New Intra Prediction Methods Based on Channel Correlation and their Combination for Color Image Compression

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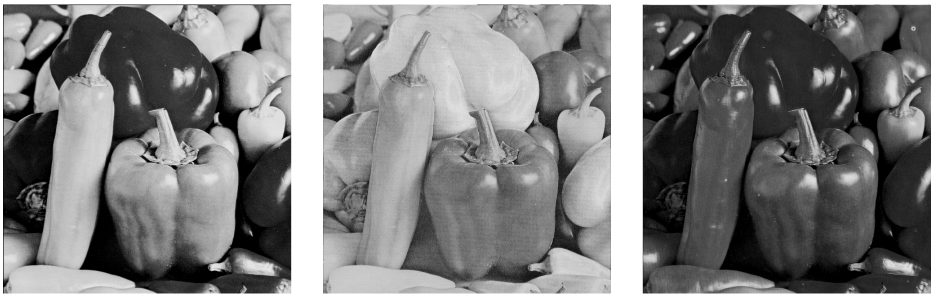
***Abstract*—This paper proposes two new intra prediction methods for color image compression, which exploit the correlation between the base and non-base colors. The first method predicts a pixel in non-base color as a weighted sum of neighboring pixels, where the weights are determined as a function of photometric distances from the pixel to the neighboring ones in the base color. The second exploits the linear relationship between the channels, where the parameters for the model are found from the already reconstructed base color, so that no side information is needed. In the implementation, it is also found that the weighted combination of new predictors gives better coding gain, where one of predictors is chosen based on the RD optimization. The experimental results show that the proposed method provides higher coding gain than the conventional H.264/AVC, up to 1.2dB for luminance and 2.3dB for the chrominance image.**

I. Introduction

Color images can be encoded in a various combination of color spaces (RGB, YUV) and resolutions (4:2:0, 4:2:2 and 4:4:4). However, the most common color format for the commercial application is the YUV 4:2:0, which has been preferred to others owing to less memory requirements and compatibility with black and white displays. For several decades, many compression tools that exploit signal correlation (temporal correlation and spatial correlation) are proposed, but the inter-color channel correlation has not been used in the previous researches on the compression of YUV 4:2:0 format.

The goal of this paper is to develop two new intra prediction methods that exploit the inter-color channel correlation, and also their combination for more efficient compression of YUV 4:2:0 color format. In the case of color image, it can be easily observed that there is quite high correlation between the color channels in addition to the spatial correlation. For example, the average of the inter-color channel correlations of several images is shown in Table 1, where the correlation is measured in the unit of 16×16 macroblock. It can be seen that the correlation between the color channels is quite high, especially in the case of RGB format. The inter-color channel correlation can also be observed in the examples of Fig. 1 for RGB space and Fig. 2 for YUV. To be specific, we can find that significant edges and textures are common to every color channel, which means that we may estimate a color channel from the other ones. The correlation between the color channels has already been exploited in many image/video processing applications such as denoising, interpolation, and also image compression in RGB 4:4:4 format [1], [2], [3], [4], [5], [6]. However, the inter-color channel correlation in YUV 4:2:0 color format has not been considered significantly. The reason for this may be : (1) the YUV format is believed to be sufficiently decorrelated compared to the RGB. According to the RGB to YUV conversion equation, U and V signals are calculated as differences between color channels. Thus spectral overlap in RGB color space is reduced in the case of U and V channel and, thus the channel correlation is reduced (Table 1 shows that correlation between the channel is reduced by about 10∼50% in YUV format), (2) non-base colors (U and V in the YUV format) in YUV 4:2:0 format take only a small portion in the overall bits due to its lower resolution and variance than the base color. Thus it has been believed that increasing the coding gain in the non-base color does not much contribute to the gains of entire image compression. However, as we can see in Fig. 2 and Table 1, the YUV format still has some inter-color channel correlations, although less obvious than in the RGB format. Also, non-base colors sometimes take significant portion in the YUV 4:2:0 format in the case of recently taken high resolution/color photos. For example, the information of the chrominance (U and V) channel in the compressed “Lena” image (taken and scanned long time ago) comprises about 23% of total compressed bits, whereas colorful images taken by recent DSLR cameras need much more information for the chrominance channels. Specifically, the “flower_foveon” image in [7] needs 38% for the chrominance signal when compressed by H.264/AVC intra coding with YUV 4:2:0 format using QP 22.

In summary, we believe that increasing the coding efficiency in the non-base colors is now as important as that in the base color. Hence, we focus on the prediction of non-base colors by using the base color, for more efficient compression of YUV 4:2:0 format. Our previous conference papers [8], [9] have shown that the inter-color channel correlation can be used efficiently in the YUV 4:2:0 compression at first. In



(a) (b) (c)

Fig. 1. Channel images of Pepper in RGB format. (a) G channel image, (b) R channel image, (c) B channel image.

(a) (b) (c)

Fig. 2. Channel images of Pepper in YUV format. (a) Y channel image, (b) U channel image, (c) V channel image.

this paper, we propose new prediction method that includes our previous ideas. In the proposed method, two inter-color channel prediction models are added to the set of existing intra prediction models. In the first model, a pixel is predicted by the input-dependent extrapolation using neighboring pixels, where the extrapolation coefficients are determined from the base color image [8]. The second model predicts a pixel in the non-base color by finding linear relationship between the base and non-base colors [9]. A general approach to the intra compression is to test all the prediction models, including existing intra prediction and proposed prediction models, and then select one of them under R-D optimization framework. However, it is found that combining the prediction models in the form of weighted sum gives lower residual than choosing just one of the models. Hence, our prediction scheme is to find two predictors among two new inter-color channel models and existing prediction models, and also the weights for their combination. Experiments show that the proposed method achieves the coding gain of 0.48dB on average for the base color and 0.8dB for the non-base in the case of YUV 4:2:0 format, compared to the conventional H.264/AVC.

TABLE I
MEAN OF THE CORRELATION MAGNITUDES BETWEEN THE BASE COLOR AND NON-BASE COLOR MEASURED IN THE UNIT OF 16×16 MACROBLOCKS.

Image	σ_{GR}	σ_{GB}	σ_{YU}	σ_{YV}
Pepper	0.70	0.60	0.56	0.61
Artificial	0.86	0.89	0.42	0.46
Flower_foveon	0.75	0.72	0.51	0.69
Baboon	0.79	0.77	0.47	0.42

The rest of this paper is organized as follows. Section 2 reviews the conventional works for the color image compression in the RGB 4:4:4 format, which exploit the inter-color channel correlation. Section 3 describes the proposed intra prediction method proposed in our previous works, and Section 4 presents the schemes to combine the predictors. Section 5 shows experimental results and analyzes the results in YUV 4:2:0 color format. Finally, Section 6 concludes the paper.

II. Review of Previous Algorithms Using Inter-Channel Correlation

Most of conventional inter-color channel prediction methods were developed for the compression of RGB 4:4:4 format [3], [4], [5], where the inter-color channel correlation was described by a linear equation or in the polynomial form. In the case of linear model, the color channel intensity at a pixel position p in a block Ψ is related with a pixel in other colors as

$$\hat{I}_n(p) = \alpha_\Psi I'_m(p) + \beta_\Psi \tag{1}$$

where the $\hat{I}_n(p)$ represents the n^{th} color channel at pixel position p and $I'_m(p)$ means reconstructed m^{th} color channel at pixel position p. Then the energy of the prediction error is defined as

$$\begin{aligned} E &= \sum_{p\in\Psi}(I_n(p) - \hat{I}_n(p))^2 \\ &= \sum_{p\in\Psi}(I_n(p) - (\alpha_\Psi I'_m(p) + \beta_\Psi))^2 \end{aligned} \tag{2}$$

where the Ψ means a set of pixels in one macroblock. The optimal α_Ψ and β_Ψ which minimize E can be calculated using a partial differential equation as

$$\frac{\partial E}{\partial \alpha_\Psi} = 0, \frac{\partial E}{\partial \beta_\Psi} = 0, \tag{3}$$

and the solution of two variables are

$$\begin{aligned} \alpha_\Psi &= \frac{\sum_{p\in\Psi}(I'_m(p) - \frac{\sum_{p\in\Psi} I'_m(p)}{n(\Psi)})(I_n(p) - \frac{\sum_{p\in\Psi} I_n(p)}{n(\Psi)})}{\sum_{p\in\Psi}(I'_m(p) - \frac{\sum_{p\in\Psi} I'_m(p)}{n(\Psi)})(I'_m(p) - \frac{\sum_{p\in\Psi} I'_m(p)}{n(\Psi)})} \\ \beta_\Psi &= \frac{\sum_{p\in\Psi} I_n(p)}{n(\Psi)} - \alpha \frac{\sum_{p\in\Psi} I'_m(p)}{n(\Psi)} \end{aligned} \tag{4}$$

where $I_n(p)$ is the original non-base color, $I'_m(p)$ is the reconstructed base color signal at the pixel location p and $n(\Psi)$ means the number of pixels in Ψ.

Prediction with this model reduces the residual energy, but increases the side information for the transmission of (α_Ψ, β_Ψ). Hence the reduction of side information is an important matter, and thus the delta modulation of parameters was tried in [3]. This conventional method is applied to JPEG scheme, and the results show similar objective quality but better subjective results compared to the conventional JPEG. In [4], a linear relationship with fixed parameters ($\alpha = 1$ and $\beta = 0$ which are fixed from statistics) was applied to H.264/AVC in the residual signals in order to avoid the parameter transmission. In [5], the residual signals are acquired by the "common mode" prediction (all color channels share the same intra prediction direction) in the High 4:4:4 profile and RD-optimized quantized parameter α is transmitted, where there are 8 steps with the step size of 0.25 in (-1.0,+1.0]. These methods are shown to yield significant coding gain in the case of RGB 4:4:4 format, but their effectiveness with the YUV 4:2:0 formats has not been reported. Although our previous paper [9] tries to apply it with simple modification, it does not show satisfactory coding gains. Moreover, the state-of-the-art inter-color channel prediction method in [5] is developed for the "common mode" intra prediction in RGB 4:4:4 format and thus cannot be directly applied to the other formats.

In summary, since the existing methods are designed only for the high quality non-reduced format, we develop new prediction models that are also effective in the color reduced formats. It will be shown that the proposed method gives better coding efficiency for the YUV 4:2:0 format compared to the H.264/AVC.

III. Proposed Prediction Models

In this section, we propose two intra prediction models which exploit the inter-color channel correlation. The first model predicts a pixel in a non-base color by the extrapolation of neighboring pixels, where the extrapolation coefficients are determined from the base colors. That is, the pixel values are calculated from neighboring pixels in the non-base color, and the coefficients multiplied to the pixel values are obtained from the pixels in the base color. The second model uses the linear relation between the given non-base color and the reconstructed base color. The linear parameters are derived from the already reconstructed neighboring pixels based on the spatial similarity. Then a pixel in the non-base color is predicted from the corresponding pixel in the reconstructed base color, with the estimated linear parameter.

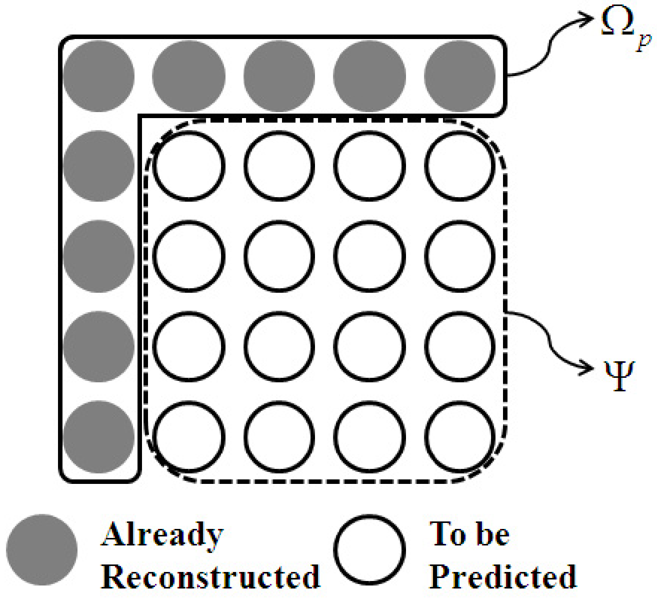
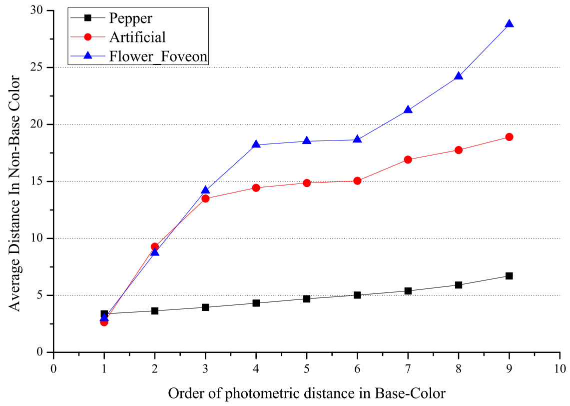


Fig. 3. A 4×4 block to be predicted (Ψ), and its neighboring pixels ($p_k \in \Omega_p$) that are already reconstructed. The pixels adjacent with left and upper boundary of Ψ are used as neighboring pixels.

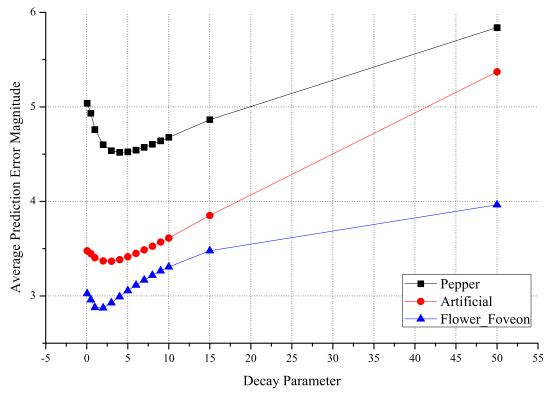
A. Extrapolation Using Inter-Color Channel Correlation

The intra prediction scheme in H.264/AVC predicts a pixel p in a block Ψ by extrapolating the already reconstructed pixels in the neighboring regions of Ψ as shown in Fig. 3. For each pixel $p \in \Psi$, let us define a set of reference pixels $\Omega_p = \{p_1, p_2, \cdots, p_n\}$ where p_i are the "already reconstructed" pixels. The extrapolation coefficients in the conventional scheme was determined according to the prediction direction and the geometric relationship between p and p_k, in the same color channel. This scheme works quite well in the areas with unidirectional edge, but often fails to bring small residual in the areas with complex textures. Hence this paper attempts to add a data dependent extrapolation method, i.e., the prediction of a pixel in non-base color channels as a weighted sum of neighboring pixels, where the weights are derived from the already reconstructed base color channel considering the inter-color channel correlation. The main idea is that the similarity between a targeting pixel and its neighboring reference pixel in non-base color can be inferred from the relation between



(a)

Fig. 4. Square of photometric distance between a targeting pixel and neighboring ones in the non-base color in the increasing order of photometric distance between the corresponding pixels in the base color. (a) Results in YUV sequences.



(a)

Fig. 5. Average prediction error magnitudes for different decay parameter σ. (a) Results in YUV sequences.

the pixels in non-base color at the corresponding position in a different color channel. In other words, a pixel in a non-base color is predicted as a weighted sum of neighboring pixels, where the weights are defined as a function of relation between the corresponding pixels in the already reconstructed base color that are common to encoder and decoder. This scheme obviates the transmission of extrapolation coefficients, and since the base color usually keeps the significant edges or textures under the severe compression, the relation between the pixels in base color can well be reflected to the similarity between the corresponding pixels in the non-base color.

In summary, a pixel in a non-base color is predicted as

$$\hat{I_n}(p) = \frac{\sum_{p_k \in \Omega_p} w_{p_k} I'_n(p_k)}{\sum_{p_k \in \Omega_p} w_{p_k}} \tag{5}$$

where $I'_n(p_k)$ is the reconstructed pixel intensities in the non-base color and w_{p_k} is the weight. Specifically, the weight is defined as a function of photometric distance between the pixels, i.e.,

$$\begin{aligned} w_{p_k} &= f(d_m(p, p_k)) \\ d_m(p, p_k) &= \mid I'_m(p) - I'_m(p_k) \mid - \min_{r \in \Omega_p} \mid I'_m(p) - I'_m(r) \mid \end{aligned} \tag{6}$$

where $I'_m(p)$ is the reconstructed base color intensity at a pixel p, and $f(\cdot)$ is a function that relates the photometric distance in the base color to the similarity (or dissimilarity) of the pixels in the non-base color. Note that the minimum photometric difference in base-color is subtracted from the photometric difference in base color of given pixel pairs to define the photometric distance. It makes the most similar pixel for each block has the same weight to use it as reference for calculating the weights of other pixels.

For determining the shape of function $f(\cdot)$, we plot the photometric distance between the pixels in the non-base color in the increasing order of distance in the base color channel, in Fig. 4. Specifically, the x-axis is the order of photometric distance between the pixels in the base color, and the y-axis is the photometric distance between the corresponding pixels in the non-base color. It can be seen that the photometric distance in the non-base color is definitely correlated with the distance in the base color, and the distance in the non-base color monotonically and rapidly increases. Among many functions that fit this shape, we select a Gaussian function in the form of

$$f(d_m(p, q)) = \exp\left(\frac{-d_m(p, q)^2}{2\sigma^2}\right) \tag{7}$$

where σ is a free parameter that controls the decay speed of coefficient magnitude. The best σ is investigated using several test sequences by calculating the average of absolute prediction errors for each σ. The experimental results given in Fig. 5 shows that the proposed prediction gives minimum prediction error when $1 \leq \sigma \leq 10$. Thus, we select $\sigma = 5$ for every sequences tested in this paper.

The proposed extrapolation model requires too many floating point operation. Thus exponential coefficients w_{p_k} is scaled to be an integer value and pre-calculated in the actual implementation to minimize the required floating point operation. The pre-calculated values are stored in the look-up table, and encoder and decoder refer the look-up table to calculate the weighting coefficients.

The efficiency of the proposed extrapolation method is investigated with some experiments. In the experiments, we predict each of 4×4 block using the conventional 9 intra prediction method and the proposed extrapolation respectively and measure the PSNR for each 4×4 block. Then the portion of the blocks that the proposed method outperforms the conventional method is calculated. Also, the average of PSNR for the blocks that the proposed method performs better is measured in Table 2. It can be seen that the proposed extrapolation outperforms the conventional method for many blocks and the PSNR for those are significantly reduced.

TABLE II
COMPARISON OF PROPOSED EXTRAPOLATION METHOD AND CONVENTIONAL PREDICTION. THE "PORTION OF BLOCKS" MEANS THE RATIO OF BLOCK THAT THE PROPOSED METHOD PRODUCED LESS RESIDUAL THAN THE CONVENTIONAL METHOD

Sequences	Color Space	Portion of Blocks	Average PSNR of conventional model	Average PSNR of proposed model
Artificial	YUV	18.16%	32.71dB	37.74dB
Flower_Foveon		3.68%	36.44dB	38.43dB
Pepper		29.98%	35.50dB	37.42dB

B. Linear Prediction Model Between the Color Channels

The linear relationship between the color channels is a widely accepted assumption and also a useful tool for the color image processing as shown in many applications [1], [2], [3], [4], [5]. In the case of color image compression methods that use the linear relationship, they apply the linear model for the color channel residuals for obviating the side information [4] or for transmitting slope parameter α only [5]. Moreover, the existing methods are applied only to the RGB 4:4:4 format as previously stated. In the case of YUV 4:2:0, it is noted that the residual signals are more coarsely quantized than those of RGB 4:4:4 format because it is usually used for the low to middle range of bit-rates. Furthermore, the portion of side-information is comparatively large in the YUV 4:2:0 image for the same reason. Hence we focus on obviating the side information, while using the linear prediction model and applying the linear model in the original domain not in the residual domain. To be precise, unlike the existing linear parameter estimation in eq. (4) where the original pixel values are involved, we estimate the parameters as

$$\alpha_\Psi = \frac{\sum_{p_k\in\Omega_p}\left(I'_m(p_k) - \frac{\sum_{p_k\in\Omega_p} I'_m(p_k)}{n(\Omega_p)}\right)}{\sum_{p_k\in\Omega_p}\left(I'_m(p_k) - \frac{\sum_{p_k\in\Omega_p} I'_m(p_k)}{n(\Omega_p)}\right)} \cdot \frac{\left(I'_n(p_k) - \frac{\sum_{p_k\in\Omega_p} I'_n(p_k)}{n(\Omega_p)}\right)}{\left(I'_m(p_k) - \frac{\sum_{p_k\in\Omega_p} I'_m(p_k)}{n(\Omega_p)}\right)} \tag{8}$$

$$\beta_\Psi = \frac{\sum_{p_k\in\Omega_p} I'_n(p_k)}{n(\Omega_p)} - \alpha_\Psi \frac{\sum_{p_k\in\Omega_p} I'_m(p_k)}{n(\Omega_p)}.$$

Note that the pixels in the current block Ψ are used for the parameter estimation in eq. (4), whereas the "already reconstructed" pixels in Ω_p are used in the proposed method. In summary, the linear parameters are derived from the neighboring pixels and it is applied to predict the remaining color channels with linear model in current block. It enables inter-color channel prediction of original signal without any side information. Of course, the parameters from the proposed method is not identical to the optimum parameters for the block Ψ, but they often give better prediction results than the conventional predictors. This is demonstrated with some sequences in Table 3, which shows the portion of the 4×4 blocks that the proposed method outperforms the conventional intra prediction. Also, the average PSNR of 4×4 blocks that the proposed method outperforms the conventional method is presented. The results show that the proposed method outperforms the conventional intra prediction of the H.264/AVC in the 30%∼60% of blocks and the PSNR for those blocks are reduced significantly. Although some blocks show worse performance than conventional prediction, it does not matter because the proposed method is used jointly with conventional spatial prediction. To be precise, some block will use inter-color channel predictions (thus, performance will be improved) and remaining blocks will use spatial predictions (thus, performance will be nearly same).

IV. BLOCK ADAPTIVE WEIGHTED PREDICTION

An important factor of the compression efficiency in the hybrid encoder such as H.264/AVC is the accuracy of prediction. Thus the H.264/AVC prepares several predictors for each of the blocks, and selects the best predictor that minimizes the prediction error. Then the prediction residual and the information for the predictor are transmitted to the decoder. In general, the prediction error decreases as the number of predictor increases, but it also increases the side information. Thus the number of predictors should be designed considering the trade-off between the prediction error and side information. One of the efficient method to increase the number of predictors while suppressing the side information is the weighted combination of two predictors [10]. In this section, we propose a block adaptive weighted prediction using the proposed prediction model for further decreasing the prediction error. The weighted prediction is denoted as

$$\hat{I}_n(p) = \alpha \hat{I}_1(p) + (1-\alpha)\hat{I}_2(p) \tag{9}$$

where $\hat{I}_1(p)$ and $\hat{I}_2(p)$ mean the prediction values from two different intra prediction models. Although the consideration of every possible combinations guarantees the minimum prediction error, it requires too much side-information and thus the trade-off is required. Furthermore, the amount of side information does not significantly change according to QPs but the amount of residual bits decrease significantly in high QPs. Thus we cannot increase number of predictors too much when applying it to the YUV 4:2:0 format, because this format is usually for the low bit-rates environments.

TABLE III
COMPARISON OF PROPOSED LINEAR PREDICTION METHOD AND CONVENTIONAL PREDICTION. THE "PORTION OF BLOCKS" MEANS THE RATIO OF BLOCK THAT THE PROPOSED METHOD PRODUCED LESS RESIDUAL THAN THE CONVENTIONAL METHOD

Sequences	Color Space	Portion of Blocks	Average PSNR of conventional model	Average PSNR of proposed model
Artificial	YUV	27.77%	33.94dB	42.41dB
Flower_Foveon		31.43%	42.76dB	45.75dB
Pepper		45.92%	36.34dB	38.70dB

TABLE IV
SOME ENCODING PARAMETER SETTINGS IN THE EXPERIMENTS.

Encoding Options	Setting
RD-Optimization	On
Adaptive Rounding	On
Entropy Coding	CABAC
8×8 Intra Luma Prediction	On
8×8 Transform	On
Fast Chroma Mode Decision	Off

A. Weighted Prediction for YUV 4:2:0 Format

In the conventional H.264/AVC intra prediction for the YUV 4:2:0 format, there are 4 intra prediction directions for non-base color with the size of 8×8. Thus 6 prediction models are prepared for each macroblock in the proposed method (including two proposed prediction models in the previous section). Then, the number of all the possible weighted combinations is $15 \times N$, where N is the number of steps for α values, which requires too much side information for each non-base color block and might decrease the overall coding efficiency at low bit rates. Thus only two proposed prediction models in the previous section are used for the weighted prediction with 5 different $\alpha = \{0, 0.25, 0.5, 0.75, 1.0\}$ values, and the rest of prediction models are independently considered. In summary, 9 prediction candidates (4 conventional predictors and 5 combinations of $\alpha \hat{I}_1(p) + (1-\alpha)\hat{I}_2(p)$ where $\alpha = \{0, 0.25, 0.5, 0.75, 1.0\}$, and the I_1 and I_2 are the new predictors introduced in the previous section) are evaluated for each 8×8 block. Thus the increased side information is about 1 bit for one macroblock.

V. EXPERIMENTAL RESULTS

The proposed compression method with the new intra prediction scheme is evaluated with the YUV 4:2:0 format in terms of the RD-performance and complexity. We implement the proposed prediction method in the JM 15.0[11] High profile. The details of some important parameter settings are given in Table 4.

A. RD-performances of the proposed method with the YUV 4:2:0 format

In the experiment with the YUV 4:2:0 format, we use 7 different test sequences. Three sequences are the still images "Pepper", "Artificial" and "Flower_Foveon". The "Pepper" has 512×512 resolution and other images have 1024×688 resolution. For the conversion from the original RGB to YUV 4:2:0, the "any2yuv" software is employed [12]. Also, the 4 test videos "Ballroom", "Flamenco2", "Race1" and "Akko&Kayo" for the Multi-View Video Coding (MVC) standardization are used in the experiments.

The proposed algorithm is evaluated separately and incrementally with the QPs = {26, 30, 34, 38} for the "flower_foveon" and QPs = {22, 27, 32, 37} for the other sequences. First, we simply insert the proposed extrapolation method (Section III. A) in the conventional chroma prediction and denote it as "Extrapolation". Second, we insert the proposed linear method (Section III. B) in the conventional chroma prediction and denote it as "Linear." Finally, the two proposed models are inserted with the weighted prediction in Section IV and denoted as "Weighted". The BD-PSNR and BD-Rates [15] for each color channel are used to evaluate the RD-performances between the H.264/AVC and the proposed method.

The experimental results in Table 5 show that the "Weighted" provides about 0.48dB PSNR gains on average in luminance channel compared to the intra prediction of the H.264/AVC. Though the proposed method is applied only to the chrominance prediction, the decrease in the bits for chrominance channels also brings the decrease of the overall bits for the entire image. Thus, it also shows PSNR gains for the luminance channel because we measure the BD-PSNR and BD-Rates for the luminance channel with the overall bits for the entire image. It can be interpreted that the saved bits in the chrominance channel can be allocated to the luminance channel, and improves the PSNR of the reconstructed luminance channel. For the chrominance channels, the proposed method gives about 0.8dB PSNR gains on average compared to the original H.264/AVC intra coding. According to the experiments, the proposed method introduces overall bit reduction and increase of the reconstructed image quality (PSNR) in chrominance channels. Thus the chrominance channels show the better BD-PSNR compared to the luminance channel.

Also, the experimental results show that the linear prediction method is more efficient than the extrapolation method. Because the extrapolation method calculates a prediction value using neighboring pixels as the conventional spatial intra prediction, it cannot get desirable prediction results when neighboring pixel values are too much different with current block. However, linear prediction method determines predic-

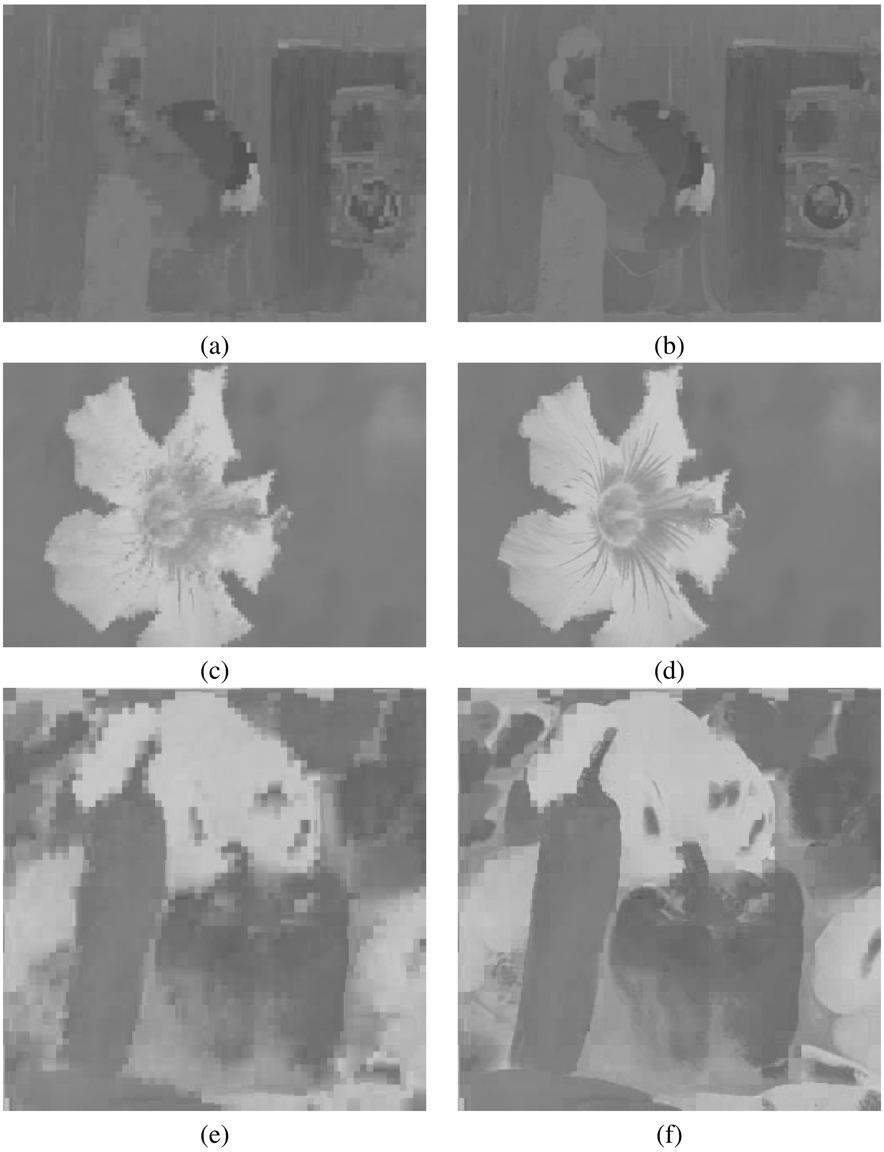


Fig. 6. Intra prediction results of the several test sequences. (a) Original H.264/AVC Intra prediction for the Akko&Kayo U Channel, (b) Proposed method for the Akko&Kayo U Channel, (c) Original H.264/AVC Intra prediction for the flower_foveon V Channel, (d) Proposed method for the flower_foveon V Channel, (e) Original H.264/AVC Intra prediction for the Pepper U Channel, (f) Proposed method for the Pepper U Channel

tion parameter based on spatial correlation but prediction value is calculated from luminance pixels at same pixel position. Thus, the linear prediction method can get a better prediction results if inter-color channel relationship is not significantly changed although pixel values of neighboring regions are significantly different.

Fig. 6 shows the predicted image of U or V channel for some test sequences “Akko&Kayo”, “Flower_Foveon” and “Pepper”. In the H.264/AVC, since the chrominance prediction for YUV 4:2:0 format has only 4 prediction directions, some edges and textures are not well predicted as can be seen in Fig. 6 (a), (c) and (e). However the proposed method provides better predicted image especially near the image edges compared to the original H.264/AVC.

B. Complexity Analysis in YUV 4:2:0 format

The proposed method requires more chrominance prediction modes (9 prediction modes in the proposed method and 4 prediction modes in the conventional method) and some floating point operation for the prediction. Thus the the complexity of the proposed method needs to be investigated. We measure the complexity by calculating the encoding and decoding time. Using a PC with INTEL 3.0GHz CPU and 1G RAM, we measure the total encoding and decoding time with “Weighted” method (the most complex method) for QP 22. The experimental results in Table 6 show that the proposed method increases encoding time about 130%. In case of the decoder, the decoding complexity increases about 30%.

TABLE V
BD-PSNR AND BD-RATE OF THE PROPOSED METHOD FOR YUV 4:2:0 FORMAT

Images	Method	BD-PSNR(Y)	BD-Rate(Y)	BD-PSNR(U)	BD-Rate(U)	BD-PSNR(V)	BD-Rate(V)
Pepper	Extrapolation	0.291dB	-7.40%	0.313dB	-10.02%	0.173dB	-5.03%
	Linear	0.273dB	-6.94%	0.424dB	-13.50%	0.182dB	-5.18%
	Weighted	0.361dB	-9.09%	0.470dB	-14.83%	0.336dB	-9.41%
Artificial	Extrapolation	1.082dB	-12.44%	1.600dB	-22.15%	1.608dB	-21.85%
	Linear	0.989dB	-11.22%	2.119dB	-26.70%	2.061dB	-25.28%
	Weighted	1.206dB	-13.51%	2.283dB	-28.25%	2.272dB	-27.45%
Flower_foveon	Extrapolation	0.504dB	-9.77%	0.489dB	-10.26%	0.725dB	-14.26%
	Linear	0.569dB	-10.94%	0.621dB	-13.00%	1.059dB	-19.80%
	Weighted	0.613dB	-11.63%	0.678dB	-14.18%	1.140dB	-21.00%
Flamenco2	Extrapolation	0.249dB	-4.18%	0.327dB	-6.68%	0.192dB	-4.14%
	Linear	0.367dB	-6.10%	0.718dB	-14.24%	0.482dB	-10.02%
	Weighted	0.352dB	-5.83%	0.647dB	-12.49%	0.490dB	-10.16%
Akko&Kayo	Extrapolation	0.231dB	-4.08%	0.183dB	-4.81%	0.171dB	-3.63%
	Linear	0.268dB	-4.69%	0.402dB	-10.37%	0.311dB	-6.98%
	Weighted	0.298dB	-5.21%	0.410dB	-10.39%	0.313dB	-7.07%
Ballroom	Extrapolation	0.174dB	-3.21%	0.229dB	-6.69%	0.109dB	-3.00%
	Linear	0.221dB	-4.05%	0.625dB	-18.57%	0.221dB	-6.30%
	Weighted	0.228dB	-4.15%	0.576dB	-15.91%	0.236dB	-5.99%
Race1	Extrapolation	0.194dB	-3.70%	0.413dB	-8.42%	0.032dB	-0.65%
	Linear	0.318dB	-5.94%	1.335dB	-25.53%	0.218dB	-5.00%
	Weighted	0.312dB	-5.84%	1.028dB	-19.45%	0.183dB	-4.47%
Average	Extrapolation	0.389dB	-6.40%	0.508dB	-9.86%	0.471dB	-7.51%
	Linear	0.429dB	-7.13%	0.892dB	-17.42%	0.648dB	-11.22%
	Weighted	0.481dB	-7.89%	0.870dB	-16.50%	0.710dB	-12.22%

TABLE VI
ENCODING & DECODING TIME COMPARISON FOR YUV 4:2:0 FORMAT

	Encoding Time			Decoding Time		
Sequence	H.264/AVC	Proposed	ΔT(%)	H.264/AVC	Proposed	ΔT(%)
Pepper	3922ms	9031ms	130.3 %	54.5ms	70.0ms	29.4 %
Artificial	8859ms	20390ms	130.2 %	117.0ms	148.0ms	26.5 %
Flower_foveon	6610ms	15625ms	136.4 %	86.0ms	117.0ms	36.0 %
Flamenco	3578ms	8312ms	132.3 %	32.0ms	45.0ms	40.6 %
Akko&Kayo	3953ms	9203ms	132.8 %	55.0ms	70.0ms	27.3 %
Ballroom	4312ms	10016ms	132.3 %	55.0ms	70.5ms	28.2 %
Race1	3250ms	7656ms	135.7 %	39.0ms	54.5ms	39.7 %
Average			132.9 %			32.5 %

VI. CONCLUSIONS

We have proposed two new intra prediction methods and their combination with the existing ones for the efficient intra compression of color images. The proposed prediction methods estimate a pixel in a non-base color as a weighted sum or as a linear function of pixels in the base color channel. The weights in the first method are derived as a function of photometric distance from a targeting pixel to the reference ones in the already reconstructed base color, and thus requires no side-information. In the second method, a linear relationship between the targeting non-base color and base color is used, where the parameters for the linear models are found also from the already reconstructed base color channel. In the implementation of compression algorithm with the proposed prediction methods, it is found that the weighted combination of proposed methods and the existing ones give better coding gain than selecting one of them as in the conventional algorithms. Experiment results show that the proposed method gives higher coding gain than the conventional methods, especially when there are more color information.

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