HVS-Based Image Compression Scheme in Wavelet-Contourlet Domain

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Abstract

In this paper, we present an image compression scheme which exploits content-based quantization step considering the human visual system (HVS) in the Wavelet-Contourlet (DWT-CT) domain. Unlike usual DWT or CT algorithm, we decompose the image into DWT subbands followed by directional filters to account for the redundancy of the decomposition coefficients. We analyze the statistical property of the coefficients, and propose the adaptive quantization step according to the image content. Experimental results show that compared with the traditional EZW, the proposed scheme guarantees low compression ratio and distortion as well.

Keywords: Image Compression, Contourlet Transform, HVS, EZW

1. Introduction

In the information environment, a large number of digital images is represented, stored and transmitted in the digital form. As a result, it requires enormous storage capacity. Therefore, it is necessary to proceed digital image compression, which becomes one of the key technologies in multimedia information processing. Transform based image compression method currently is widely used, and in various transform algorithm, the wavelet transform is adopted by the international image compression standard JPEG 2000 [1], since its base functions of the limited support combined with its excellent ability to concentrate energy etc. However, as a special two-dimensional signal, digital image has its own characteristics which it is composed of the smooth regions with oblivious directions and the edges, textures with strong obvious directions. In many cases, the separable wavelet transform image representation is not efficient enough. The support area of its base function expands to the square, as a result, the base function does not possess multi-direction property, so a lot of coefficients with large energy will be produced. Under this background, the multi-scale geometric analysis for image was proposed, one of its aims is to be able to represent the image sparsely, and the transform is of the strong non-linear approximation ability [2]. Contourlet Transform proposed by Minh N. Do and Martin Vetterli is one of the most outstanding transformations, which makes use of the directional filters, and achieves not only the multi-resolution and time-frequency localization of Wavelet Transform, but also the more selectivity of direction in frequency domain [3]. Contourlet Transform has been applied in many fields, including image processing [4,5,6]. Eslamihe, Belbachir, Ahmed et al. proposed Contourlet-based image compression coding scheme [7-12]. However, due to the 4/3 redundancy of Laplacian pyramid decomposition, the transform coefficients increase significantly and affect the image compression. To eliminate redundancy, Eslami proposed Wavelet-Based Contourlet Transform (WBCT), and the SPIHT coding algorithm based on WBCT [13]. They proposed to comprise two stages of filter banks that are non-redundant and perfect reconstruction. Furthermore, they proposed a new image coding scheme using a new contourlet-based set partitioning in hierarchical trees (CSPHT) algorithm that provides an embedded code. Their experiments demonstrate that the proposed approach is efficient in coding images that possess mostly textures and contours. In addition, Yang et al. also proposed a SPIHT coding algorithm based on WBCT [14]. In their scheme, the wavelet transform is applied to original image, and the directional filter banks(DFB) are employed to middle and high frequency subbands. The encoding scheme is realized by the idea of SPIHT. Their experiment results show that the new image compression scheme performs better especially for low bit-rate and texture image.

But the above algorithms regard little the human visual characteristics and the redundancy of Contourlet transform coefficients, affecting the coding results. The paper presents a novel visually
lossless image compression coding scheme based on human visual system in Wavelet-Contourlet domain, which combines the wavelet filters and the statistical properties of Contourlet decomposition coefficients. Furthermore, combined with the contrast sensitivity function, the scheme exploits the human visual characteristics, and adopts the adaptive quantization step in the different frequency bands, resulting in the quantized coefficients can quantitatively reflect the human visual characteristics.

In this paper, we propose a novel composite domain image compression scheme employing DWT filters, directional filter banks and HVS. The outline of the rest of the paper is as follows. In section 2, the contourlet transform algorithm is mentioned, we analysis the statistical property of the DWT-CT coefficients further. In section 3, the human visual characteristics is presented, we give the sensitivity function. In section 4, we propose the novel scheme, where we exploit the adaptive quantization step according to the statistical property of the coefficients and HVS. In section 5, some experimental results are mentioned. Finally, conclusions are given.

2. Contourlet Transform (CT)

2.1 DFB and Laplacian Pramid

DWT provides the characteristics of multi-scale decomposition and time-frequency localization which facilities the representation of the 2-D natural image. However it can only offer the information in few directions, horizontal, vertical, diagonal and lowpass components. Unlike DWT, the CT coefficients are locally correlated due to the smoothness of the contours, which allows for different and flexible number of directions at each scale, and can obtain a sparse expansion for natural images by a double filter bank structure. CT is illustrated in Figure 1.

![Figure 1. Block diagram of CT](image)

In the structure, Laplacian Pyramid (LP) is used first for the multiresolution decomposition of the image to capture the point discontinuities, followed by a directional filter bank (DFB) to gather the nearby basis functions at the same scale and link point discontinuities into linear structures [15]. Finally, the image is represented as a set of directional subbands at multiple scales.

Composed of lowpass filtering and downsampling, LP is indeed the high frequency components of the Gaussian Pyramid (GP) at the same scale, namely, the detailed parts of the image. LP image can be obtained by subtracting the two neighbouring images in GP. Generally, we need to expand the finer scale image to the coarser scale, that is, perform the interpolation to the rows and columns of the image, afterwards, the interpolated results through a lowpass filter will subtract the image at the coarser scale. The reconstruction of LP is the inverse of the decomposition.

Suppose the image \( I \in L_2(\mathbb{R}^2) \), LP in CT uses orthogonal filters and downsampling by 2 in each dimension, the \( l \)-level of LP decomposes \( I \) into a coarser image \( V_j \) and a sequence of detail image \( W_j \), where \( V_j \) is the approximation subspace at the scale \( l (l = 2^l) \), which provides the multiresolution subspaces \( V_j = \cdots \subset V_3 \subset V_2 \subset V_1 \subset V_0 \), whereas \( W_j \) contains the details in the neighbouring level, that is, \( V_{j-1} = V_j \oplus W_j \). So \( I \) can be denoted as
The directional filter bank (DFB) is generally implemented via an $l$-level binary tree decomposition that leads to $2^l$ subbands with wedge-shaped frequency partition as shown in Figure 2 (3 levels, 4, 8, 8 directions in each level respectively).

\[ L_2(\mathbb{R}^2) = V_j \oplus \bigoplus_{j=0}^{l} W_j \]  

(1)

In CT, the DFB partition further $W_j$ from LP. The results are detailed subbands in multiple directions.

\[ W_j = \bigoplus_{k=0}^{2^j-1} W_{j,k}^l, (j, k) \in \mathbb{Z}^2 \]  

(2)

Figure 3 shows an example of CT on the “Lena” image.

Figure 2. Frequency partition in CT

Figure 3. Decomposition of Lena using CT
The image is decomposed into a lowpass subband and a set of directional subbands. We notice that CT effectively represents the true image where edges are localized in both location and direction.

2.2 Wavelet-Contourlet coefficients statistical properties

Establishing an accurate mathematical statistical model for Wavelet-Contourlet coefficients constitutes the foundation of designing the optimal image compression algorithms. By analyzing the histogram of Wavelet-Contourlet transform coefficients in the finest subband for Lena which adopts 2-level and 8-direction decomposition, we conclude that the probability distribution of sub-band coefficients in the zero point is at a very sharp peak and the peak of the two side is of a heavy tail, which is not similar with the Gaussian statistical distribution. In signal processing, usually kurtosis is adopted to measure the Gaussian property of the signal, the kurtosis of the Gaussian signal is equal to 3, whereas the kurtosis of Lena image decomposed through Wavelet-Contourlet transform is 46, far higher than the Gaussian signal, so the Gaussian distribution can not be used to approximate the statistical properties of the signal. In the paper, we exploit the generalized Gaussian distribution (GGD). Assume that Wavelet-Contourlet decomposition coefficients satisfy the GGD, we compute the mean value, \( \alpha \), and \( \beta \).

\[
f_x(x) = A \exp\left(-\beta x^\alpha\right)
\]

(3)

Where \( A = \frac{\beta c}{2 \Gamma(1/c)} \), \( \beta = \frac{1}{\sigma} \sqrt{\Gamma(3/c)/\Gamma(1/c)} \), \( \Gamma(z) = \int_0^\infty e^{-t^{1/c}+zt} dt \), \( (z > 0) \). \( \sigma \) represents the standard deviation, and \( c \) denotes the shaping coefficient.

The results show that the distribution fits the statistical characteristics of the decomposition coefficients well. Finally, we calculate the Kullback-Leibler distance further to validate the hypothesis of GGD statistical models.

3 Analysis of the human visual characteristics

The traditional coding techniques is limited to remove the statistical redundancy in the image data, ignoring inner mechanism of the human visual system in the observing image, with little regard to the observer's visual redundancy. The information imperceptive or not easy to be perceptive by the human eyes is redundant, and the removal of these redundant can improve the compression ratio further. On the contrary, preserving the information sensitive to human eyes can improve the subjective quality of recovered images.

Study on Human visual system (HVS) showed that the sensitivity to the human eyes varies with different frequency \([16,17] \). The sensitivity in the frequency above a certain frequency is lower than that of the relatively low frequencies. Furthermore, sensitivity differs in the different directions and the diagonal direction is usually the least sensitive.

Many algorithms have been proposed to characterize the human visual perceptible characteristics. Mannos et al. proposed the famous contrast sensitivity function (CSF) model, which describes the sensitive nature of the human eyes to the spatial frequency. CSF is expressed as follows:

\[
H(f) = 2.6(0.192 + 0.114 f) \exp\left[-(0.114 f)^{1.1}\right]
\]

(4)

Where \( f \) represents spatial frequency, \( f = (f_x^2 + f_y^2)^{0.5} \). \( f_x, f_y \) denotes the horizontal and vertical frequency respectively. The 1-dimension CSF curve is shown in figure 4, which shows that the sensitivity is highest at middle-low frequency and with the frequency increases, the sensitivity drops gradually.
4 Image compression algorithm based on human visual model in the Wavelet-Contourlet domain

In the proposed coding scheme, we make use of a decomposition strategy in the composite domain, where the original image is decomposed by wavelet transform, followed by direction decomposition for the middle-high frequency wavelet subbands. In the first step, it overcomes the 4/3 redundancy of the CT coefficients by using nonredundant wavelet filters instead of LP. The procedure of wavelet decomposition followed by direction decomposition reduces the redundancy efficiently.

We carried on a large number of experiments, whose results show that the image transformed by Wavelet-Contourlet gathered most energy at the low frequency, and the energy at the directional high frequency is relatively small, which corresponds to the image texture and detail information. Since the human eyes are more sensitive to the low frequency data, usually a smaller or no quantization step is adopted to ensure the visual quality of the recovered image. As a result, the compression effect mainly relies on the quantization of the high frequency data.

Till now, the quantization of high frequency data is classified two main categories. The first one uses a unified quantization step, where all the coefficients are divided by a same step. The second one uses stair-step quantization step, where according to human visual characteristics, the quantization step is increased with the increasing frequency.

Combined with the energy distribution and visual characteristics, we adopt adaptive quantization step for Wavelet-Contourlet coefficients in different directional subbands. We determine the quantization step due to the following factors:

In the different directional subbands at the same decomposition level, the energy in the neighboring horizontal is close to that in the neighboring vertical subband and the energy in the neighboring diagonal subband is relatively smaller, which fits the directional sensitivity. However, for the image with high texture, the energy increases first and then decreases from low frequency to highest frequency in the same direction at different decomposition level, which does not fit the nature of the CSF. Hence, increasing the quantization step in various levels will lose a lot of energy at the middle frequency. As a result, we decrease quantization factor at the middle frequency, preserving the information to recover the texture in the reconstructed image.

We present a novel EZW compression scheme based on HVS in the composite Wavelet-Contourlet domain.

In the EZW algorithm, each subband is treated at the initial approach, producing the visual redundancy due to the different visual sensitivity [18]. Unlike the traditional EZW algorithm, before the primary search, each pixel is divided by the energy weight in the subband to generate a new coefficients matrix, where energy weight changes the quantization step according to the frequency characteristics, and then on this basis, the primary search and the secondary search are proceeded to establish the primary table and secondary tables, reducing the range of coefficients. As a result, the system coding sequence becomes shorter.
5 Experimental Results

To evaluate the performance of the proposed scheme, a large number of experiments were carried out. The original image was 512×512 gray scale Lena image with 8 pixels/bit. The Lena image was transformed by DWT followed by CT using ‘pkva’ directional filter to obtain a 2-level decomposition. Experimental results are shown in figure 5.

The performance comparison is shown in table 1.

**Table 1. Performance Comparison**

<table>
<thead>
<tr>
<th></th>
<th>EZW</th>
<th>Proposed Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lena</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Compression ratio</td>
<td>Distortion</td>
</tr>
<tr>
<td></td>
<td>93.192%</td>
<td>0.117</td>
</tr>
<tr>
<td></td>
<td>79.683%</td>
<td>0.268</td>
</tr>
<tr>
<td>Tire</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Compression ratio</td>
<td>Distortion</td>
</tr>
<tr>
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<td>92.008%</td>
<td>0.149</td>
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<tr>
<td></td>
<td>57.405%</td>
<td>0.345</td>
</tr>
</tbody>
</table>

From the table 1, The performance of our scheme is also a great improvement to the traditional EZW scheme.

**Conclusion and future work**

In this paper, we adopt the HVS in the Wavelet-Contourlet domain. We exploit the frequency sensitivity model, and adopt variable quantization step to the decomposition coefficients, resulting in the coefficients fitting HVS well and preserving the frequency-sensitive information. The experimental results show that the proposed scheme enhances the compression ratio while improving visual quality. The key idea of the proposed algorithm is the combination of the HVS in the composite Wavelet-Contourlet domain. First of all, the accuracy of modeling HVS influences the quantization step. Secondly, How to make use of the Wavelet decomposition filters and based on them, to apply the Contourlet directional filters constitutes the foundation of the proposed scheme. Furthermore, the proposed scheme is based on the EZW algorithm, further work of integrating the characteristics of other image compression algorithms such as SPIHT, SPECK algorithms into our approach is in progress.
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