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A Novel Computational Model for Transform Coding of Colour Images with Orthogonal Polynomials in difference Colour Spaces

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ABSTRACT: In this paper, a new computational model for transform coding of colour images based on a set of orthogonal polynomials is proposed in different colour spaces. Initially, a three dimensional point spread operator is devised from a set of orthogonal polynomials and a linear transformation is defined in terms of matrix operation that takes less computation time. The proposed model is configured to take not only the interactions in the individual colour planes but also takes into account interactions between the colour planes. Based on the energy grouping property of orthogonal polynomials transform, the single dimensional energy vectors generated by point spread operator of proposed transform coding are rearranged so that the high energy transformed coefficients are grouped to yield higher compression ratio. After the proposed transformation, the transform coefficients of the colour images are subjected to quantization and entropy coding with a new nipple-dictionary substitution technique. The performance of the proposed colour image transform coding is reported by computing the peak-signal-to-noise ratio and is compared with DCT and wavelet based coding schemes. The proposed model is experimented in RGB colour space and extended to different colour spaces such as YC_bC_r, YIQ, XYZ and HSI models.

KEYWORDS: Orthogonal Polynomials, Quality Factor, Nipple-Dictionary Substitution, Colour Spaces**.**

I. INTRODUCTION

Image compression plays a significant role in many multimedia applications, such as image storage and transmission. The basic goal of compression is to represent an image with minimum number of bits of an acceptable image quality. In general, the compression scheme is classified as: lossless and lossy. The lossless compression scheme reproduces the same original data without any loss of information and is preferred in applications such as medical image compression. In the lossy compression scheme, the approximation of the original data can be obtained at a higher compression rate and is favored in multimedia applications. Techniques in the art of compressing 2-D image data can be classified into two categories: i) time-domain (or space domain) encoding and ii) transform domain coding. The time domain techniques that appear practical are mostly of the prediction-compression type. This includes schemes like delta modulation and differential pulse code modulation [1]. The transform coding schemes are proved to be an effective image compression scheme and is the basis of all world standards for lossy compression [2]. These transforms being unitary, conserve the signal energy in the transform domain, but typically most of this energy is concentrated in relatively few samples which are usually the lower frequency samples. The simple and powerful class of transform coding is linear block transform coding, where the entire image is partitioned into a number of non-overlapping blocks and then the transformation is applied to yield transform coefficients. This is necessitated because of the fact that the original pixel values of the input image are highly correlated [2]. Compression is achieved by considering the high energy samples to be sufficient for reconstruction subsequent to transmission, storage or processing. The international compression standards JPEG [3] and JPEG2000 [4] use the Discrete Cosine Transformation [5,6] and wavelet transform [7,8] respectively for image coding. In the early works on monochrome image compression, utilization of other transforms such as Haar [9], Slant [10], K. L Transformation [11, 12], Hadamard [13], Walsh [14] and Orthogonal Polynomials based transform Coding [15] are also reported and hence it is concluded that the choice of

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transform plays a significant role in image coding.

II. RELATED WORK

The general design procedure for the colour image transform coding system [16] consists of i) the selection of colour coordinate conversion matrix, ii) the choice of unitary transform for each colour signal plane and iii) the specification of the quantization law for transform samples. Gharavi et. al. [17] have proposed the YIQ coordinate conversion before applying transformation for colour image compression. Another approach for the lossy compression of colour images with limited palette using YC_bC_r and DCT transform coding is reported by Zaccarin et. al.[18]. Different coordinate system for colour-coordinate conversion of colour images were reported by Pratt [19], and concluded that K.L Transform conversion provides a reasonably good energy compaction with YIQ coordinate system. Reversible integer Discrete Cosine Transform is employed in [20], for both lossy and lossless compression. The reversible DCT coefficients are reorganized into sub-band structure, and then coded by context-based block coding. Athar Ali Moinuddin et. al.[21] reported a wavelet transform based coding, in which the set partitioning strategies of trees and blocks are integrated into single algorithm and applied for image transformation. The correlation among three colour components is explored in [22], where green component is coded using SPIHT algorithm and other two components are encoded with the correlation vectors calculated between three components in the same sub region. The coding of colour image is usually deduced from the coding of grayscale, and not much research works have been devoted on colour image coding. Recently few colour image coding based on wavelet transforms are reported [23-25] wherein transformation is applied on three individual colour planes separately. In these woks, the inter-correlation property of three colour planes are not considered and encoded as if there are three monochrome images. Ricardo L. De Queiroz [26] introduced a method to devise a colour transform for compression that takes into account the spatial correlation of the image planes. The transform aims at decorrelating the colour planes of multispectral image data, while increasing the spatial correlation within each plane. But in the case of colour image compression, it is not only sufficient to take the individual colour planes, but also the interactions between the colour planes.

Motivated by the fact that transformations play a significant role in colour image coding, and to utilize the interactions between colour planes, in this paper, a new Orthogonal Polynomials based transform coding is proposed that takes the advantage of decorrelation, energy compaction and the interactions in the three individual colour planes as well as among the colour planes. The proposed coding scheme has resulted from our earlier investigations into some low level feature extraction problems such as detection of textures and edges, in monochrome and colour images [27-29]. In another work, we have designed a coding scheme that separates significant signal components from the noise, with the help of statistical design of experiments approach [30]. In this present work, a computational model has been devised that takes into account the interactions in the three individual colour planes as well as the interactions between the colour planes in the Orthogonal Polynomials model and is utilized to propose a colour image coding technique.

This paper is organized as follows: The Orthogonal Polynomials model and basis operator reported in our earlier work [31] is extended here for transform coding in difference colour spaces. The framework for transform coding of colour images is presented in section III. The quantization and entropy coding of transformed coefficients is explained in section IV. The performance analysis and evaluation of the proposed compression scheme is given in section V. The experimental results are presented in section VI. In this section the proposed scheme is also compared with existing DCT and wavelet based compression schemes and also tested in various colour spaces. Finally, section VII concludes the paper.

III. FRAMEWORK FOR COLOUR IMAGE TRANSFORM CODING

As the observed gray level $I(x, y, z)$ at any pixel in an $(n \times n \times n)$ image region, where x and y are two spatial coordinates and z the colour coordinate, may be considered as a random variate, the occurrences of gray levels in that region can be thought of as yields of an n^3 factorial experiment where the two factors are for spatial coordinates and the third for colour coordinate considered at n different levels. Hence,

$$I(x, y, z) = g(x, y, z) + \eta(x, y, z) \qquad \dots (1)$$

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where $g(x,y,z)$ accounts for meaningful variation in $I(x,y,z)$ due to discriminable low level features such as colour edge and colour texture and $\eta(x,y,z)$ is the spatial/colour variation due to unexpected sources which may be called noise. At different pixels, we consider $\eta(x,y,z)$ as independent normally distributed variates with zero mean and constant variance σ_η^2. The meaningful spatial variation $g(x,y,z)$ can be parameterized into two different forms for two major classes of colour image regions, namely, colour edge response in untextured regions and colour texture response in the case of textured regions.

In order to parameterize the spatial variation $g(x,y,z)$ either in the form of edge or texture in the colour image, we assume that colour image regions with edges or texture have gray level variations as a class of orthogonal polynomial functions of the two spatial coordinates and the colour coordinates. Next we represent each of the two classes, namely, colour edge and colour texture, in terms of amplitude responses of a suitably chosen set of polynomial operators. Let $\Phi = \{O_{ijk},\ \ i,j,k = 0,1,2,\ldots,n-1\}$ denote the polynomial basis, where O_{ijk} are polynomial operators. It has been already established in [28], that Φ_L a proper subset of Φ is sufficient to represent uniquely any member of any of two classes C_L colour edge or colour texture. We may characterize in the absence of noise, the gray level variation of C_L by

$$g_L(x,y,z) = \sum\sum\sum\nolimits_{O_{ijk}\in\Phi_L} Z_{ijk}.O_{ijk}(x,y,z) \qquad \ldots (2)$$

In the presence of noise the observed gray level variation of C_L may be expressed as

$$I(x,y,z) = \sum\sum\sum\nolimits_{O_{ijk}\in\Phi_L} Z_{ijk}.O_{ijk}(x,y,z) + \sum\sum\sum\nolimits_{O_{ijk}\notin\Phi_L} Z_{ijk}.O_{ijk}(x,y,z) \qquad \ldots (3)$$

$$= \hat{g}(x,y,z) + \hat{\eta}(x,y,z)$$

where Z_{ijk} is the amplitude response per unit length of the polynomial operator O_{ijk}. The Z_{ijk} is obtained by convolving the $(n\times n\times n)$ image region with O_{ijk}. Since Φ is a orthogonal basis, $\hat{g}$ and $\hat{\eta}$ in equation (16) are linearly independent. It can also be shown that each $Z_{ijk} : O_{ijk} \notin \Phi_L$ has an expected value zero and variance σ_η^2. Since for an $(n\times n\times n)$ image region the observations of gray level variation have a total n^3 degrees of freedom of which 1^0 of freedom is accounted for $\sqrt{n}Z_{000}$, the DC component each of the remaining (n^3-1) independent Z_{ijk}^2 is a $\chi^2\sigma_\eta^2$ variate with 1^0 of freedom. As per the statistical design of experiments paradigm we may caldl Z_{ijk}^2, the estimates of orthogonal effect and variation due to the polynomials source O_{ijk}.

IV. QUANTIZATION AND CODING

It can be observed from equation (5), that the proposed Orthogonal Polynomials model produces the transform coefficients in one dimensional dictionary sequence for the corresponding RGB input image blocks that takes care of individual colour planes as well as interactions among the colour planes. Now, we need to code efficiently the transform coefficients of the colour image regions for transmission, storage or processing. Due to the unitary property of proposed transformation, most of the signal energy is concentrated into few low frequency samples, which are observed to be lower frequency samples. Since the output of the polynomial transformation viz., the transform coefficients require more space to store its values, quantization is applied to reduce the number of bits needed to store the transformed coefficient values by reducing the precision. In this work the quantization is implemented using simple quantum values and is given as follows:

$$\textit{Quantized Value}_{ij} = round\left[\frac{OPT_{ij}}{Quantum_{ij}}\right] \qquad \ldots (4)$$

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where OPT_{ij} is the transformed matrix obtained with the proposed orthogonal polynomials transform and $Quantum_{ij}$ is generated with the formula:

$$Quantum_{ij} = 1 + \left((1 + i + j) \frac{(100 - quality\_factor)}{100} \right) \quad \ldots (5)$$

where $quality\_factor$ is an user input that ranges from 100 to 1 that represents full quality to lowest quality. It is made adaptive and depends upon the amount of quality required in the reconstructed image and compression ratio. As the $quality\_factor$ value decreases, the compression ratio increases but with reduced quality of reconstructed image. The $quality\_factor$ is chosen in such a way that it can discard higher frequency coefficients gracefully.

Additional lossless compression is achieved by rearranging the quantized coefficients based on energy grouping followed by entropy coding with a new nipple-dictionary substitution technique. It is observed that the point spread operation of the proposed transform distributes the high energy values in equal intervals in the one dimensional quantized co-efficients β_{ijk} . These energy information are grouped using $Interval$, which is given by

$$Interval = \frac{(height + width)}{2} \quad \ldots (6)$$

where the $height$ and $width$ represent the block $height$ and $width$ values of the image segment. The rearranged quantized co-efficients are entropy coded with nipple-dictionary substitution, which gives high rate of compression. This nipple-dictionary encoding method combines runlength, bitstuffing and dictionary encoding mechanisms. The property of the runlength encoding and bitstuffing are designed as code words of nipple sized information and are stored in dictionary-code book as presented in table 1. This table represents the runlength of a bitstuffed data and this bitstuffing is based on the amount of the information in terms of bits. The quantized coefficients are encoded with the number of bits allocated using the proposed look up table 1, which gives the compressed bit stream. The complete algorithm for colour image coding is presented below:

Table 1. Proposed Nipple-Dictionary Substitution Encoding Scheme

Nipple Code	Preceding Information
0000	End of block
0001	2 bit information
0010	4 bit information
0011	6 bit information
0100	8 bit information
0101	Preceding Zero
0110	Runlength of 2 bit size
0111	Runlength of 4 bit size
1000	Runlength of 6 bit size
1001	2 bit of negative information
1010	4 bit of negative information
1011	6 bit of negative information
1100	8 bit of negative information
1110	Runlength for zero of 2 bit size
1111	Runlength for zero of 4 bit size
1101	Runlength for zero of 6 bit size

Algorithm for Colour Image Encoding :

Input : Colour image having three components R,G, and B, each of size ROW X COL. [ ] denotes the matrix and the suffix denotes the elements of the matrix. Let $|M| = |M| \otimes |M| \otimes |M|$ be the 3-D polynomial operator of size (27 × 27), and [I] be the (3 × 3) colour image region extracted from each of the R, G, B components and arranged in dictionary sequence, so as to take into account interactions among colour planes.

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Begin
Step 1 Repeat through step 8 for i = 1 to ROW.
Step 2 Repeat through step 7 for j = 1 to COL.
Step 3 Extract a small region [I] from the image centered at (i, j) from each of the three R, G, B components and arrange them in dictionary sequence.
Step 4 Compute the orthogonal polynomial transform co-efficients [β'] = [M]^t[I]..
Step 5 Quantize the forward transformed coefficients [β'] using scalar quantization.
Step 6 Rearrange the quantized coefficients using equation (19) and then subject to nipple-dictionary substitution entropy coding as explained in section IV.
Step 7 Store the compressed bit stream and increment j by 3.
Step 8 Increment i by 3.
End.

Decoding is the reverse process of encoding, and is done as a simple look up table manner. First entropy decoding is applied on the compressed bit streams and the results are multiplied with quantum values for de-quantization. The inverse transform is applied based on proposed Orthogonal Polynomial basis operator to reconstruct the image back and the results are evaluated using performance measure.

V. EXPERIMENTS AND RESULTS

The proposed orthogonal polynomials based transform coding of colour images is experimented with more than 3000 images of different types. Among these 3000 images two sample benchmark images viz Lena and Baboon images which are of size (256×256) with pixel values in the range of 0-255 in each of R, G and B colour planes are shown in figures 1(a) and 1(b) respectively. The images are divided into non-overlapping blocks of size (3×3) in the three R, G, B colour space, arrange in one dimensional dictionary sequence and the proposed transform coding is applied to obtain the transformed co-efficients $\beta^{'}_{ijk}$ as described in [31]. These coefficients are scalar quantized with various $quality\_factor$ as a user input given in equation (4). The quantized co-efficients are then rearranged based on energy grouping and then entropy coded according to the proposed nipple-dictionary substitution using table 1, which results in compressed bit stream. One of the main novelty in the proposed colour image compression with Orthogonal Polynomials transform is the interaction effects between the colour information of the chosen colour model. This interaction effect may vary depending upon the colour space we employ. So experiments are conducted in different colour spaces by first transforming the input image in RGB colour space into various colour models such as YC_bC_r, HSI, YIQ and XYZ and then the proposed transform coding is applied. The results for the same lena and baboon images are presented in table 4(a) and 4(b) respectively.

Table 2 (a) PSNR values for various bits per pixel (bpp) using proposed scheme in different colour spaces for lena image

bits per pixel (bpp)	RGB	YCbCr	XYZ	YIQ	HIS
(24 bpp)	PSNR(dB)	PSNR(dB)	PSNR(dB)	PSNR(dB)	PSNR(dB)
6.0	41.13	36.57	36.24	35.57	31.92
4.8	39.77	33.16	35.26	33.48	30.64
3.6	36.22	31.45	33.73	30.59	29.21
2.4	33.98	30.29	30.71	28.42	27.93
1.2	31.86	28.57	28.53	26.12	25.32

Table 2 (b) PSNR values for various bits per pixel (bpp) using proposed scheme in different colour spaces for baboon image

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bits per pixel (bpp)	RGB	YCbCr	XYZ	YIQ	HSI
(24 bpp)	PSNR(dB)	PSNR(dB)	PSNR(dB)	PSNR(dB)	PSNR(dB)
6.0	38.91	31.17	32.03	31.00	30.31
4.8	34.80	27.51	29.781	26.34	28.12
3.6	32.12	26.36	28.69	25.17	26.21
2.4	27.80	25.22	26.17	24.34	24.46
1.2	26.76	24.43	24.81	23.11	22.11

VI. CONCLUSION

In this research work, we have proposed a new Orthogonal Polynomials based transform coding for encoding colour images in different colour spaces. This scheme starts by first transforming the image data to the frequency domain using a class of Orthogonal Polynomials. After applying the proposed transformation, the transform coefficients are scalar quantized and energy grouped quantized co-efficients are entropy encoded based on nipple-dictionary encoding which is a combination of runlength, bitstuffing and dictionary encoding mechanisms. The performance of the proposed integer transform coding is reported by computing peak signal to noise ratio and is also compared with the wavelet and DCT based schemes. The experiments are conducted in RGB colour space and are also extended to other colour spaces such as YC_bC_r, YIQ, HSI and XYZ.

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