter λ. This is particularly useful in our application, where, using a remote control, a low vision user can set the level of the enhancement to his preference and change it frequently depending on the type of images shown.

Simulation experiments were conducted with normally sighted observers wearing a pair of scattering glasses, simulating vision

Figure 2 a. The original decompressed image used, PSNR= 35.5 dB

Figure 2c. The image of fig2a enhanced with λ = 1.5. Higher levels of enhancement cause artifacts noted even by visually impaired people.

Figure 2b. The image of Fig. 2a enhanced with λ = 1.2. The effect of the enhancement as seen on the TV monitor is more dramatic than appears in print here (see PDF file).

Figure 2d. Enhanced image with one direction with λ=1.9. Note, many of the compression artifact seen in this prints are not visible on the screen display of this image

with moderate cataracts. With these glasses the observers could note obvious enhancement and improved perception of details

Significant flickering artifacts were noted when the enhanced images were shown on the TV (but not on computer display). This flickering was a result of field interlacing. While flickering artifacts in a single interlaced frame are well known to occur due to image motion between the two fields, these artifacts were noted also in images selected to have no or minimal motion. We observed that the artifacts occurred when the enhancement resulted in two abutting raster lines segments having high brightness. As these segments were refreshed consecutively they appeared to move or flicker. The effect is even stronger from the shorter observation distance typically used by low vision persons (1-2 ft). Since the artifacts appeared associated only with the enhancement of horizontal line segments we tested a variation of the enhancement in which horizontal line segments were not enhanced.

2.4. One-directional enhancement

Using the same formulation as above, a contrast enhancement in the vertical direction in the DCT domain is achieved by limiting the enhancement to the upper-right segment of the coefficients matrix using

$$\bar{d}_{ij} = \begin{cases} \lambda^{i+j} d_{i,j} & i \le j \\ d_{i,j} & i > j \end{cases} \quad (12)$$

Similar to the approach in section 2.2, this can be realized by weighting the quantization table.

Figure 2d shows the enhanced image using one directional enhancement. We found that by application of the vertical enhancement only, the flickering artifact was completely removed. The beneficial effect of the enhancement remains, although clearly some horizontal features are not enhanced.

3. Acknowledgements

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