Rate-Distortion Oriented Joint Video Pre-filtering and Compression

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Abstract

This paper proposes a rate-distortion oriented joint video pre-filtering and compression algorithm with pre-filtering by VBM3D and compression by H.264/AVC standard. Practical results show that proposed approach enhances the performance of H.264/AVC by improving subjective visual quality and saving bitrates.

Index Terms: pre-filtering, compression, rate control.

I. Introduction

In current video compression systems, the most essential task is to fit a large amount of visual information into a narrow bandwidth of transmission channels or into a limited storage space, while maintaining the best possible visual perception for the viewer [1]. H.264/AVC is one of the most commonly used video compression standard in the areas of broadcasting, streaming and storage. It has achieved a significant improvement in rate-distortion efficiency relative to previous standards [2].

Digital video sequences can be easily corrupted by noise during acquisition, processing or transmission, and the noise in video sequences not only degrades the subjective quality, but also affects further coding processes in video compression. However, codecs based on H.264/AVC standard only have filter to decrease blocking artifacts caused by quantization instead of other type of source noise. Therefore, it will be desirable to prefilter input video sequence before compression process, since pre-filtering can enhance both the visual quality and coding efficiency of compression system [4].

Traditional video pre-filtering and compression are separate processes and cannot guarantee those chosen filtering and quantization parameters are optimal taking into account of rate-distortion framework. However, a rate-distortion based control scheme for pre-filtering has been presented in the literature [3]. Also it has been suggested that joint pre-filtering and compression algorithm improves the performance of the coding process by producing higher quality compressed video frames, with increased Peak-to-noise ratio (PSNR) and reduced compression artifacts, at the same bitrate, compared to compression without pre-filtering [4].

In this paper we continue this research direction in the case of joint parameters selection for compression system with pre-filtering by VBM3D [5] and compression by H.264/AVC standard.

This paper is structured as follow. Section II-A first gives the typical scheme of separate pre-filtering and compression, and section II-B proposes the optimization task of joint pre-filtering and compression, then follows brief description of VBM3D in section II-C and practical results in section II-D.

II. Joint pre-filtering and compression

A. Typical pre-filtering scheme

Typical video compression systems [6], [7], [8] have two separate parts for pre-processing and compression, and parameters are chosen separately for them, in other words, heuristic methods are typically employed.

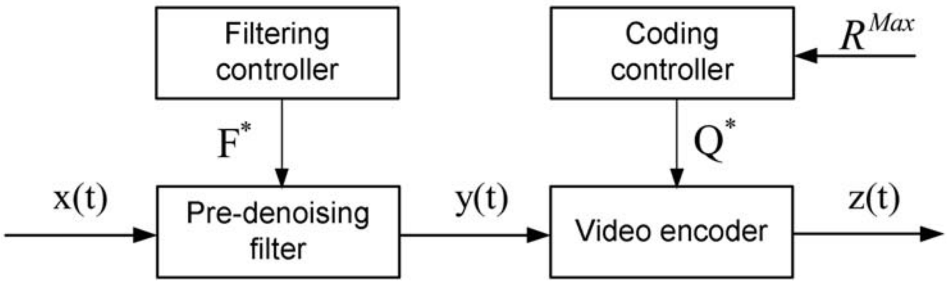


Fig. 1: Typical pre-filtering and compression scheme

In this scheme (see Fig. 1) video sequence $x(t)$ is filtered by pre-processing filter with parameter F^* and the system obtains the filtered sequence $y(t)$, then inputs $y(t)$ into video encoder with quantization parameters Q^* and outputs compressed bitstream $z(t)$. Since filtering parameters and quantization parameters are selected separately, this system cannot guarantee those chosen parameters are optimal in the sense of rate-distortion framework.

B. Definition of Optimization Task

In [4], an integrated approach to pre-filtering and compression of image sequences was introduced, where Gaussian filter and MPEG-2 video compression standard are employed to improve compression performance by removing blocking artifacts with consideration of the operational rate-distortion framework.

In this section, we continue this research direction in case of joint parameters selection for compression system with pre-filtering by VBM3D (see part II-C) and compression by H.264/AVC encoder.

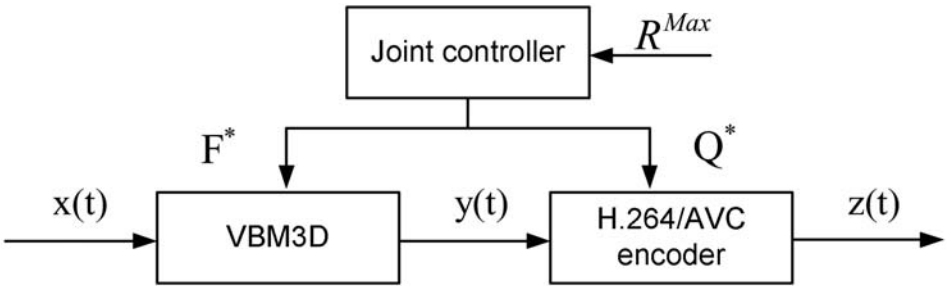


Fig. 2: Joint pre-filtering and compression scheme

In this scheme (see Fig. 2) video sequence $x(t)$ is filtered by VBM3D with parameter F^* and the system obtains the filtered sequence $y(t)$, then input $y(t)$ into H.264/AVC encoder with quantization parameters Q^* and output compressed bitstream $z(t)$. Filtering parameters and quantization parameters are chosen based on bit-budget and rate-distortion framework by *Joint Rate controller*.

The task of joint video denoising and compression is to select the sequence of filtering parameters F^*, and quantization parameters Q^*, so that

$$\begin{cases} F^*, Q^* = \arg \min_{\substack{F \subseteq \{F\} \\ Q \subseteq \{Q\}}} \sum_i D(F_i, Q_i), \\ \sum_i R(F_i, Q_i) \leq R^{Max}. \end{cases} \tag{1}$$

where, F_i and Q_i are filtering and quantization parameters for frame i. Respectively, $D(F_i, Q_i)$ and $R(F_i, Q_i)$ are the distortion and rate of frame i with filtering parameter F_i and quantization parameter Q_i. R^{Max} is the bit-budget, which means the maximum bandwidth in data transmission.

In joint pre-filtering and compression, we provide a set of filtering parameter F and a set of quantization parameters Q (see Section II-D). A full search is used here to find the optimal solutions for parameters according to bit restriction and rate-distortion framework.

C. Video Block-Matching and 3D Filtering

VBM3D is an effective video denoising method based on highly sparse signal representation in local 3D transform domain [5]. It is the extension of Block-Matching and 3D Filtering for Image [9], and achieves state-of-the-art denoising performance in terms of both peak signal-to-noise ratio and subjective visual quality.

The general procedure consists of two different steps: hard-thresholding and Wiener filtering. In the first step, a noisy video is processed in raster scan order and block-wise manner. As for each reference block, a 3D array is grouped by stacking blocks from consecutive frames which are similar to the currently processing block. In grouping, a predictive-search block-matching is proposed. Then a 3D transform-domain shrinkage (hard-thresholding in first step, and Wiener filtering in second step) is applied to each grouped 3D array. Since the obtained block estimates are always overlapped, they are aggregated by a weighted average to obtain an intermediate estimate. In second step, the intermediate estimate from first step is used together with noise video for grouping and applying 3D collaborative empirical Wiener filtering.

D. Practical Result

In our experiments, proposed joint pre-filtering and compression algorithm is based on VBM3D (see filter setting in Table I and parameters are explained in Table II) and H.264/AVC reference software JM V.17.1 [10] in baseline profile (see codec setting in Table III).

Recall Equation 1, the set of filtering parameters $\{F\}$ include two parts: one is fixed setting which is shown on Table I; the other are different sigma values, varying 0 to 5 with a step of 0.5. Similarly the set of quantization parameters $\{Q\}$ include $QPI \in \{21, 22 \ldots 45\}$ for *I* frame, and respectively $QPP_i = QPI_i + 5$ for *P* frames [11]. Then full search is used to find best sigma used in pre-filtering for each quantization parameter in compression.

Practical results were obtained for the test video sequences $hall$ with 352×288 resolution at a frame rate of 30 fps. The performance of the proposed approach is compared to that of H.264/AVC reference software JM V.17.1 encoder in baseline profile (codec setting is the same as in Table III).

Two experiments modes are used here: *quantization mode* and *constant bitrate mode*.

- In *constant quantization mode*: in filtering part, eleven σ are used as input filtering parameters for VBM3D, varying 0 to 5 with a step of 0.5, because noise level in original video sequences is typically small, less than 5 according to experiments. In compression part, we set quantization parameter $QPI \in \{21, 22 \ldots 45\}$ for *I* frame, and respectively $QPP_i = QPI_i + 5$ for *P* frames [11]. Then we use full search to find the best filtering parameters F^* for each quantization parameters Q^*.

- In *constant bitrate mode*: in filtering part, we use the same strategy, but in compression part, we enable the constant bitrate control in H.264/AVC encoder and fix the bitrate with a proper value.

TABLE I
VBM3D SETTING

Parameters	Settings
denoiseFrames	5
transform-2D-HT-name	Identity transform
transform-3rd-dim-name	Haar
N1	8
Nstep	6
Nb	16
N2	4
Ns	5
tau-match	3000
lambda-thr3D	2.7
Wiener filtering	–

TABLE II
SUMMARY OF PARAMETERS INVOLVED IN VBM3D SETTING

Parameters	Description
denoiseFrames	Temporal window length
transform-2D-HT-name	2D transform used for hard-thresholding filtering
transform-3rd-dim-name	tranform used in the 3-rd dim
N1	N1 × N1 is the block size used for the hard-thresholding (HT) filtering
Nstep	sliding step to process every next refernece block
Nb	number of blocks to follow in each next frame, used in the predictive-search BM
N2	maximum number of similar blocks (maximum size of the 3rd dimension of the 3D groups)
Ns	length of the side of the search neighborhood for full-search block-matching (BM)
tau-match	threshold for the block distance (d-distance)
lambda-thr3D	threshold parameter for the hard-thresholding in transform domain

Fig. 3 shows the case of *constant quantization mode for IPPP coding*. We can tell from the result, joint pre-filtering and compression have consistent PSNR gains which is up to 0.5 dB, and bitrate savings is up to 13.4%.

Fig. 4 shows that within *constant bitrate mode* (target bitrate = 215 kbit/s), joint pre-filtering and compression make PSNR gain up to 1.2 dB for *hall*. Fig. 5 and Fig. 6 are two different frames taken from output video sequences under two compression modes. The results show proposed joint pre-filtering and compression system can improve the visual quality by removing some noise at the door (compare (c) and (e)) and ringing artifacts around the foot (compare (d) and (f)).

TABLE III
CODEC'S SETTING

JM codec V.17.1	Settings
Profile	Baseline
Motion estimation	16×16 block in radius 16
search mode	Simplified UMHexagon search
Number of reference frames	1
Skip mode	Enable
De-blocking filter	Enable
RD optimization	Low complexity mode
Rate control	Disable
slice size	50 macroblocks

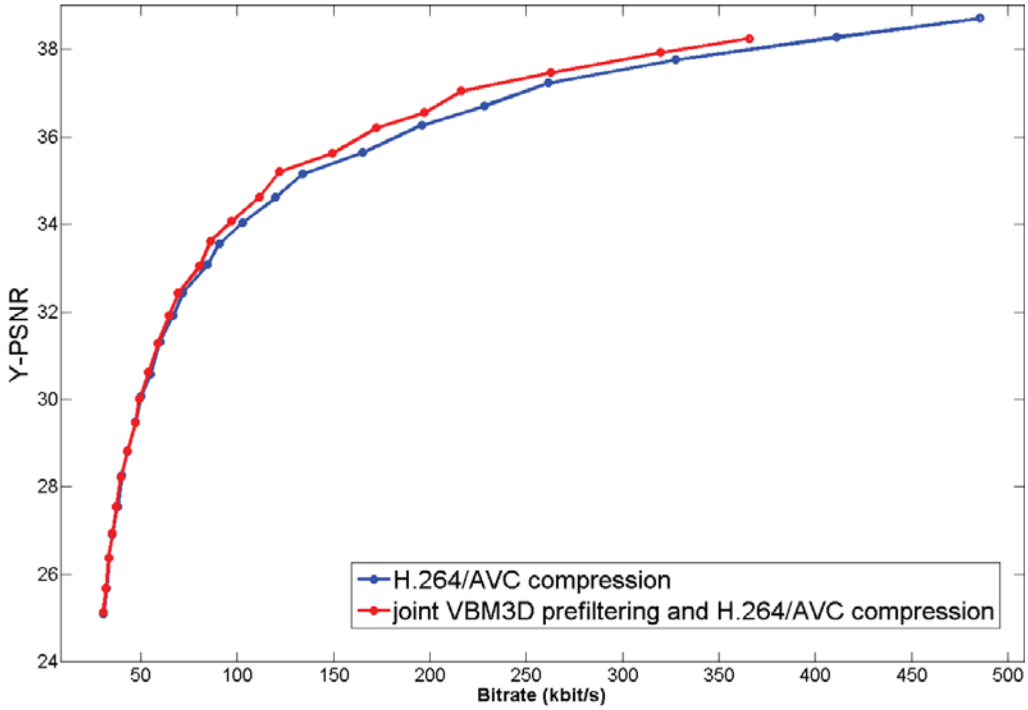
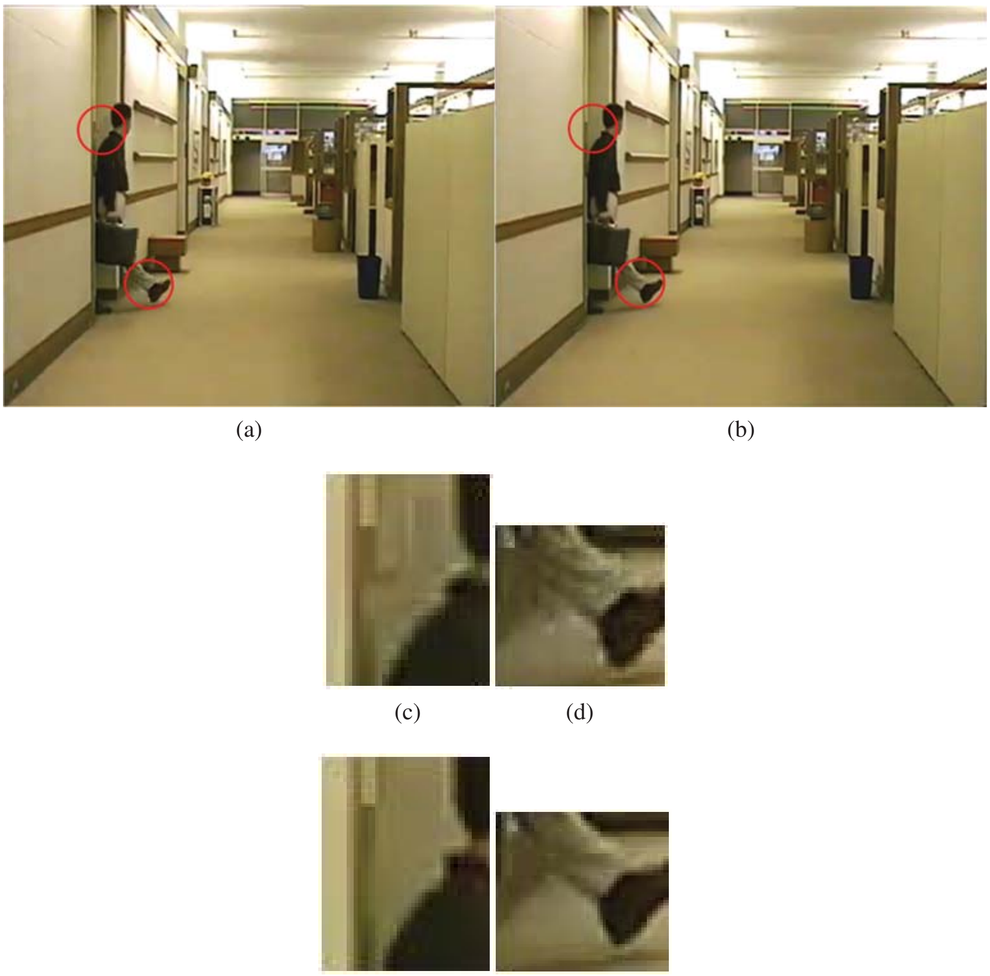


Fig. 3: Rate-distortion comparison for video *hall* (352×288) in two compression modes: H.264/AVC compression; joint pre-filtering and H.264/AVC compression

III. CONCLUSION

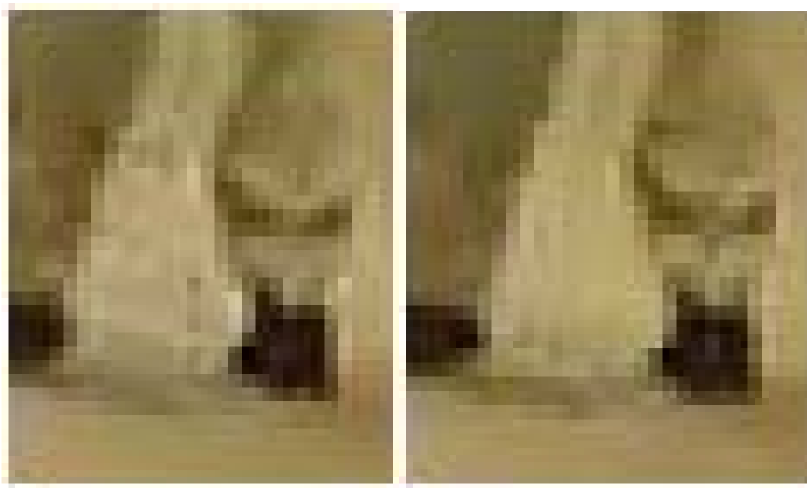
Typical pre-filtering and compression system cannot guarantee optimal filtering and compression parameters. Thus we propose joint parameters selection for pre-filtering and compression system with pre-filtering by VBM3D and compression by H.264/AVC encoder, and full search is employed to find optimal filtering and compression parameters in the system. Our results show that the joint pre-filtering and compression produces output video frames with less compression artifact and increased PSNR up to 1.2 dB under *constant bitrate mode* and up to 0.5 dB under *constant quantization mode for IPPP coding*. What's more, the joint pre-filtering and compression can save the bitrate up to 13.4% in comparison with only compression. In our future work, it's desirable to use an more efficient approach instead of full search to find optimal filtering and quantization parameters for joint system.



(a) (b) (c) (d) (e) (f)

Fig. 5: For video *hall*, (a) is the 23rd frame of the output video from H.264/AVC compression system with enabled constant bitrate control, (b) is the 23rd frame of the output video from joint VBM3D pre-filtering and H.264/AVC compression system with enabled constant bitrate control, (c) and (d) are highlights from (a),(e) and (f) are highlights from (b).

(a) (b)



(c) (d)

Fig. 6: For video *hall*, (a) is the 91st frame of the output video from H.264/AVC compression system with enabled constant bitrate control, (b) is the 91st frame of the output video from joint VBM3D pre-filtering and H.264/AVC compression system with enabled constant bitrate control, (c) and (d) are highlights from (a) and (b) respectively.

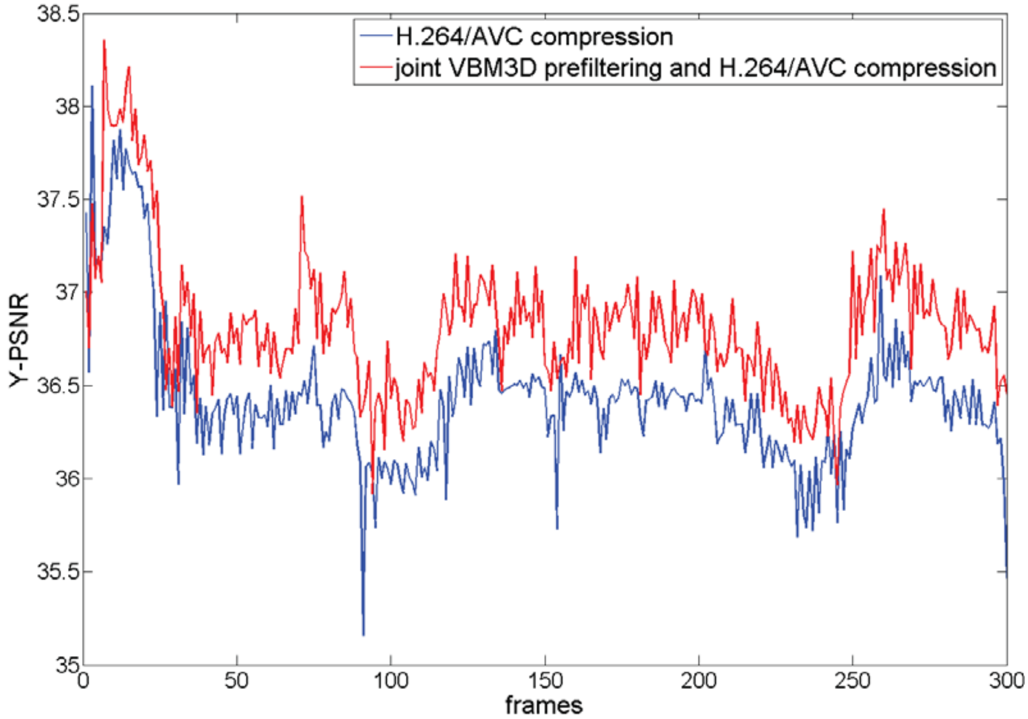


Fig. 4: Enable constant bitrate control (bitrate = 215 kbit/s), frame by frame PSNR comparison for video *hall* (352×288) in two compression modes: H.264/AVC compression; joint pre-filtering and H.264/AVC compression.

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