An Adaptive Base Plane Filtering Algorithm for Inter-plane Estimation of RGB Images in HEVC RExt

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SUMMARY This letter proposes an adaptive base plane filtering algorithm for the inter-plane estimation of RGB images in HEVC RExt. Because most high-frequency components of RGB images have low inter-plane correlation, our proposed scheme adaptively removes the high-frequency components of the base plane in order to enhance the inter-plane estimation accuracy. The experimental results show that the proposed scheme provides average BD rate gains of 0.6\%, 1.0\%, and 1.2\% in the G, B, and R planes, respectively, with slightly decreased complexity, as compared to the previous inter-plane filtering method.

key words: HEVC RExt, RGB images, inter-plane estimation, inter-plane correlation, adaptive base plane filtering

1. Introduction

Recently, HEVC RExt (high-efficiency video coding range extension) standardization has been under active discussion in JCT-VC (Joint Collaborative Team on Video Coding) meetings. Unlike the previous HEVC, which considers the YUV 4:2:0 color sampling format, with sample precisions less than 10 bits [1], HEVC RExt supports the RGB, YUV 4:2:2, and YUV 4:4:4 color sampling formats, with over 10 bit-depth images, that are used in many professional studio video applications [2].

In natural RGB images, all three channels are very likely to have the same edge content, which means that the inter-plane correlations of RGB images are high. Using this property, inter-plane estimation for the extended color formats was proposed in JCT-VC RCE1 (range extension core experiment 1) [3],[4]. This algorithm estimates the pixels of the current plane using the information of the base plane pixels that have already been coded at the same location of the current block, and it shows good coding performance with RGB images. However, in general, RGB images have low inter-plane correlation in high-frequency subbands [5]. Because of this, high-frequency components of RGB images are one cause of the reduced accuracy of inter-plane estimation.

So, it is a good idea to remove the high-frequency components in the base plane for improving the accuracy of inter-plane estimation. With this point, Ma et al. apply a block-based, switchable de-ringing low-pass filter in the up-sampled base plane (or layer) of SHVC (scalable HEVC) [8]. Due to the fact that the correlation of high-frequency components between enhancement plane and its down-sampled base plane are low in the most part of an image area, this algorithm improves the efficiency of inter-plane prediction of SHVC.

However, this algorithm can not consider the various degree of the inter-plane correlation just because it uses the one low-pass filter in the same color plane. And because the each block of RGB images have a wide range of inter-plane correlation, it requires more filter levels for the sensitive filtering. In addition, it is not easy to find the ringing artifact in the reconstructed base plane of RGB images since the HEVC RExt is targeted the high-quality video applications. So, the de-ringing filter is not necessary for the RGB image coding of HEVC RExt.

Therefore, in this letter, we propose an adaptive base plane filtering algorithm without de-ringing filter to improve the accuracy of inter-plane estimation of RGB images. In our scheme, we use three low-pass filters adaptively in the G base plane prior to the inter-plane estimation in order to remove any high-frequency components of the G base plane. As referred to earlier, we do not apply the de-ringing filter in the base plane to reduce the complexity. For the adaptive filtering, we decide whether or not to apply the filter at each block unit, and select the filter level based on the inter-plane correlation of the templates around the current block.

2. Inter-Plane Estimation of RGB Images

The inter-plane estimation technique estimates the current plane at each block unit using the information of the base plane that has already been encoded [4]. With this algorithm, we can obtain good coding gains in RExt test images, and significantly better gains in RGB images. This scheme is added as a new mode in the chroma intra-prediction, and is selected through competition with previous chroma intra-prediction modes.

The inter-plane estimation for RGB images in the B or R plane is estimated at each block unit using the information of the G base plane, which is defined as

\begin{equation}
C_{\text{pred}}[x,y] = \alpha G_{\text{recon}}[x,y] + \beta
\end{equation}

where \(C_{\text{pred}}\) is the estimated block of the B or R plane, \(G_{\text{recon}}\) is the decoded block of the G base plane, and \([x,y]\) is the location of the pixel in the block. \(\alpha\) and \(\beta\) are weighted values that are inferred by the templates around the \(G_{\text{recon}}\) and \(C_{\text{pred}}\) blocks, and are defined as follows:

\begin{itemize}
\item \(\alpha = \frac{\sum_{i=0}^{W-1} \sum_{j=0}^{H-1} |G_{\text{recon}}[x+i,y+j]-G_{\text{recon}}|[x,y]|}{\sum_{i=0}^{W-1} \sum_{j=0}^{H-1} |G_{\text{recon}}|[x,y]|}
\item \(\beta = \frac{\sum_{i=0}^{W-1} \sum_{j=0}^{H-1} \max\{|G_{\text{recon}}[x+i,y+j]|, \delta\}}{\sum_{i=0}^{W-1} \sum_{j=0}^{H-1} \max\{|G_{\text{recon}}|[x,y]|, \delta\}}
\end{itemize}
\[ \alpha = \frac{R(T_G, T_C)}{R(T_G, T_G)}, \quad \beta = M(T_C) - \alpha M(T_G) \]  

(2)

where \( T_G \) and \( T_C \) are template pixels of \( G_{\text{recon}} \) and \( C_{\text{pred}} \), respectively, \( M(A) \) is the average value of \( A \), and \( R(A,B) \) is the cross-covariance value of \( (A,B) \). Figure 1 shows the inter-plane estimation of RGB images.

3. Proposed Algorithm

As referred to earlier, RGB images generally have low inter-plane correlation in high-frequency subbands [5]. To confirm this, we calculate the inter-plane correlation in four subbands of RGB test images using the frequency analysis method [6]. Table 1 shows the inter-plane subband correlation of the first frame images, which are used in HEVC RExt. The four subbands include the LL (both rows and columns are low-pass filtered), the LH (rows are low-pass filtered and columns are high-pass filtered), the HL (rows are high-pass filtered and columns are low-pass filtered), and the HH (both rows and columns are high-pass filtered) subbands. As shown in Table 1, the correlation of the high-frequency subbands (HH, HL, and LH) is lower than that of the low-frequency subband (LL) for most images, except for the EBULupoCandlelight and EBURainFruits images. This is the main cause of the diminished inter-plane estimation accuracy, because it is directly proportional to the inter-plane correlation of RGB images.

We also calculate the variations of the inter-plane correlation within a frame of RGB images to confirm that the each block of images have a wide range of inter-plane correlation. Figures 2 (b) and 2 (c) show the inter-plane HH subband correlations for every 8x8 block unit within the first frame of the ParkScene RGB image. In this figure, the brightness is proportional to the correlation. As shown in Figs. 2 (b) and 2 (c), the various range of inter-plane correlation areas exist within the same frame of the image, so to optimize the low-pass filtering scheme, we should control the strength of the filter.

Based on these experimental results, we propose an adaptive PU (prediction unit)-based low-pass filtering algorithm in inter-plane estimation to remove the high-frequency components of the G base plane. By eliminating the high-frequency components that have low inter-plane correlation, we can improve the inter-plane correlation of the RGB images and therefore, the coding efficiency of the inter-plane estimation will be increased. In our algorithm, we add a proposed filtering mode in the chroma intra-prediction for the PU-based adaptive filtering. For the elaborate filtering, we also control the filter strength based on the inter-plane correlation of the templates around the current block for considering the variations of the inter-plane correlation within a frame of images, as referred to earlier.

At first, we calculate the inter-plane HH subband cor-
relation of the templates around the \( G_{\text{recon}} \) and \( C_{\text{pred}} \) blocks, such as

\[
\begin{align*}
\text{Corr}(T_{G_{\text{HH}}} \cdot T_{C_{\text{HH}}}) &= R_{\alpha}(T_{G_{\text{HH}}} \cdot T_{C_{\text{HH}}}) \\
\text{Corr}(T_{G_{\text{HH}}} \cdot T_{C_{\text{HH}}}) &< T_1 \\
\text{Corr}(T_{G_{\text{HH}}} \cdot T_{C_{\text{HH}}}) &\geq T_2
\end{align*}
\]

(3)

where \( T_{G_{\text{HH}}} \) and \( T_{C_{\text{HH}}} \) are the HH subbands of \( T_G \) and \( T_C \), respectively, and \( R_{\alpha}(A, B) \) is the normalized cross-covariance of \( (A, B) \). We can estimate that the inter-plane HH subband correlation of the \( G_{\text{recon}} \) and \( C_{\text{pred}} \) blocks will be similar to \( \text{Corr}(T_{G_{\text{HH}}} \cdot T_{C_{\text{HH}}}) \). Based on this estimation, we select the low-pass filter strength that will be used in the base plane filtering, such as

\[
\text{LPF coefficient} = \begin{cases} 
(1, 2, 1)/4, & \text{if } \text{Corr}(T_{G_{\text{HH}}} \cdot T_{C_{\text{HH}}}) < T_1 \\
(1, 14, 1)/16, & \text{if } \text{Corr}(T_{G_{\text{HH}}} \cdot T_{C_{\text{HH}}}) \geq T_2 \\
(1, 6, 1)/8, & \text{otherwise}
\end{cases}
\]

(4)

where \( T_1 \) and \( T_2 \) are the thresholds and are set to 0.3 and 0.7 in our implementation. In the integer shift operation and to minimize the complexity, we use simple 3-tap low-pass filter coefficients, as shown in (4). In this step, we select a strong LPF coefficient if \( \text{Corr}(T_{G_{\text{HH}}} \cdot T_{C_{\text{HH}}}) \) is low, and if \( \text{Corr}(T_{G_{\text{HH}}} \cdot T_{C_{\text{HH}}}) \) is high, then we select a weak LPF coefficient. And otherwise, we select a medium LPF strength. Using this method, we can apply the filter level adaptively in accordance with the current block’s inter-plane correlation of high-frequency components. After selecting the LPF coefficient, we apply the low-pass filter in \( G_{\text{recon}} \) and perform the inter-plane estimation, which is defined as

\[
C_{\text{pred}}[x, y] = \alpha G_{\text{LPF}}^{\text{recon}}[x, y] + \beta
\]

(5)

where \( G_{\text{LPF}}^{\text{recon}} \) is the low-pass filtered block in \( G_{\text{recon}} \) at the rows and columns with the filter coefficient selected in (4). \( \alpha \) and \( \beta \) are derived using the same process as in (2).

Figure 3 shows the overall process of chroma intra-prediction with the proposed algorithm in HEVC RExt.

4. Experimental Results

To verify the performance of the proposed algorithm, we compare our scheme with the previous inter-plane estimation method. For the experiment, we use HM10.0_RExt version of software with eight RGB test images based on the common test conditions of HEVC RExt[7]. Because the inter-plane estimation is performed in the chroma intra-prediction only, we get the coding results in A1 (all intra) with SHT (super-high tier, QP: 12, 17, 22, 27).

For our proposed algorithm, we add a one-prediction mode in the chroma intra-prediction. Table 2 shows the binarization setting of the \text{intra\_chroma\_pred\_mode} flag for a new chroma intra-prediction mode.

Table 3 and 4 shows the performance of previous CU (Coding Unit)-based adaptive filtering algorithm [8] with the de-ringing filter compared to the inter-plane estimation [4].

Table 2 Specification of \text{intra\_chroma\_pred\_mode} on \text{chroma\_pred\_from\_luma\_enable\_flag} for proposed algorithm.

| \text{intra\_chroma\_pred\_mode} | \text{chroma\_pred\_from\_luma\_enable\_flag} = 1 | \text{chroma\_pred\_from\_luma\_enable\_flag} = 0 |
|---|---|---|
| prefix | suffix | prefix | suffix |
| 6 (DM,CHROMA) | 0 | n/a | n/a |
| 5 (proposed algorithm) | 10 | 1 | 0 | n/a |
| 4 (inter-plane estimation) | 10 | 0 | 0 | n/a |
| 0 (PLANAR) | 11 | 11 | 1 | 100 |
| 1 (VERTICAL) | 11 | 01 | 1 | 01 |
| 2 (HORIZONTAL) | 11 | 10 | 1 | 10 |
| 3 (DC) | 11 | 11 | 1 | 11 |

Table 3 The BD-rate gain and complexity of encoding/decoding of previous filtering algorithm [8] with the de-ringing filter compared to the inter-plane estimation [4].

| Test image | BD-rate gain(%) | Complexity(%) |
|---|---|---|
| Traffic | 0.4 | 0.0 | 0.2 | 111 | 102 |
| Kimono1 | 0.3 | 0.6 | 0.7 | 110 | 111 |
| EBULapoCandlelight | 0.3 | 0.4 | 0.5 | 110 | 110 |
| EBURainFruits | 0.9 | 0.1 | 0.4 | 110 | 105 |
| VenueVu | 0.0 | 0.4 | 0.5 | 110 | 110 |
| DucksAndLegs | 0.9 | 0.0 | 0.0 | 110 | 102 |
| OldTownCross | 0.7 | 2.9 | 3.0 | 110 | 107 |
| ParkScene | 0.2 | 0.5 | 0.5 | 110 | 107 |
| Overall | 0.0 | 0.6 | 0.7 | 110 | 106 |

Table 4 The BD-rate gain and complexity of encoding/decoding of previous filtering algorithm [8] without the de-ringing filter compared to the inter-plane estimation [4].

| Test image | BD-rate gain(%) | Complexity(%) |
|---|---|---|
| Traffic | 0.4 | 0.1 | 0.1 | 108 | 97 |
| Kimono1 | 0.2 | 0.6 | 0.6 | 108 | 101 |
| EBULapoCandlelight | 0.5 | 0.1 | 0.1 | 108 | 101 |
| EBURainFruits | 0.9 | 0.3 | 0.2 | 107 | 96 |
| VenueVu | 0.2 | 0.1 | 0.0 | 107 | 101 |
| DucksAndLegs | 0.0 | 0.0 | 0.0 | 108 | 100 |
| OldTownCross | -2.3 | -4.1 | 0.1 | 108 | 101 |
| ParkScene | -0.2 | -0.5 | -0.5 | 108 | 101 |
| Overall | 0.0 | -0.5 | -0.7 | 108 | 100 |
filter is almost zero with the increased decoding complexity. So, we can say that the de-ringing filter is not effective in the inter-plane estimation of RGB images. Besides, with the previous filtering algorithm, the average BD-rate gain in the G plane is almost zero, and the BD-rate gain in the B,R planes are small, except ‘OldTownCross’ sequence. Because this algorithm uses the one low-pass filter in all area of the G base plane, it can not consider the various degree of inter-plane correlation in the image. For this reason, it has some BD-rate loss in three test sequences, ‘Traffic’, ‘EBULupoCandlelight’, and ‘EBURainFruits’, because these test sequences have high-average inter-plane correlations in all frequency subbands, as shown in table 1. Therefore, we can say that the various filter levels for the highly correlated images are needed for the sensitive inter-plane estimation.

Table 5 shows the performance of the proposed adaptive base plane filtering algorithm compared to the inter-plane estimation of RGB images [4]. The proposed scheme has average BD-rate gains of 0.6%, 1.0%, and 1.2% in the G, B, and R planes, respectively, which shows that the proposed filtering is effective at increasing the accuracy of inter-plane estimation. As shown in this table, proposed algorithm also has more average BD-rate gains of 0.5% in each color planes than the previous filtering algorithm. In the three test sequences as mentioned earlier, we can see that the proposed algorithm has some coding gains. With this results, we can know that our proposed scheme is also effective for the highly correlated RGB images.

A comparison of the complexity shows that the average encoding and decoding times of the proposed algorithm decreased 1% and 3%, respectively, as compared to those of the previous inter-plane filtering algorithm with the de-ringing filter. These results show that proposed scheme is effective at increasing the coding efficiency with the decreased complexity compared to the previous inter-color plane filtering algorithm.

| Test image        | BD-rate gain (%) | Complexity (%) |
|-------------------|-----------------|----------------|
|                  | G    | B    | R    | G    | B    | R    |
| Traffic           | 0.1  | -0.2 | -0.7 | 109  | 103  |
| Kimono1           | -0.8 | -1.0 | -1.2 | 110  | 104  |
| EBUlupoCandlelight| -0.4 | -0.7 | -1.2 | 109  | 102  |
| EBURainFruits     | 0.3  | -0.3 | -0.9 | 108  | 104  |
| VenueVu           | -0.7 | -1.3 | -1.4 | 109  | 102  |
| DucksAndLegs      | -0.6 | -0.6 | -0.5 | 110  | 102  |
| OldTownCross      | -2.0 | -2.6 | -2.2 | 108  | 102  |
| ParkScene         | -0.8 | -1.1 | -1.1 | 108  | 103  |
| Overall           | -0.6 | -1.0 | -1.2 | 109  | 103  |

5. Conclusions

In this letter, we propose an adaptive base plane filtering algorithm to improve the accuracy of the inter-plane estimations of RGB images in HEVC RExt. The proposed scheme applies an adaptive low-pass filter in the G base plane to remove the high-frequency components that have low inter-plane correlation, which reduce the efficiency of the inter-plane estimation. In the experimental results, the proposed algorithm has average BD-rate gains of 0.6%, 1.0%, and 1.2% in the G, B, and R planes, respectively, with the decreased complexity as compared to the previous inter-plane filtering method. The proposed algorithm also has average BD-rate gains of 0.5% in each color planes than the previous filtering algorithm. These results show that the proposed algorithm is effective at increasing the coding efficiency of HEVC RExt.

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