Residual Signal Compression Based on the Blind Signal Decomposition for Video Coding

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Abstract. In this paper, a new residual signal compression method is proposed based on the blind signal decomposition for video coding. Blind signal decomposition is derived based on the fact that most of the natural signals in the real world could be decomposed into their basis signals and their weight values used in the composition process. In the proposed video coding system, composite data generated by adding two or more blocks are coded. Then the proposed decoder parses the coded bitstream and reconstructs the composite residual. The reconstructed composite residual is decomposed into the original residual blocks based on the blind signal decomposition. In the proposed system, the blind source separation is selectively used, depending on the performance of source separation. It is found that we can achieve approximately $2 \sim 3$dB gain by embedding our algorithm into an MPEG-4 baseline encoder.

Keywords: ICA, video, coding, BSD, residual coding, MPEG.

1 Introduction

Many video coding technologies have been standardized as MPEG-1/2/4 and H.264/AVC and widely used for many commercial multimedia applications [1]. Video compression is a key technology for better video quality with a constraint channel capacity. There have been many attempts in either enhancing video coding efficiency or adding new functionalities. However, all the coding standards are based on a hybrid motion-compensated transform coding, which is confronted with difficulties in improving the coding efficiency. These days, a model-based video coding technology has been proposed to resolve those problems. However, there is no new technology to significantly improve video coding efficiency [1],[2],[3].

In this paper, we propose a new residual signal compression method based on a blind source separation. The proposed video coding system encodes composite

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data generated by adding two blocks. Then the composite residual is reconstructed at a decoder side. The reconstructed composite residual is decomposed into the original residual blocks based on the blind signal decomposition. The latter is selectively used depending on the performance of source separation.

2 Independent Component Analysis (ICA) Algorithm

Independent component analysis is widely used as one approach for blind signal decomposition [4],[5]. It was suggested for solving the cocktail-party problem. At a cocktail party, there are mixed sounds consisting of peoples voices, music, and other types of noise. If we want to either talk with a friend or listen to music in the party, we need to separate either the friends voice or the music from the mixed sound. Human beings can do this without any problem. However, there is no perfect mathematical or computerized method to decompose all the source signals, called as basis signals. For the decomposition, we need to estimate not only the basis signals but also the mixture matrix that represents how the basis signals are mixed. Independent component analysis was hence proposed to find basis signals and a mixture matrix assuming that those basis signals are statistically independent [6],[7]. This approach was successfully ap-plied to many medical images and signal processing applications.

Let basis signals be denoted by $(s_1, s_2, \ldots, s_i)$ and $(x_1, x_2, \ldots, x_j)$ represent observed signals generated with a mixing matrix A. The observed signal can then be defined by

$$x_i = \sum a_{ij} s_j \tag{1}$$

where a_{ij} is each element of A. By replacing x_i, s_j, and a_{ij} with vector notations, $X = \{x_1, x_2, \ldots, x_j\}^T, S = \{s_1, s_2, \ldots, s_i\}^T$, and A. Eq. 1 can be denoted by

$$X = AS \tag{2}$$

We can obtain the mixture matrix W, by

$$W = A^{-1} \tag{3}$$

$$X = AS = W^{-1}S \tag{4}$$

and the basis signals can be computed by

$$S = WX \tag{5}$$

3 Proposed Video Compression Based on the BSD

Without any additional information, independent component analysis (ICA) can separate mixed signals by assuming that the basis signals are statistically independent. If the ICA can decompose the mixed signals into basis signals, the intentionally mixed signal would also be decomposed. Figure 1 is the block diagram for the proposed video coding system by applying the ICA algorithm to an

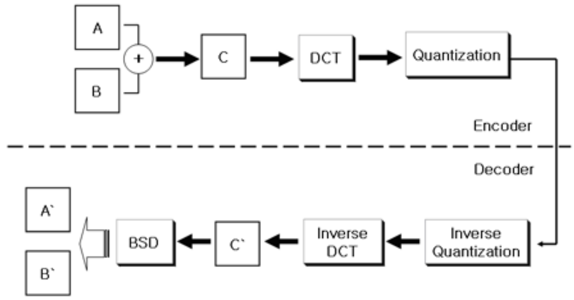

Fig. 1. The proposed ICA-based residual composition and decomposition

intentional composite residual signal. At the encoder side, the block $C(x, y)$ is composed by adding the blocks $A(x, y)$ and $B(x, y)$, where $A(x, y)$ and $B(x, y)$ are residual blocks by inter- or intra-predictions. Then C is coded by the conventional transform and quantization method, and the coded bits are sent to the decoder. The decoder reconstructs A'and B' blocks by decomposing the reconstructed C' block with the BSD. The blocks A and B are considered as basis signals, and the reconstructed A' and B' correspond to the original A and B blocks. The reconstructed blocks contain the error caused from the quantization and imperfection of the BSD. However, we can achieve coding efficiency by coding one composition block instead of two blocks. In this application, we know the mixture model of basis signals and how many signals are composed, so that the basis signals are likely to be accurately estimated.

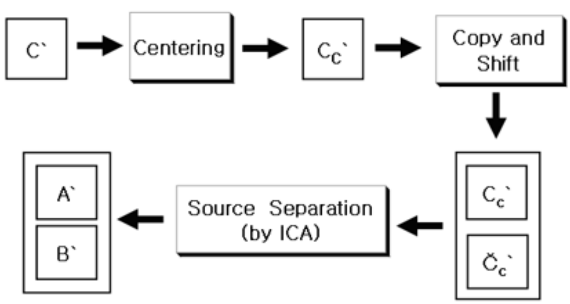

Fig. 2. Decomposition of the mixed block by the ICA

The decomposition procedure based on the ICA is performed with three steps, as shown in Figure 2. For the first step called centering, the reconstructed C_c' is compensated by the average of the block, and this is defined by

$$C_c{}'(x, y) = C'(x, y) - \frac{\sum_{x=0}^{X} \sum_{y=0}^{Y} C'(x, y)}{XY} \tag{6}$$

At the second step, $\check{C}_c$ should be generated by shifting $C'_c(x, y)$. For applying the ICA algorithm to the source separation, the dimension of the input mixed signal should be the same as that of the basis signals to be estimated. That is, the virtual mixed signal, $\check{C}_c$ is generated by copy and shift operations.

4 Proposed Video Compression Method by the Selective BSD

Figure 3 shows the block diagram of the proposed ICA-based video coding system. As shown in the figure, the residual blocks are mixed by adding the residual pixel values that are transformed and quantized. Then the entropy coded bit-stream is decoded, and the mixed signal which is degraded by the quantization is reconstructed. The degraded mixed signal via quantization is decomposed into two residual blocks by the BSD. These two decomposed two residual blocks are similar to the original residual block. However, they are different not only because the composite block is quantized but also the BSD cannot be perfectly separated into its original sources.

Most of the conventional video coding systems including the MPEG-4 part 2 compress six 8×8 blocks per macroblock for the 4:2:0 format. One macro block consists of four 8×8 luminance blocks and two 8×8 chrominance blocks, as shown in Figure 4. The proposed algorithm should compress only three mixed blocks. Note that the transform coding of the H.264/AVC is conducted on 4×4 blocks.

As mentioned before, the separated blocks are not identical to the original residual blocks because two error sources introduced in the proposed video coding system. Figure 5 shows two residual basis blocks (S), and the composite and virtual composite blocks (X). In addition, S represents the separated signal block.

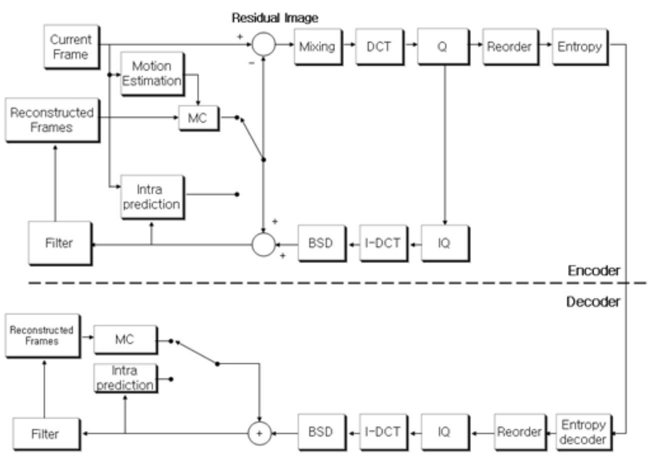

Fig. 3. The proposed ICA-based video coding system

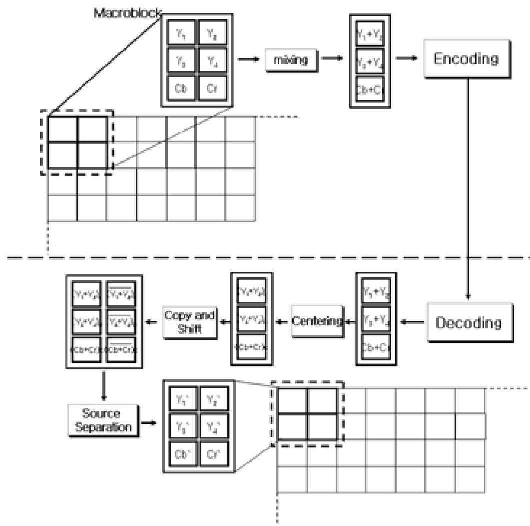

Fig. 4. The proposed block composition and decomposition

S looks similar to the original source signal but is not identical to it. The error is produced by the quantization, and the ICA can occasionally not perfectly decompose the source signals, depending on the characteristics of the source signals. Furthermore, ICA is based on the iterative statistical method so that it

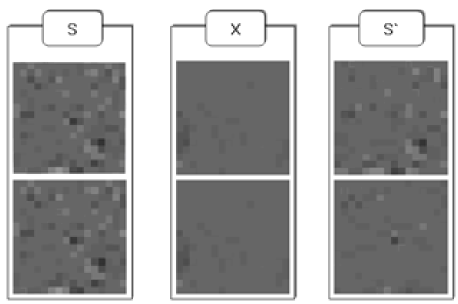

Fig. 5. The separated block S‘ and original block S

may not converge into the solution. Figure 6 shows the proposed selective ICA-based video coding system that selects the conventional transform coding or the ICA-based residual coding, depending on the reconstruction errors. Figure 7 shows the flowchart of the proposed decision flow whether or not the conventional DCT or ICA-based residual coding is used. At first, we need to calculate the pure ICA error by subtracting the error of the conventional DCT method from

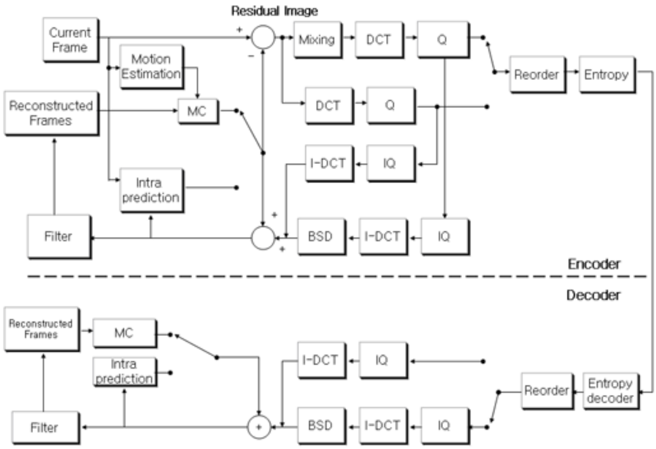

Fig. 6. The proposed selective ICA-based video coding system

the error of the ICA-based one. Then if this pure ICA error is larger than the threshold, the conventional DCT approach is activated. Otherwise, the encoder selects the proposed ICA-based transform coding. We need to send an indicating bit to represent whether the ICA-based coding is used or not.

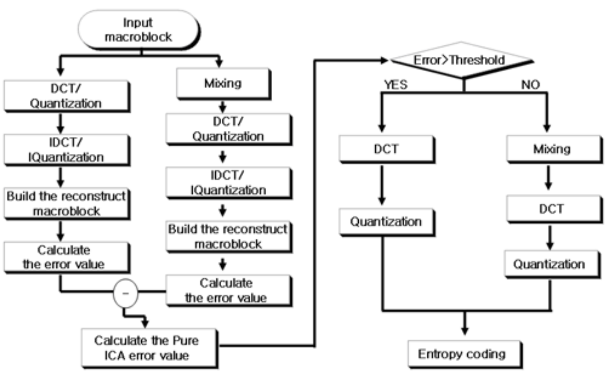

Fig. 7. Decision flow of the ICA-based mixed coding/conventional DCT-based coding

5 Experiment Results

The coding performance of the proposed system was evaluated with several standard video sequences and was compared with that of the MPEG-4 baseline video coding. We used “Stefan,” “Mother_daughter,” and “Mobile” sequences of

176×144 (QCIF). In our experiment, we set QP from 4 to 12, and the intra frame interval was set to 10.

Figure 8 shows several examples of reconstructed frames with the conventional and proposed coding methods. Figure 8(a) is the reconstructed image with MPEG-4 baseline, Figure 8(b) is the reconstructed image with the proposed algorithm applying the ICA mode to all the macro-blocks. Figure 8(c) shows the reconstructed images with the proposed selective ICA-based method. We found that the reconstructed images with the ICA-based method have annoying artifacts in subjective quality than those of the anchor. However, the proposed selective ICA-based method has comparable quality to the anchor algorithm with relatively smaller bitrate usage.

Fig. 8. Examples of the reconstruct images with MPEG-4, ICA-based, and selective ICA-based algorithms. (a) MPEG-4 baseline, (b) ICA-based method, (c) Selctive ICA-based method (Threshold = 2).

Table 1 shows the PSNR and the generated bits for each image of the sequences shown in Figure 8. In "Stefan" sequence, the bitrate of the ICA-based video coding method is one fourth of that of the MPEG-4 video baseline. However, we found that the PSNR drop is approximately 5dB. Because of the "Stefan" sequence has high motion activity so that the ICA is deteriorated and does not converge on a proper solution for several macro-blocks. As shown in the table, the proposed selective ICA-based algorithm yields almost the same quality with one third of the bitrate of the MPEG-4 video baseline by using the conventional video coding method for five macro-blocks. We also achieved significant gain for the rest of sequences. However, the selective ICA-based method has the best performance for all the sequences.

Figure 9 shows the PSNR in terms of bitrates for the three test sequences. We found that the proposed selective ICA-based algorithm can achieve approximately

Table 1. PSNR and generated bits for example image in Fig. 8

Sequence name	MPEG-4 baseline		ICA-based video coding		Selective ICA-based video coding (Threshold =2)		
	PSNR	Bits	PSNR	Bits	PSNR	Bits	Select ratio of ICA MB
Stafan	31.6	1879	25.1	588	30.8	605	95/99
Mother_daughter	35.8	550	35.8	110	35.8	350	69/99
Mobile	29.9	1957	26.4	572	29.5	708	98/99

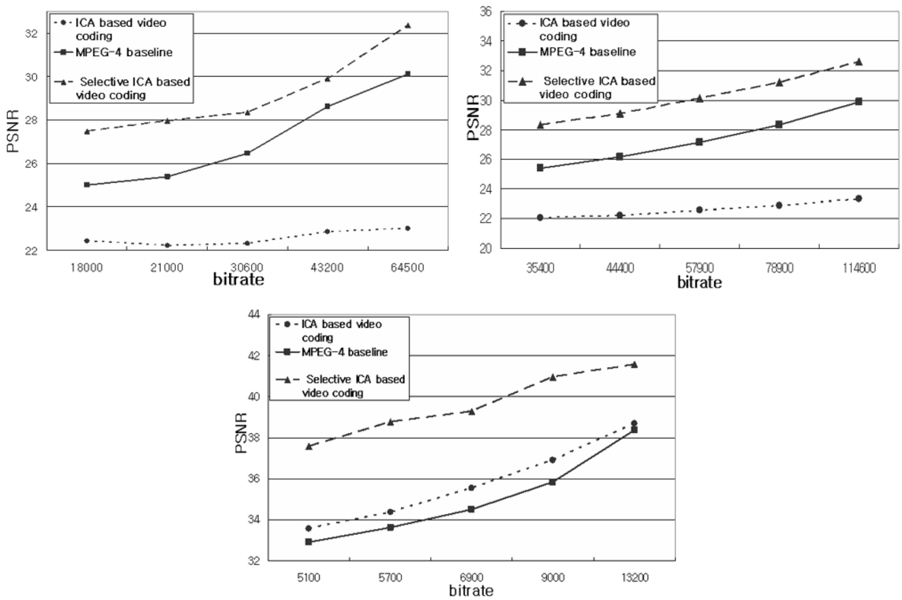

Fig. 9. Comparison of the RD performance for MPEG-4 and the proposed methods (a) Mother_daughter (b) Mobile (c) Stefan

$2 \sim 3$ dB gain by embedding the proposed algorithm into the MPEG-4 baseline encoder. Generally, the proposed method exhibits better performance for low-activity videos than high-activity videos. The selective ICA-based method yields the best perform-ance, but without the selective approach, it occasionally deteriorated for high-activity videos. For the "Mother_daughter" sequence, the ICA-based algorithm without the selective approach shows moderate RD performance because the sequence has low motion activity, resulting in a lower frequency of deterioration of the ICA.

6 Conclusion

In this paper, a new residual signal compression method was proposed based on the blind signal decomposition for video coding. The composite data of two or more residuals blocks were transformed and quantized. Then the composite block was reconstructed by inverse quantization and IDCT. The reconstructed composition block was decomposed into the residual blocks. The blind source separation was selectively used depending on the performance of source separation. We found that the proposed selective ICA-based video coding can obtain approximately $2 \sim 3$ dB gain, compared with the MPEG-4 video baseline. Further study will be focused on decreasing the amount of the pure ICA error by modifying the BSD algorithm with other a priori assumptions.

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