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A Lossless Color Image Compression-Hierarchical Prediction & Context Adaptive Coding

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Abstract: This paper introduces a algorithm of hierarchical prediction and context-adaptive arithmetic coding for the lossless compression of an RGB image. RGB image is first transformed to YCuCv by a reversible color transform(RCT). After that a conventional lossless image coder like CALIC is used to compress the luminance channel Y. The proposed method used for hierarchical scheme to encode the chrominance image. In this process, the chrominance image is decomposed by even row and odd row image. This decomposed image is compressed using arithmetic coding and decoded so that we can get the original image by using color reverse transformation after the image can be reconstructed and performance measure can be calculated. Hierarchical scheme enables the use of upper, left, and lower pixels for the pixel prediction, but the conventional raster scan prediction methods use upper and left pixels for pixel prediction.An appropriate context model for the prediction error is defined and the arithmetic coding is done to the error signal related to each context. It is shown that the proposed method i.e., hierarchical prediction and context-adaptive arithmetic coding further reduces the bit rates compared with JPEG2000 and JPEG-XR for several sets of images.
Keywords: Lossless color image compression, reversible color transform, pixel prediction, hierarchical prediction, context adaptive arithmetic coding.

I. INTRODUCTION

The data compression becomes significant for reducing data redundancy, so can save more hardware space and transmission bandwidth. Image compression coding stores the image into bit-stream as less as possible and displays the decoded image exactly. Image compression is encoding the original image with few bits. When the encoder receives the original image file, the image file will be converted into a series of binary data.The decoder then receives the encoded binary data and decodes it to form the decoded image. If the total data quantity of binary data is less than that of the original image, this is called image compression.

The main intention of this project is to develop a hierarchical prediction scheme, where most of the existing prediction methods in lossless compression uses raster scan prediction which is inefficient in the high frequency region. In this project design an edge directed predictor, propose a method that uses lower row pixels, upper and left row pixels for the prediction of a pixel to be encoded. For the compression of color images, the RGB is first transformed to YCuCv by an RCT, and Y channel is encoded by an image compression algorithm. And the chrominance components are compressed using hierarchical prediction method. After the compression of luminance component, two chrominance components and the prediction matrix are transmitted through the channel using the orthogonal frequency division multiplexing.

However, there are many cases where the loss of information due to compression needs to be reduced, such as medical, prepress, scientific and artistic images. As cameras and display systems are going high quality and as the cost of memory is low, we wish to keep our precious and artistic photos free from compression artifacts. Hence efficient lossless compression will become more important.

II. EXISTING METHODS

Some of the algorithms used by image compression are JPEG [1], LOCO-I [2], CALIC [3], JPEG2000 [4] and JPEGXR [5].

A. JPEG

"JPEG" stands for Joint Photographic Experts Group. JPEG is a common method of lossy compression for digital images. This compression method is lossy, and some data is lost and cannot be recovered.

B. LOCO-I

Low complexity lossless compression for images (LOCO-I) is an algorithm for lossless and continuous-tone still images and this is

Volume 5 Issue III, March 2017
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based on a simple fixed context model. In this LOCO-I prediction of pixels are done accurately.

C. CALIC

Context-based adaptive lossless image codec (CALIC). CALIC is mainly applied on data modeling images. This is used mainly for modeling contexts to a condition. In non-linear prediction, this is used for an error feedback mechanism. CALIC estimates only the expectations of prediction errors contained a more number of conditional error probabilities.

D. JPEG 2000 (Joint Photographic Experts Group 2000)

This is a wavelet image compression standard. This was created by the Joint Photographic Experts Group committee with the aim of superseding their original discrete cosine transform based on JPEG standard. JPEG 2000 has higher compression ratios than JPEG.

III. PROPOSED METHOD

The aim of this paper is to develop a hierarchical prediction scheme, but most of existing prediction methods in lossless compression uses the raster scan prediction which is proved inefficient in high frequency region. The "hierarchical" prediction was already proposed in [11], but pixel interpolation only is used here. In this paper, we had designed an edge directed predictor and context adaptive model for the hierarchical scheme. To be exact, we propose a method that uses lower row pixels, upper and left row pixels for the prediction of a pixel to be encoded. In this proposed method, compression of color images, the RGB is first transformed to *YCuCv* by an RCT(Reversible Colour Transform) mentioned above [9], and Y channel is encoded by a grayscale image compression algorithm like CALIC. While coming to chrominance channels (*Cu* and *Cv*), the variation of signal is much smaller than that of RGB image, but variation is still large near the edges. To get more accurate prediction of these signals, and also for accurate modeling of prediction errors, we use the hierarchical scheme: the chrominance image is converted into two subimages; i.e. a set of even numbered rows and a set of odd numbered rows. Firstly the even row subimage *Xe* is encoded, then we can use all the pixels in *Xe* for the prediction of a pixel in the odd row subimage *Xo*. Since the statistical properties of two subimages are not so different, the pdf(probability distribution function) of prediction errors of a subimage can be accurately modelled from the other one.

A. Hierarchical Decomposition and Pixel Prediction

The chrominance channels *Cu* and *Cv* which results from the RCT usually have different characteristics from *Y* , and also different from the original color components *R*, *G*, and *B* of the RGB image. In the chrominance components, the signal variation is removed by the color transform, but the variation is still large near the boundaries of the object. Since, the prediction errors present in a chrominance channel are mostly reduced in a smooth region, but remain relatively large near the edges or within a texture region. For the efficient lossless compression, it is important to estimate the pdf of prediction error for better modeling, along with the accurate prediction. For this, we propose a hierarchical decomposition scheme as depicted in Fig. 1,

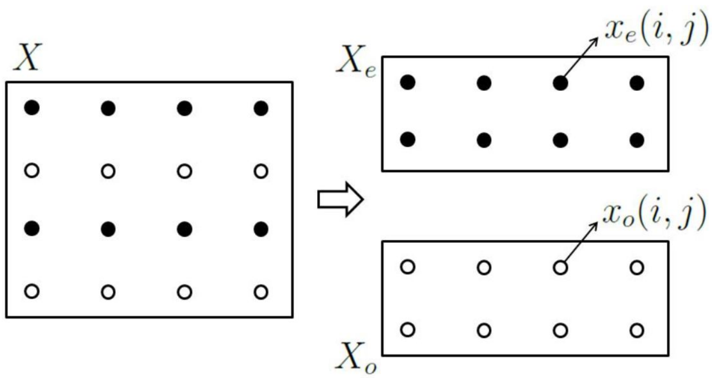

Fig. 1 Input image and its decomposition.

which shows that pixels in an input image *X* is separated into two subimages: an even subimage *Xe* and an odd subimage *Xo*.
Then, *Xe* is encoded first and is used to predict the pixels in *Xo*. In addition, *Xe* is also used to estimate the statistics of prediction errors of *Xo*. In actual implementation, *Xe* is decomposed once more as will be explained later. *Xo* pixels are compressed using *Xe*, during this directional prediction is used to avoid large prediction errorsa at the edges. For each pixel *xo(i, j)* in *Xo*, the horizontal

predictor $\hat{x}_h(i, j)$ and vertical predictor $\hat{x}_v(i, j)$ are defined as

$$\hat{x}_h(i, j) = x_o(i, j-1)$$
$$\hat{x}_v(i, j) = round\left(\frac{x_e(i, j) + x_e(i+1, j)}{2}\right), \qquad \text{-------------- (1)}$$

and one of them is selected as a predictor for $x_o(i, j)$. By these two predictors, the common mode of approach for encoding is "mode selection," where suitable predictor for every pixel is selected and the horizontal or vertical mode is also transmitted as side information. However, the vertical predictor is more correct than the horizontal one when the predictors are defined as (1) because upper and lower pixels are used for the "vertical" but just only a left pixel is used for the "horizontal." The horizontal predictor is more accurate only if there is a strong horizontal edge. Hence, the vertical predictor is used for most pixels, and mode selection is used only when the pixel is a strong horizontal edge. For application of this method, we define a variable for the direction of edge at each pixel $dir(i, j)$, which is given either H or V. Actually, it is given H only when the horizontal edge is more strong, and given V for the remaining. Deciding $dir(i, j)$ is summarized in Algorithm 1,

Algorithm 1 Calculation of $dir(i, j)$

if $|x_o(i,j) - \hat{x}_h(i,j)| + T_1 < |x_o(i,j) - \hat{x}_v(i,j)|$ **then**
    $dir(i,j) \leftarrow H$
else
    $dir(i,j) \leftarrow V$
end if

Where we can see that the direction is given H only when $|x_o(i, j) - \hat{x}_h(i, j)|$ is much smaller than $|x_o(i, j) - \hat{x}_v(i, j)|$ by adding a constant $T1$ to the former when comparing them. Based on the directions of pixels, the overall prediction scheme is summarized in Algorithm 2.

Algorithm 2 Calculation of $\hat{x}_o(i, j)$

if $dir(i-1,j) = H$ **or** $dir(i,j-1) = H$ **then**
    Calculate $dir(i,j)$ by Algorithm 1
    Encode $dir(i,j)$
    if $dir(i,j) = H$ **then**
        $\hat{x}_o(i,j) \leftarrow \hat{x}_h(i,j)$
    else
        $\hat{x}_o(i,j) \leftarrow \hat{x}_v(i,j)$
    end if
else
    $\hat{x}_o(i,j) \leftarrow \hat{x}_v(i,j)$
    Calculate $dir(i,j)$ by Algorithm 1
end if

It can be seen that the mode selection is tried when more than one of $dir(i-1, j)$ or $dir(i, j-1)$ are H, and the vertical prediction is performed for the rest.

B. Estimation of Prediction Error

In this predictive lossless compression, for efficient encoding of the prediction error

$$e(i, j) = x_o(i, j) - \hat{x}_o(i, j)$$

plays an important role.Even the proposed prediction method normally generates small prediction errors owing to the RCT and the prediction scheme, there are still large errors near the edge or texture region, which reduces compression performance. For the efficient compression, the characteristics of symbols (prediction errors) should be well described by an appropriate model and/or parameters. We assume the prediction error as a random variable with pdf $P(e|Cn)$, where Cn is the coding context that represents

Volume 5 Issue III, March 2017
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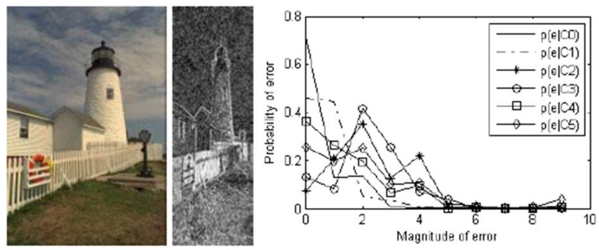
the magnitude of edges and textures. To be specific, Cn is the level of quantization steps of pixel activity $\sigma(i, j)$ defined as

$$\sigma(i, j) = |xe(i, j) - xe(i + 1, j)| \qquad \text{--------------} \ (2)$$

Local activity and its quantization steps are calculated with the pixels in Xe, because all the pixels in Xe are available and its property would be almost the same as that of Xo. The local activity is quantized into K steps so that Cn represents the step

$$qn-1 \leq \sigma(i, j) < qn \qquad \text{--------------} \ (3) \qquad \text{for } n = 1, \ldots, K \text{ with } q0 = 0 \text{ and } qK = \infty.$$

The quantization steps length is determined such that each step contains the same number of elements (local activities).To encode the prediction error, a generic adaptive arithmetic coder [12] is used for each context.
For illustration, Fig. 3



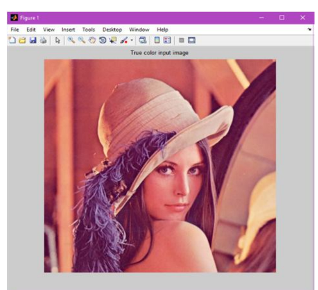
(a) (b) (c)

Fig. 3. An example of context and pdf of error depending on the context. (a) Input image. (b) Context. (c) Conditional pdf.

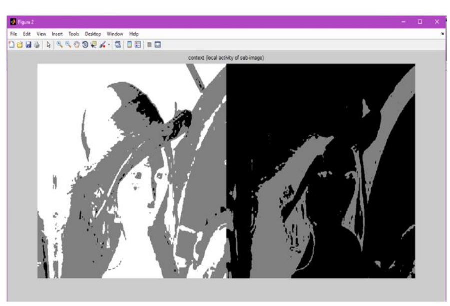
Shows an input image, the local activity of a subimage (context), and $P(e|Cn)$ for several Cn. This describes the statistical property of prediction error, in this the error magnitude is large when the local activity is strong. Hence the proposed model Can be effective for the compression with arithmetic coding.

IV. SIMULATION OUTPUTS

Applying the proposed prediction scheme and context adaptive coding for a image, the results show that the proposed method has reduced compressed bit rates compared to the previous methods like JPEG2000, JPEG-XR.
The below window shows the input image selected for the proposed method.



Once the image is taken and the image is compressed and the context values of the input image are shown in the below figure window.



To show that there is no loss in the compressed image, both original and compressed images are compared in the below figure window.

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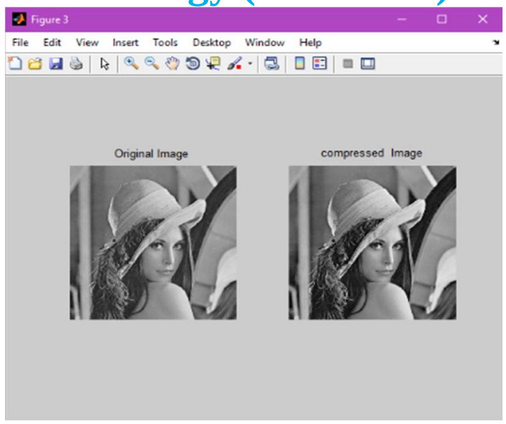

The bit rates of different lossless compressing methods including the proposed method are compared in the below tabular column.

TABLE I

AVERAGE OF COMPRESSED BIT RATES (bpp) FOR 24 KODAK IMAGES

	BPP
JPEG2000	9.5353
JPEG2000 with RCT [9]	9.4586
JPEG-XR	10.9214
JPEG-XR with RCT [9]	10.8521
Proposed	8.8587

V. CONCLUSION

An enhanced lossless RGB image compression based on hierarchical prediction and context adaptive coding has been proposed to reduce the bit rate and to achieve high compression gain. The color image is first converted to $YCuCv$ by reversible color transform in which the chrominance channel is encoded based on pixel prediction , hierarchical decomposition and conventional compression method encodes luminance component Y. The prediction error is measured based on context model and the adaptive coding is applied to the error signal. The proposed method and several conventional methods have been tested on the various images and shown that average bit rate is less in the proposed method.

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