TRANSMISSION OF POST-FILTER HINTS FOR VIDEO CODING SCHEMES

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ABSTRACT

In the field of video coding, it is common to apply post-filtering in order to enhance the quality of a decoded video signal. An optimal post-filter can be designed by minimizing the error between the original signal and the decoded filtered signal. This approach requires information about the statistics of the decoded image and the original signal, which is available on encoder-side only. In order to provide this necessary information to a post-filter on the decoder-side, this paper presents a technique to transmit so-called post-filter hints in the bit-stream of a video coding scheme. In H.264/AVC, mean picture quality improvements of 0.4dB are achieved with this technique compared to H.264/AVC without post-filtering. This corresponds to a mean bit-rate reduction of 8.5% at same picture quality. The mean improvements are calculated as an average over all sequences and bit-rates that are specified in the common test conditions of JVT for professional applications as well as over additional HD sequences.

***Index Terms*—**Wiener filter, post-filter, video coding, H.264/AVC

1. INTRODUCTION

In a hybrid video coder, the input image is divided into macroblocks. These macroblocks are coded using prediction schemes, transformation, quantization, and entropy coding. Due to the quantization, errors are introduced. Especially at lower bitrates, these errors lead to blocking artifacts. In order to reduce these blocking artifacts, a de-blocking filter is applied in H.264/AVC [1].

One drawback of such a de-blocking filter is that it cannot reduce the quantization error inside a block, because it filters only the pixels at the boundary of an image block. Another drawback is related to video coding at high-fidelities (e.g. 45dB) used for professional applications. At these fidelities, blocking artifacts cannot be observed and the quantization error has more a noise-like characteristic. Thus, a de-blocking filter does not lead to subjective or objective improvements at high-fidelities.

In order to overcome these drawbacks of the de-blocking filter and to improve the picture quality, especially at higher bit-rates, we present an optimal Wiener post-filtering technique. This Wiener post-filter is designed to reduce the quantization noise and thus enhance the decoded signal. Since such a Wiener post-filter requires information, which is only available at the encoder-side (i.e. information from the original image signal), this information is transmitted in the bit-stream of a video coding scheme. On the decoder-side this information is extracted from the bitstream and is used to design and apply an optimal Wiener post-filter.

The background of the Wiener filter technique is described in the next section. Two different ways of applying this technique as a post-filter to video coding schemes are introduced in section 3. Section 4 presents experimental results. The paper closes with conclusions and references.

2. OPTIMAL WIENER FILTERING

Linear optimum discrete-time filters are collectively known as Wiener filters. Figure 1 shows a block diagram that depicts the basic idea of Wiener filtering.

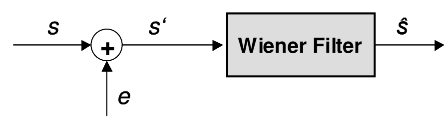


Figure 1: Block diagram illustrating Wiener filtering

The goal of a Wiener filter is to remove additive noise e that has corrupted the input signal s. For this purpose, the corrupted signal s’ is processed in the Wiener filter unit.

In this paper s represents the original video signal and we interpret the quantization noise, which is introduced by a video coding scheme, as the additive noise e. The disturbed signal s', which represents the decoded signal, is processed in the Wiener post-filter unit. Such a Wiener post-filter is designed to minimize the mean-square error between the distorted signal s' and the original signal s. Thus, the resulting filtered signal $\hat{s}$ is closer to the original signal s than to the distorted signal s' and therefore the picture quality is improved.

In order to calculate an optimal Wiener filter, the autocorrelation function $r_{s's'}$ of the decoded signal *s'* and the cross-correlation function $r_{s's}$ between the decoded signal *s'* and the original desired signal *s* is calculated. The size of the derived correlation matrices define the maximum size of the Wiener post-filter (let's assume that *M* defines the maximum length of the Wiener filter in one direction). Then, the *MxM* autocorrelation matrix $R_{s's'}$ of the decoded signal is derived from the autocorrelation function $r_{s's'}(k,l)$:

$$r_{s's'}(k,l) = \frac{1}{width \cdot height} \sum_{m}^{width-1} \sum_{n}^{height-1} s'(m,n) \cdot s'(m+k, n+l) \quad (1)$$

The cross-correlation matrix $R_{s's}$ is derived from the cross-correlation function $r_{s's}$ between the original signal *s* and the decoded signal *s'*:

$$r_{s's}(k,l) = \frac{1}{width \cdot height} \sum_{m}^{width-1} \sum_{n}^{height-1} s'(m,n) \cdot s(m+k, n+l) \quad (2)$$

With the knowledge of the correlation information and applying Wiener-Hopf equations, the optimal Wiener filter coefficients *w* can be derived as follows:

$$w = R_{s's'}^{-1} \cdot R_{s's}, \quad (3)$$

where $R_{s's'}^{-1}$ denotes the inversion of the autocorrelation matrix $R_{s's'}$. [2][3].

In order to calculate the cross-correlation function $r_{s's}$, which is needed to solve equation (3), the input signal s is needed (see equation (2)).

3. TRANSMISSION OF POST-FILTER INFORMATION

Since a Wiener post-filter requires information, which is only available at the encoder-side (see section 2), this information is transmitted in the bit-stream of a video coding scheme. In the following, the transmissions of two types of post-filter information (so-called post-filter hints) are introduced.

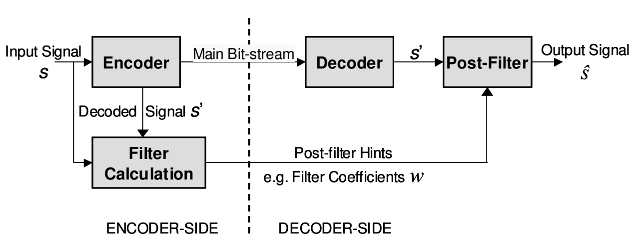


Figure 2: Post-filter in a video coding scheme that applies filter coefficients, which are calculated on the encoder-side and transmitted to the decoder-side.

Figures 2 shows a block diagram that illustrates the transmission of the first type of post-filter hints.

On the encoder-side, the filter coefficients *w* are calculated using the input signal *s* and the decoded signal *s'*. The filter coefficients *w* are transmitted to the decoder. At the decoder-side, the transmitted filter coefficients are used for post-filtering of the decoded signal s' and generate the output signal $\hat{s}$.

In order to provide more flexibility, the second type of post-filter hint transmission includes generalized post-filter hints and shifts the calculation of the filter to the decoder-side. This second type is illustrated in the block diagram of Figure 3.

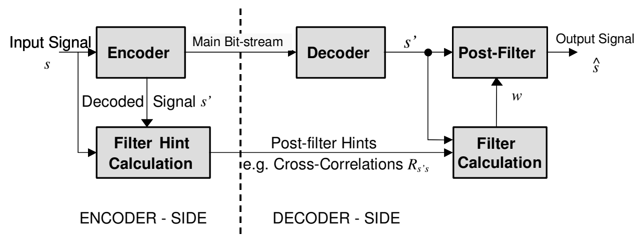


Figure 3: Post-filter in a video coding scheme that applies filter coefficients, which are calculated on the decoder-side using transmitted cross-correlations.

In this second variant, a 'Filter Hint Calculation' block generates post-filter hints on the encoder-side using the input signal *s* and the locally decoded signal *s'*. In the example of Figure 3, these hints are the cross-correlations $r_{s's}$ from equation (2). On the decoder-side, a 'Filter Calculation' block uses the post-filter hints to design the post-filter. In the example of Figure 3, *s'* is used to calculate the autocorrelation matrix $R_{s's'}$. Together with the transmitted cross-correlations $R_{s's}$, equation (3) can be solved to calculate the Wiener filter coefficients *w*. In the Post-filter block, the coefficients *w* are applied to generate the output signal $\hat{s}$.

The second variant provides more flexibility, because the filter design is shifted to the decoder-side. For example, it provides scalability in terms of complexity spent for the post-filtering. A decoder has the choice to design and perform an individual post-filter method exploiting the post-filer hints of the input signal. A low-complexity decoder applies the correlation information in order to calculate a Wiener post-filter with short-length resulting in a reduced amount of additional complexity. A decoder allowing higher complexity to the filtering, applies a Wiener post-filter with maximum length in order to achieve the highest quality of the filtered video signal. Since $R_{s's}$ and *w* have the same size, the amount of post-filter hint data to be transmitted is similar for both variants.

For the implementation in H.264/AVC, we defined a new so-called 'Post-Filter Hint' SEI message to transmit the additional filter data (SEI – Supplemental Enhancement Information). SEI messages assist in processes related to decoding, display, post-processing or other purposes. The post-filter hint SEI message provides the decoder with the coefficients of a post-filter designed on encoder-side or with the correlation information to design a post-filter on decoder-side.

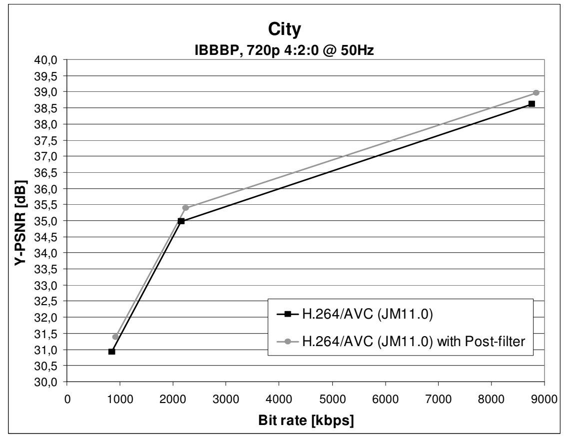
4. EXPERIMENTAL RESULTS

The improvement of coding efficiency achieved with the optimal post-filter was evaluated for sequences with different color samplings (4:2:0, 4:4:4) focusing on higher bit-rates. At high bit-rates the quantization error has a noise-like character and can thus be reduced significantly by the presented Wiener filter approach. With the described technique, mean quality improvements of 0.4dB are achieved compared to H.264/AVC coding without post-filtering. This corresponds to a mean bit-rate reduction of 8.5% at same picture quality. These mean improvements are calculated as an average over the whole JVT test-set for professional applications described in [5] as well as over other HD sequences. Maximum bit-rate reductions of 15% can be observed. All results presented in this paper include the overhead, which is necessary to encode the post-filter hint SEI message.

The used post-filter is a non-separable Wiener filter with 5x5 taps. In addition, the de-blocking filter is enabled during H.264/AVC encoding.

Each of the following Figures 4, 5, and 6 shows an exemplary rate-distortion plot for three different encoding settings. Furthermore, it is common in the area of video coding to express coding efficiency improvements in terms of bit-rate reductions. Therefore, each of the figures shows an additional bar diagram with the derived bit-rate reductions at a fixed PSNR. In these diagrams, different quality levels, i.e. PSNR values, are evaluated.

Figure 4 shows the experimental results for 4:2:0 sequences in the YUV color space. In the case of 4:2:0 color sampling, the reference software of the joint video team is used (JM11.0 – Joint Model) with hierarchical B-frame coding structure. 4:2:0 test-sequences are Big Ships, City, Crew and Harbour. The resolution is 720p (1280x720 pixel) at a frame rate of 50Hz.



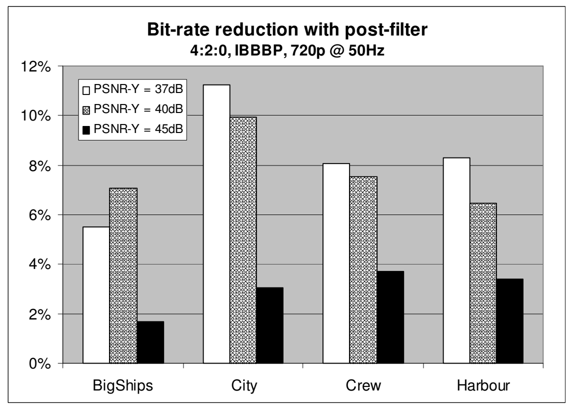


Figure 4: Exemplary RD-curve and bit-rate reductions compared to standard H.264/AVC for sequences with 4:2:0 color sampling and IBBBP coding structure.

Figure 5 and Figure 6 show the results for the 4:4:4 color sampling in the RGB color space. In that case, the 4:4:4 reference software of the joint video team (JFVM1.9 – Joint 4:4:4 Video Model) is used for simulations. As test material serve the sequences Playing Cards, Table Setting, Freeway, Man In Restaurant, Plane, Rolling Tomatoes, and Waves from the Viper test-set and the Dolby Film-Kit. The resolution is 1080p (1920x1080 pixel) at a frame rate of 24Hz.

Results for Intra-only coding (Figure 6) as well as for coding with hierarchical B-frames (Figure 5) are shown in the following. In the 4:4:4 case, each color component has a similar importance because there is no sub-sampling. Therefore the arithmetic mean PSNR values of the color components are shown in the figures.

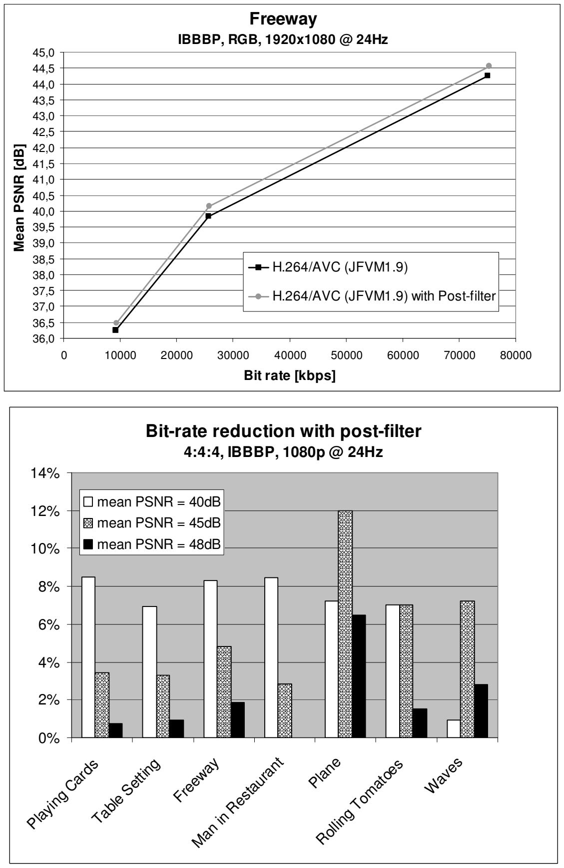


Figure 5: Exemplary RD-curve and bit-rate reductions compared to standard H.264/AVC for RGB sequences with 4:4:4 color sampling and IBBBP coding structure.

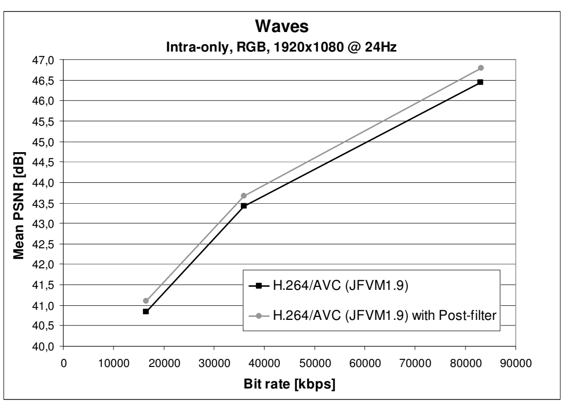


Figure 6a: Exemplary RD-curve for the RGB sequence "Waves" with 4:4:4 color sampling and for intra-only coding.

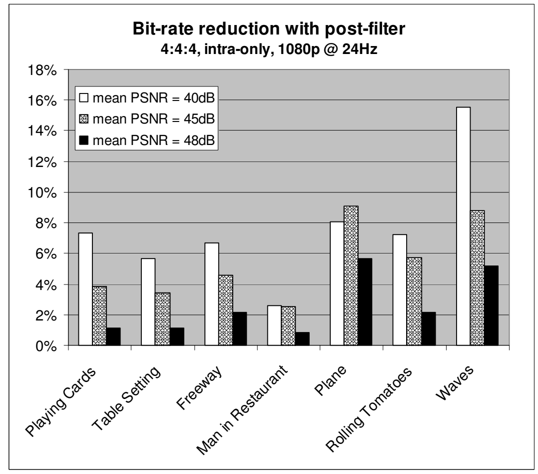


Figure 6b: Bit-rate reductions compared to standard H.264/AVC for RGB sequences with 4:4:4 color sampling and for intra-only coding.

5. CONCLUSION

In order to allow the usage of an optimal Wiener post-filter on the decoder-side of a video coding scheme, this paper presents a technique that transmits post-filter hints in the bitstream. Significant quality enhancements can be achieved with a small amount of additional information such as Wiener filter coefficients or cross-correlations. Due to these excellent improvements, this technique was recently adopted in the amendment for professional applications of H.264/AVC as the so-called post-filter hint SEI message [4].

6. REFERENCES

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