INTRA-PREDICTION FOR COLOR IMAGE CODING USING YUV CORRELATION

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ABSTRACT

In this paper we present a new algorithm for chroma prediction in YUV images, based on inter component correlation. Despite the YUV color space transformation for inter component decorrelation, some dependency still exists between the Y, U and V chroma components. This dependency has been previously used to predict the chrominance data from the reconstructed luminance. In this paper we show that a chrominance component can be more efficiently predicted by using the reconstructed data from both the luminance and the remaining chrominance signal.

The proposed chroma prediction is implemented and tested using the Multidimensional Multiscale Parser (MMP) image encoding algorithm. It is shown that the new color prediction mode outperforms the originally proposed prediction methods. Furthermore, by using the new color prediction scheme, MMP is consistently better than the state-of-the-art H.264/AVC for coding both for the luminance and the chrominance image components.

Index Terms— Color Image Coding, Inter-Component Correlation, Intra Prediction, Recurrent Pattern Matching

1. INTRODUCTION

The most efficient image coding schemes are based on exploiting the spatial redundancy. The same approach can be used for coding color images, that include additional components with a certain level of correlation. Nevertheless, efficient ways to exploit the chrominance signals' correlation must be investigated, in order to achieve good compression results.

Recent developments in digital camera technology allows the generation of images with very rich color information, which can be further exploited in order to achieve higher compression ratios. In this sense, some approaches have been proposed to exploit RGB inter-component redundancy, reducing spectral correlation without resorting to YUV transformation. In [1, 2], RGB components are uncorrelated by computing parameters, that define linear relationships between them and are transmitted to the decoder. Nevertheless, because of its good decorrelation capabilities, the use of a luminance (Y) and two chrominance components (Cb, Cr), is usually regarded as a better option for image coding.

In the YUV space, chrominance signals have usually small dynamic range and smooth variations having consequently considerably less information than luminance. Most of the spatial information is in the luminance signal, that is also the most important for the human visual system. Thus, in most image coding schemes, Cb and Cr chrominance signals are sub-sampled, in order to achieve better performance with negligible visual degradation. Often, both chrominance signals are sub-sampled by a factor of two in the vertical and horizontal directions, which is called YCbCr 4:2:0 chroma format. Due to the high degree of decorrelation achieved by the YUV format, the exploitation of inter-channel correlation between YUV channels has been considered ineffective. However, a recent proposal [3], demonstrated that it may be worthy to exploit some of the residual inter-channel correlation that still exists among the YUV signals. Thus, new methods that reduce the correlation between YUV channels are worth investigating. In this sense, in [3] a linear model has been proposed as a way to reduce the correlation among color components.

In this paper we propose a new improved chroma prediction method based on that presented in [3]. The proposed chroma prediction mode is compared with the original one, through its application on a block-based image coding algorithm referred to as Multidimensional Multiscale Parser (MMP) [4].

The MMP is an algorithm based on variable block size recurrent pattern matching, that is currently able to achieve a higher coding efficiency than most state-of-the-art encoders for grayscale images [5].

This paper presents a way to efficiently encode the chrominance components using the MMP algorithm. These results show the efficiency of the proposed color component prediction method, that achieves relevant gains over both the original MMP for chrominance coding and MMP using the method described in [3]. Our results for MMP color image coding are also compared with the state-of-the-art encoder H.264/AVC-Intra. These tests show that MMP also achieves an overall performance higher than that of the H.264/AVC standard also for color image coding.

This paper is organized as follows: in Section 2 the proposed chroma prediction is presented; Section 3 briefly reviews the MMP algorithm; the experimental results are discussed in Section 4 and Section 5 concludes the paper.

2. CHROMA PREDICTION

As previously refered, after the RGB to YUV 4:2:0 conversion there still exists some residual correlation between luma and chroma components [3]. Such dependency can be exploited by using a linear chrominance prediction model, where each chrominance component

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can be predicted as

$$\hat{C}(x, y) = \alpha L'(x, y) + \beta, \quad (1)$$

where $\hat{C}(x, y)$ represents the predicted chrominance and $L'(x, y)$ corresponds to the reconstructed luminance, both at (x, y) position within a block. Parameters α and β belong to the linear model.

The *optimal* linear parameters for a macroblock can be calculated using a least squares method, and are given by:

$$\begin{aligned} \alpha(x, y) &= \frac{R_{L',C}(x, y; x, y)}{R_{L',L'}(x, y; x, y)}, \\ \beta(x, y) &= \bar{C}(x, y) - \alpha \times \bar{L}'(x, y), \end{aligned} \quad (2)$$

where $R_{A,B}(x_1, y_1; x_2, y_2)$ means the cross-covariance between components $A(x_1, y_1)$ and $B(x_2, y_2)$. For each macroblock, $C(x, y)$ corresponds to the original chrominance, $L'(x, y)$ is the subsampled reconstructed luminance, $\bar{C}(x, y)$ denotes the mean of the chrominance and $\bar{L}'(x, y)$ denotes the mean of the reconstructed luminance. Since it is reasonable to suppose that the blocks of an image constitute a stationary process, $\alpha(x, y)$ and $\beta(x, y)$ tend to be independent of the pixel coordinates (x, y) within a block, and we thus denote them simply by α and β.

Since the original pixels of chrominance are required to obtain optimal linear parameters, the decoder needs to receive them. In [3] both an implicit and an explicit method are proposed. The implicit method estimates the optimum parameters using the previously reconstructed neighboring samples, where the prediction parameters are given by (dropping here the dependency on (x, y) due to the stationarity supposition):

$$\alpha = \frac{R_{L',C'}}{R_{L',L'}}, \qquad \beta = \bar{C}' - \alpha \times \bar{L}'. \quad (3)$$

The explicit method is based on the transmission of the α parameter and on the estimation of the β parameter. Experimental results for these chroma prediction methods (obtained using an H.264/AVC-based implementation), show a slight performance advantage of the implicit method.

2.1. Proposed algorithm

A new algorithm is proposed, as an extension of the mentioned chroma prediction algorithm. After processing the luminance and V chrominance components, a new intra prediction mode is used for the U chrominance signal, that can be described as follows:

$$\hat{U}(x, y) = \alpha Y'(x, y) + \beta V'(x, y) + \gamma, \quad (4)$$

where $\hat{U}(x, y)$, $Y'(x, y)$ and $V'(x, y)$ are the predicted U chrominance, the reconstructed luminance and the reconstructed V chrominance at (x, y) position, respectively. The new linear prediction model now uses three parameters, α, β and γ, that can be derived using a least squares method (note that the stationarity condition still holds):

$$\frac{\partial E[\xi^2]}{\partial \gamma} = 0 \quad \Rightarrow \quad \gamma = \bar{U} - \alpha \bar{Y}' - \beta \bar{V}'; \quad (5)$$

$$\frac{\partial E[\xi^2]}{\partial \beta} = 0 \quad \Rightarrow \quad \beta = \frac{R_{U,V'} - \alpha R_{Y',V'}}{R_{V',V'}}; \quad (6)$$

$$\frac{\partial E[\xi^2]}{\partial \alpha} = 0 \quad \Rightarrow \quad \alpha = \frac{R_{U,Y'} - \beta R_{Y',V'}}{R_{Y',Y'}}, \quad (7)$$

where ξ is an error function defined by:

$$\xi(x, y) = U(x, y) - \hat{U}(x, y). \quad (8)$$

Replacing equation (6) in (7), α can be given by:

$$\alpha = \frac{R_{V',V'} R_{U,Y'} - R_{U,V'} R_{Y',V'}}{R_{Y',Y'} R_{V',V'} - R_{Y',V'} R_{Y',V'}} \quad (9)$$

Using equations (9), (6) and (5) it is possible to calculate the optimal parameters for U chrominance prediction. In this work, an implicit implementation was used. Thus, the optimal estimated parameters are calculated using the upper and left pixels of the target macroblock.

3. THE MMP ALGORITHM

MMP algorithm is a generic lossy data compression method that has been sucessfully applied to grayscale image coding. MMP divides the image into non-overlapping blocks and uses patterns at different scales from a dictionary to approximate image's blocks. MMP creates a segmentation tree for each input block, where the leaf nodes correspond to subblocks of variable sizes. The segmentation tree in MMP is represented by a sequence of segmentation flags. The encoding process associates to each leaf node of the segmentation tree an element of MMP's dictionary. Therefore, MMP encodes the input block as a sequence of dictionary indexes and segmentation flags. Concatenations of previously used patterns during the encoding process are added to the dictionary at multiple scales, adapting it to the image's characteristics.

In order to find the best block segmentation and index encoding, a rate-distortion optimized algorithm based on Lagrangian cost is used. The best segmentation is found comparing each node cost in the segmentation tree. The segmentation tree is rate-distortion optimized by means of a Lagrangian procedure [4]. The output bitstream is formed by arithmetic encoding the segmentation flags and the dictionary indexes.

MMP can also be combined with a prediction step, in order to generate a residue block that is then compressed using MMP [4]. The prediction modes used by MMP are inspired by the ones defined in H.264/AVC standard. The prediction step tends to generate more uniform residue blocks, favoring the adaptation of the dictionary and encoding efficiency. Like H.264/AVC, MMP uses an adaptive prediction block size that may vary from 16×16 down to 4×4. Each prediction mode is optimized together with the prediction block size, by using the previously mentioned Langrangian RD cost function.

Recent improvements on the algorithm [6, 5] allowed MMP to outperform the state-of-the-art image encoders H.264/AVC and JPEG2000 for grayscale image compression. Nevertheless, the performance of MMP for the compression of color components had never been studied, which motivated us to assess the chroma prediction proposed in Section 2 by developing an MMP algorithm for color images.

3.1. MMP with chroma prediction

The MMP algorithm uses a set of prediction modes based on the ones of H.264/AVC plus one LSP (least squares prediction) mode for Y prediction [5]. Five prediction modes were selected for MMP chroma compression: vertical, horizontal, plane and MFV (most frequent value), that is a variation of the DC mode [4], together with the proposed mode *Chroma* for chroma prediction.

The proposed chroma prediction depends on the previously reconstruted luminance and chrominance components, and it can only

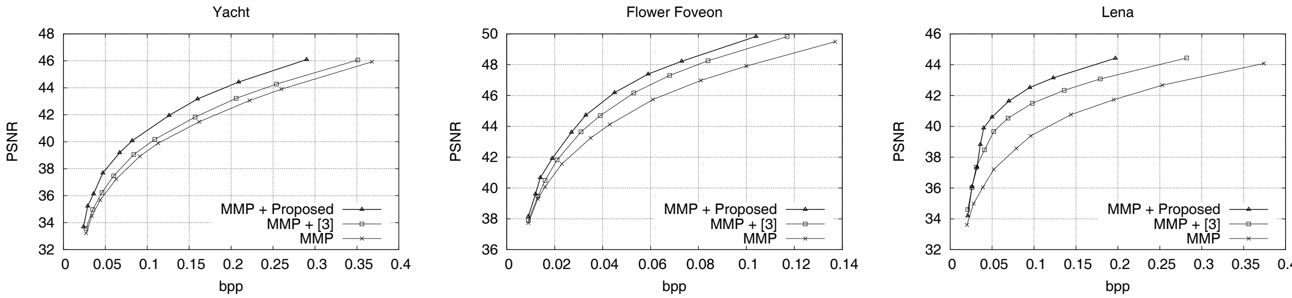

Fig. 1: Compression of the U chroma using MMP, MMP and the proposed algorithm and MMP with the method in [3].

be applied to one chrominance signal. Our experimental results have shown that the proposed method is generally more efficient when applied to U chrominance.

The MMP-based color coding scheme first encodes the Y component using the variation of the MMP algorithm proposed in [5] (with 10 intra prediction modes). Then, the V subsampled macroblock is encoded, using 5 prediction modes (including the one presented in [3]). Finally, the U component is encoded with the 4 H.264/AVC chroma prediction modes and the one proposed in Section 2, equations (5) to (9).

4. EXPERIMENTAL RESULTS

In this section we first evaluate the performance of the proposed chroma prediction mode, namely by comparing it with the original method in [3], for the MMP-based encoder. Additionally, we compare the encoding efficiency of the MMP algorithm for color images with the state-of-the-art H.264/AVC standard.

One set of three color test images was selected to demonstrate the effectiveness of the proposed algorithm. Images *Lena* and *Yacht*[1] are commonly used test images, while *Flower Foveon* is an high resolution image[2]. Prior to the encoding process, all images were converted to the YUV 4:2:0 color space.

Figure 1 presents the results for the compression of the U component of each test image, using the original MMP encoder with 4 prediction modes (MMP), the MMP encoder combined with the prediction mode in [3] (MMP + [3]) and the MMP encoder combined with the new prediction scheme (MMP + Proposed). These results show the coding gains achieved by the proposed prediction mode, which may have some variation from image to image. For image *Yacht*, the original linear prediction mode achieves a coding gain of about 0.5 dB over the original MMP; when the proposed method is used, the advantage increases to about 1.7 dB. For other images the performance advantage may vary, but one may consistently observe that the use of any of the linear prediction schemes is always advantageous and also that the proposed method consistently outperforms the original algorithm. From this, we can conclude that the proposed model allows for a more accurate prediction of one of the chroma components.

These results are consistent with those shown in Figure 2, that shows the usage rate of each prediction mode, for the U chrominance of image *Lena*. The dark bars correspond to the encoder that uses the method presented in [3] and the bright bars correspond to the use of the proposed method. One may observe higher usage rate of

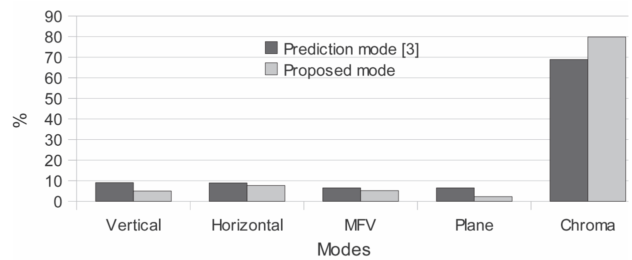

Fig. 2: Usage rate for each prediction mode for U chrominance of image Lena.

the proposed algorithm (about 10%), which demonstrates its greater prediction efficiency.

Figure 3 compares MMP using the new prediction mode with the H.264/AVC intra coding standard, High profile, version 9.0 [7]. For the luma component, the figure shows the previously mentioned advantage of MMP. For the chroma components, the MMP results depend on the considered image: for images *Yatch* and *Flower Foveon*, MMP consistently achieves a performance gain for both the U and V components. This gain ranges up to 3 dB, depending on the test image and on the considered color component. For test image *Lena* MMP presents an advantage for the U component, but is less efficient for the V component than the transform-based method. Notice however that, since MMP is more efficiently for the Y and U channels, the global YUV performance of MMP for this image is still higher than that of H.264/AVC.

Comparing the proposed method with JPEG2000, MMP consistently shows a higher efficiency for all tested images at various bitrates, as shown in Figure 4. Futhermore, identical results were achieved with different types of images, not presented here.

5. CONCLUSION

In this paper we have proposed a new chrominance intra prediction method. The proposed prediction scheme is able to achieve consistent coding gains for chrominance signals when compared with other methods described in the literature.

The investigated prediction algorithms were used in conjunction with the Multidimensional Multiscale Parser (MMP) encoder. The experimental analysis has shown that the linear relation between YUV channels is efficiently exploited using the proposed chroma prediction in MMP's RD loop. Experimental results demonstrated that MMP outperforms the H.264/AVC standard, both for coding color and grayscale images.

[1] Available at http://www.cipr.rpi.edu/resource/stills/
[2] Available at http://www.imagecompression.info/test_images

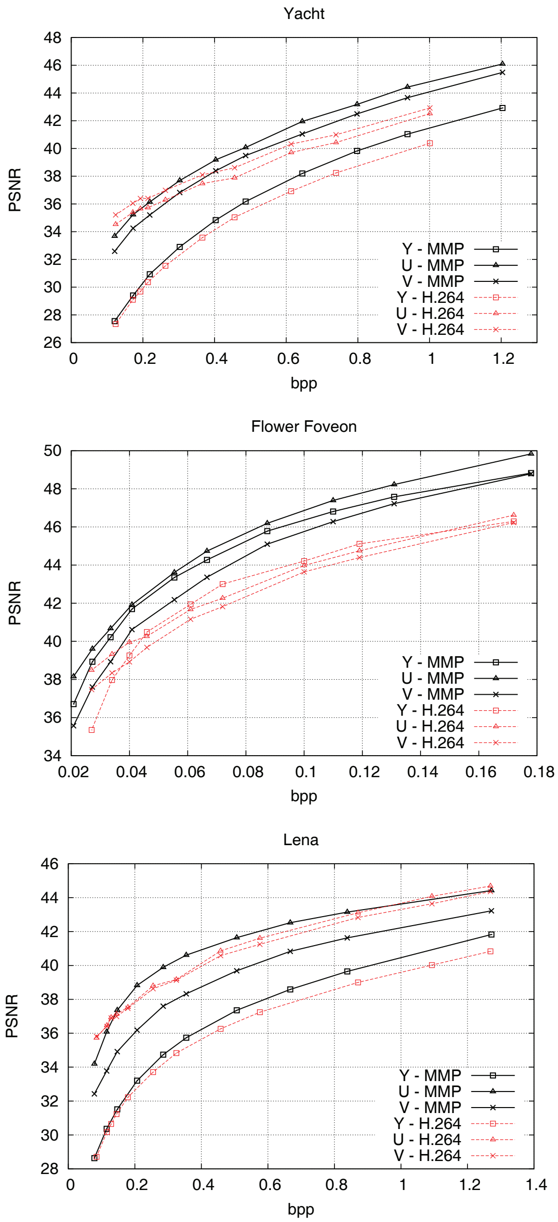

Fig. 3: RD results for MMP using the proposed method and H.264/AVC for YUV images.

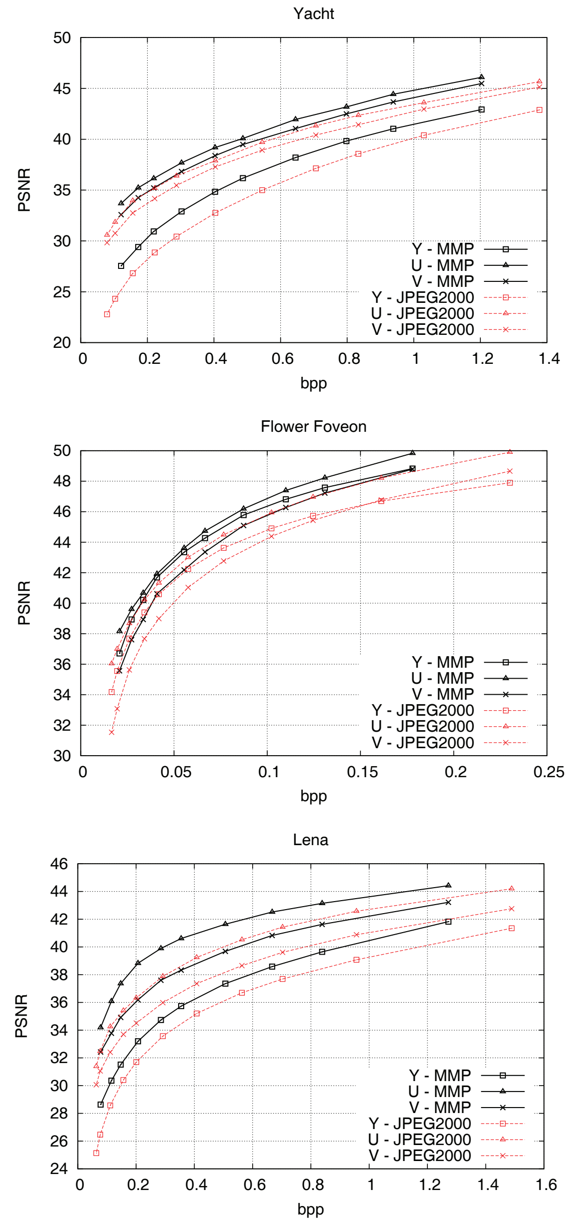

Fig. 4: RD results for MMP using the proposed method and JPEG2000 for YUV images.

6. REFERENCES

[1] W.-S. Kim, D.-S. Cho, and H. Kim, "Interplane prediction for rgb video coding," in *IEEE Int. Conf. on Image Proc.*, Oct. 2004, vol. 2, pp. 785–788.

[2] B. Song, Y. Lee, and N. Kim, "Block adaptive inter-color compensation algorithm for rgb 4:4:4 video coding," *Circ. Syst. Video Technology, IEEE Trans. on*, vol. 18, no. 10, pp. 1447–1451, Oct. 2008.

[3] S.H. Lee, , and N.I. Cho, "Intra prediction method based on the linear relationship between the channels for yuv 4:2:0 intra coding," *IEEE Int. Conf. on Image Proc.*, pp. 1037–1040, November 2009.

[4] N. Rodrigues, E. da Silva, M.de Carvalho, S. de Faria, and V. Silva, "On dictionary adaptation for recurrent pattern image coding," *Image Processing, IEEE Transactions on*, vol. 17, no. 9, pp. 1640–1653, September 2008.

[5] D. B. Graziosi, N. Rodrigues, E. da Silva, S. de Faria, and M. de Carvalho, "Improving multiscale recurrent pattern image coding with least-squares prediction," in *IEEE Int. Conf. on Image Proc.*, Nov 2009.

[6] N. Francisco, N. Rodrigues, E. da Silva, M.de Carvalho, S. de Faria, V. Silva, and M. Reis, "Multiscale recurrent pattern image coding with a flexible partition scheme," *IEEE Int. Conf. on Image Proc.*, October 2008.

[7] http://iphome.hhi.de/suehring/tml/download/.