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DCT-BASED ZEROTREE CODING OF COMPOSITED VIDEOS

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ABSTRACT

In this paper we investigate DCT-based embedded zerotree coding of composited videos for multi-point video conferencing. Zerotree coding is a progressive coding method which encodes a video or image into a bit stream with increasing precision. The embedded property is accomplished that all encodings of the same image or video at lower bit rates are embedded in the beginning of the bit stream for the target bit rate [9]. By using the embedded zerotree coder, quality of the composited videos is improved when compared to a conventional encoder.

KEYWORDS: Video coding, video compositing, multi-point video conferencing, embedded zerotree coding, successive approximation quantization.

1. INTRODUCTION

As video applications continue to grow, significance tree based image compression techniques are becoming more effective and less complex. One of these methods, embedded image coding using zerotrees of wavelets, was first introduced by Shapiro in 1993 [9]. Dependencies of wavelet coefficients in subbands are well exploited in this method. Later, beside wavelets, DCT (Discrete Cosine Transform)-based zerotree coding applications were developed and used by several researchers [10], [11], [12], [13]. These works show that DCT-based embedded coders can provide competitive compression rates with a good image quality compared to the wavelet based embedded coders. The embedded coding scheme of zerotree coding depends on coding a symbol by an entropy encoder as soon as the symbol is obtained by the zerotree coding. A zerotree is a tree whose leaves correspond to the insignificant transform coefficients which are less than a certain threshold. A zerotree can be encoded by a single symbol resulting in efficient coding. Zerotree coding proceeds iteratively producing at each iteration a significance map of all coefficients. Thus more generally zerotree coding is called significance tree quantization. As a progressive coding method, an embedded zerotree encodes the largest, most important coefficients first. In this manner, the decoder first receives the coefficients that have the largest content of information yielding the largest distortion reduction. Embedded bit stream obtained by adaptive arithmetic coder representing the symbols of the zerotree coding indicates the ordered coefficients by magnitude. To measure the distortion between the original and reconstructed transform coefficients we consider Mean Square

$$MSE_C(C-\hat{C}) = \frac{1}{IJ}\sum_i \sum_j (C_{ij} - \hat{C}_{ij})^2 \qquad (1)$$

where C_{ij} and $\hat{C}_{ij}$ are the original and the reconstructed transform coefficients of an image or video frame of size IxJ respectively. In a progressive transmission scheme, the decoder initially sets the reconstruction coefficients $\{\hat{C}_{ij}\}$ to zero and updates them according to the incoming symbols. After receiving the approximate or exact values of some transform coefficients the decoder can reconstruct the video frame. From Eq. 1, it is clear that if the exact or approximate value of the transform coefficient C_{ij} is sent to the decoder, the MSE_C of the reconstructed frame decreases. This means that the larger transform coefficients should be sent first because of their larger content of information.

Beside the progressive property there is another advantage of the embedded zerotree coding. Since the embedded zerotree encoder can be stopped at any time, it is very easy to reach the exact target bit rate or the desired quality of image or video without truncating the lower part of a video frame as in other methods. Analogously, a decoder can cease at any point where the desired quality or the bit rate is reached.

In multi-point video conferencing, incoming video streams to a node, where video compositing is realized, are decoded by DCT transcoders directly into JPEG (Joint Pictures Experts Group)-type of images in the DCT domain since the best approach for video compositing is to directly composite videos in the compressed domain instead of the spatial domain [1], [2], [3]. Then DCT decimation and compositing are performed. Composited videos are re-encoded by using a quantization scheme, and motion estimation and compensation. Finally the encoded bit stream is sent to the receiver points. Details of these processes can be found in [4], [5], [6], [1], [7] and [8].

2. CONCEPT OF DCT-BASED EMBEDDED ZEROTREE CODING

The embedded zerotree coding of DCT coefficients is based on four steps: (1) arranging DCT coefficients into hierarchical scales similar to the wavelet subband structure, (2) determining the significant coefficients across scales by exploiting the self-similarity inherent in DCT coefficients, (3) successive-approximate quantizing of DCT coefficients, (4) lossless compressing of the data from the output of the embedded zerotree coder by using an adaptive arithmetic coder.

Consider a video frame which is composed of *KxL* blocks with sizes of *MxM*, where each block is 2-D (2-dimensional) DCT transformed. Each DCT block of size *MxM*, including M^2 coefficients, can be treated as a hierarchical subband structure. Rearranging all blocks of the frame in this way, a 3-scale hierarchical subband structure of a DCT frame, which can be seen in Figure 1, is obtained. In Figure 1, the subband LL_3 includes the DC coefficients of all 8x8 DCT blocks. It is identical with the highest subband of a wavelet structure. In this layer, the number of coefficients is equal to the number of DCT blocks of the video frame. All other subbands include AC coefficients. Since most of the energy is concentrated in the DC coefficients, the quality of the decoded image depends mostly upon DC coefficients, then on the AC coefficients. Therefore the rearranged DCT structure is suitable for the zerotree encoding, and flexible to control the bit rate [13].

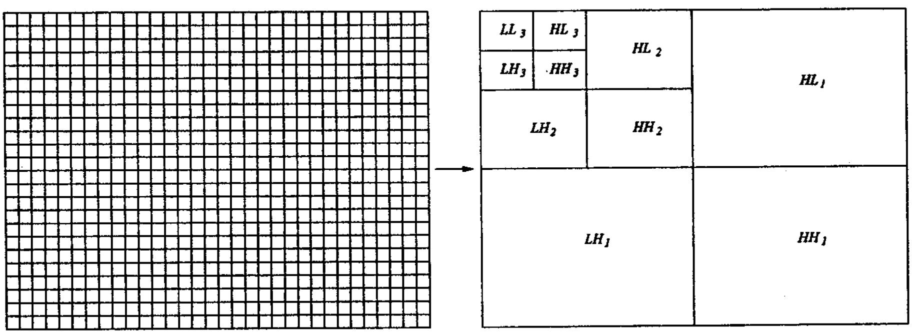

Figure 1. Conversion of a frame with 8x8 DCT blocks into a 3-scale subband frame

Several rearrangements of DCT blocks other than 3-scale structure are also possible [11], [12]. Individually each one gives comparably good results in terms of the compression ratio and quality [13]. In the hierarchical subband structure of a DCT frame, from a coarser to the next finer scale, a relationship can be established between the coefficients of similar orientation forming a tree structure. If a coefficient at a given coarse scale is called "parent", all the coefficients at the next finer scale in the same spatial location of similar orientation are called "children". Specifically, for a given child at a fine scale, all coefficients at the coarser scales of similar orientation at the same spatial locations are called "ancestors". Similarly, for a given parent at a coarse scale, all coefficients at finer scales of similar orientation are called "descendants". This parent-child relationship is shown in Figure 2. In this example, while each coefficient at LL_3 subband has three children, coefficients of

LH_3, HL_3, HH_3, LH_2, HL_2, and HH_2 subbands have four children each. During the zerotree coding, each parent is scanned before its children. In Figure 2, the dotted lines show the scanning order of the subbands, and each small square block represents a DCT coefficient. Zerotree coding depends on transmitting the positions of significant and insignificant coefficients. After arranging DCT coefficients into 3-scale subband structure, a significance test is performed. Zerotree maps indicating the positions of the significant and insignificant coefficients are called significance maps. Zerotree coding ensures a compact multi-resolution representation of significance maps [9].

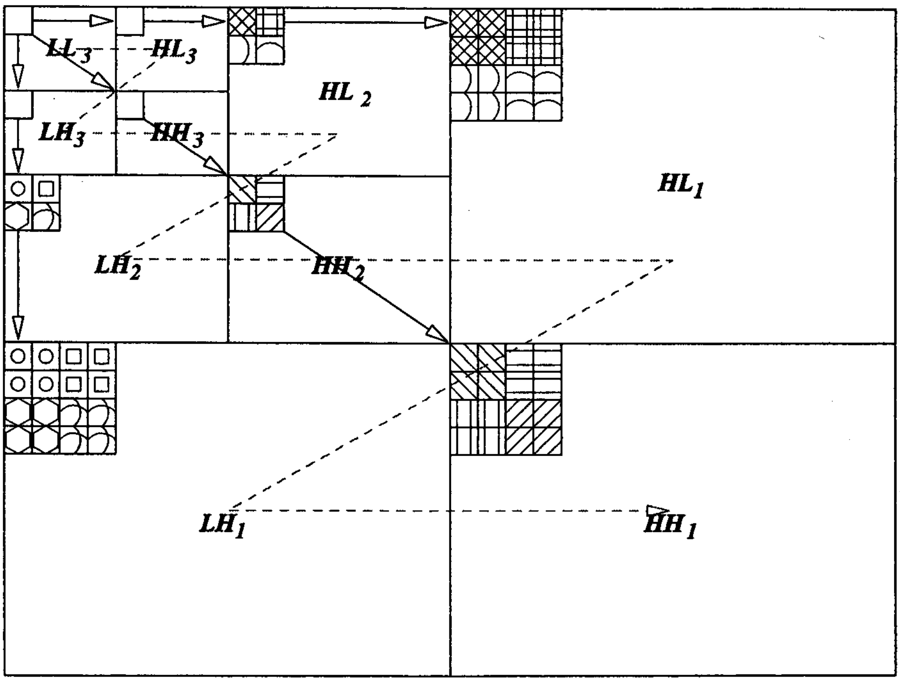

Figure 2. Parent-child relationship of 3-scale DCT subband structure

A DCT coefficient C is said to be significant with respect to a given threshold Th, if its magnitude is bigger than the given threshold, i.e., $|C|>Th$. There are four symbols used in zerotree coding: (1) T: zerotree root, (2) Z: isolated zero, (3) P: positive significant coefficient, (4) N: negative significant coefficient. If a parent and all its descendants are insignificant with respect to a given threshold, then the parent is called a zerotree root. Instead of coding all elements of a zerotree, only the zerotree root is encoded representing that the insignificance of the other elements at finer scales are entirely predictable. If a coefficient at a coarser scale is insignificant, and at least one of its descendants is significant, the coefficient at the coarser scale is encoded as an isolated zero. If a coefficient is significant, it is encoded either as positive or negative according to its sign.

Beside the scanning order of the subbands, obtained zerotree symbols are scanned according to a predetermined scan path at each subband. With this information, the decoder will be able to reconstruct the encoded signal by using the same scanning path. Three scanning examples of the zerotrees using raster, Morton, and Peano methods [15] are shown in Figure 3, respectively.

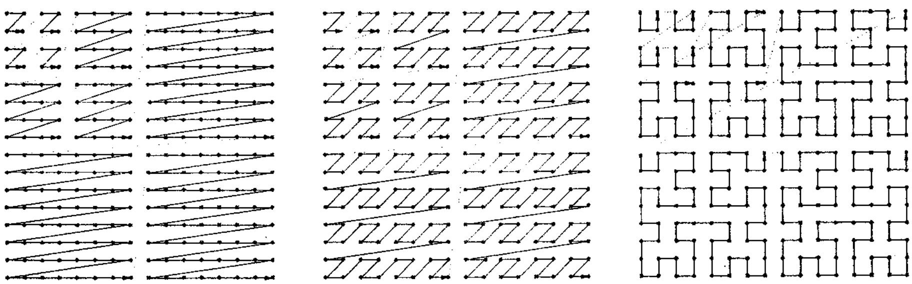

Figure 3. Raster, Morton and Peano scan paths of a 3-scale subband structure

In zerotree coding, coefficients are ordered due to their significance by using successive approximation quantization, which is explained in the next section.

3. SUCCESSIVE APPROXIMATION QUANTIZATION

Successive approximation quantization (SAQ) is implemented in two consecutive passes. At each pass, it produces embedded code parallel to the binary representation of an approximation to a real number [9]. The SAQ is applied iteratively for each new threshold. The initial threshold Th_0 is chosen as

$$Th_0=2^n \quad (2)$$

where $\lfloor n=log_2 C_{max} \rfloor$, and $C_{max}=max(C_{i,j})$ for i=1,...,I and j=1,...,J, for an IxJ DCT frame. Starting from Th_0, at each successive step the other thresholds are obtained according to $Th_i=Th_{i-1}/2$, $i\geq 1$. For each threshold two passes are performed: dominant pass and subordinate pass. They will be detailed in the following two subsections.

3.1. Dominant Pass

Dominant pass is an implementation of the zerotree coding. The dominant pass is performed from the coarsest to the finest subband (see the dotted lines in Figure 2). During the dominant pass, the set of coordinates of insignificant coefficients, which is called dominant list, is used. Initially, all DCT coefficients are considered as insignificant and put in the dominant list. Coefficients with coordinates on dominant list are compared with the threshold Th_i. If a coefficient is found to be significant, its sign is determined. The obtained significance map is zerotree coded as explained in the previous section. The magnitudes of the coefficients which have been found to be significant during the dominant pass are removed from the dominant list and put in subordinate list, which is the topic of the next subsection. To avoid the occurrence of these coefficients on future dominant passes, they are replaced with zeros in the DCT frame. Significant coefficients determined during a dominant pass are reconstructed in the decoder according to $\hat{C} = 1.5 \times Th_i$, corresponding the center of the uncertainty interval $[Th_i, Th_{i-1})$.

3.2. Subordinate Pass

The magnitudes of the coefficients found to be significant are now the contents of the significant list. After the dominant pass, to add more precision to the quantized DCT coefficients, a subordinate pass is performed. For the subordinate pass, the width of the quantization step size is cut in half. More clearly, cutting in half a previous uncertainty interval, $[In_a, In_b)$, two new uncertainty intervals, $[In_a, In_m)$ and $[In_m, In_b)$, where $In_m = median(In_a, In_b)$, are obtained. All of the previous intervals are halved in this way. Subordinate pass refines the significant coefficients by setting them as the center of one of the new intervals, adding a precision of one bit. If a significant coefficient is in the lower interval a "0" symbol, if it is in the upper one "1" symbol is generated for the refinement.

By using the dominant pass, the coefficients are automatically ordered in importance. However, since the coefficients on the subordinate list are sent to the decoder in the same scan order of the dominant list, they are not ordered according to their magnitude. In this case while adding negligible complexity, it increases coding efficiency.

The passes alternate between dominant and subordinate passes until either the desired bit budget or quality is reached. Stopping the encoding of an embedded bit stream at any point gives a precise rate control. However this is not the case for non-embedded coders, which results in a truncation at the bottom part of the video frame.

4. SIMULATIONS

We first use the conventional DCT domain video compositing system, which exploits regular scalar quantization with several decimation factors. Then we replace it with the DCT-based embedded zerotree (DCT-EZT) coder. We compare the results of both compositing systems in terms of PSNR at the same bit rate to see the quality improvement by the DCT-EZT coding. For the conventional DCT compositing, the adaptive arithmetic coder is used instead of the conventional Huffman coder to permit a fair comparison. The first video frame is coded as intra- (I), and rest are coded as interframes (P) forming a typical structure of group of pictures (GOP) [14].

To use the DCT-EZT encoder with the proposed compositing, DCT coefficients are rearranged into hierarchical structure with ten subbands. We also subtract the average of the DC values in the coarsest subband, LL_3, and transmit as an overhead in order to improve the coding efficiency. Because the correlation of the DC coefficients of neighboring blocks is very high this method decreases the unnecessary scanning of the zerotrees [12]. We also treat the coefficients in the coarsest subband as if they do not have any children. Accordingly, after zerotree coding of the coarsest subband we obtain an array consisting of three symbols, Z, P, and N for this subband, in this way we do not use the four-symbol alphabet for all zerotree coding. This improves the coding efficiency of adaptive arithmetic coder. Furthermore, all other symbols in the finer subbands except the ones in the finest scales are encoded by using the four-symbol alphabet adaptive arithmetic coder. In the finest scale subbands, there are only three symbols since the coefficients do not have any children. Thus the zerotree array of these subbands is encoded by a three-symbol adaptive arithmetic encoder.

Then the binary symbols obtained from the subordinate pass are encoded by two-symbol alphabet adaptive arithmetic encoder. The dominant and subordinate passes are subsequently used until the desired bit budget is reached. For motion estimation and compensation, DCT coefficients are inverse EZT coded and reformed to their initial 8x8 block structure. Motion compensation is done by either estimating the motion vectors from the incoming streams, or by computing the motion vectors directly from the composited video. The initial threshold, Th_0, is also sent to the decoder. Then the decoder starts to decode incoming zerotree symbols according to Th_0. The proposed DCT-EZT encoder is shown in Figure 4.

Before comparing the conventional and DCT-EZT compositing systems we first investigate if the scanning path of the EZT coefficients has any influence on the final compression result or quality. For this, we compare three of the scan paths, raster, Morton and Peano, which are shown in Figure 3. In this comparison, we use four different video sequences, Claire, Miss America, Salesman, and Trevor, in CIF format, which have the size of 288x352, and decimate them with the decimation factor, N=2. After compositing the four decimated frames into one, we encode the composited video frames by using DCT-EZT encoder with using each of three scanning methods. In Table 1, we illustrate the average PSNR results of seventy reconstructed frames for each scanning methods. As seen from Table 1, there is no major effect of the scanning methods on the performance. Thus we chose raster scan to use with the proposed DCT-EZT coder for the rest of the experiments.

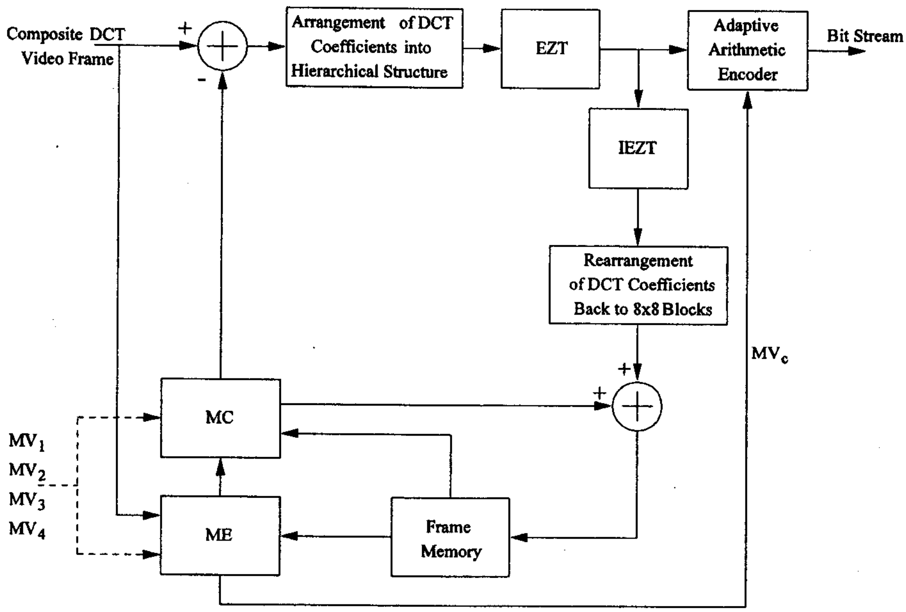

Figure 4. DCT-EZT encoder

Table 1. Average PSNR values obtained from three scan methods according to given constant bit rates

Bit Rate (bits/frame)	Raster Scan	Morton Scan	Peano Scan
20000	34.9523 dB	34.9524 dB	34.9480 dB
40000	38.5217 dB	38.5275 dB	38.5170 dB
60000	39.2390 dB	39.2288 dB	39.2525 dB
80000	40.6408 dB	40.6315 dB	40.6327 dB

For the comparison of conventional DCT compositing and DCT-EZT based compositing methods, we use two different decimation methods, one using integer factor and the other a rational factor. For the integer case, N=2, four video sequences are composited into one, while in the mixed-view six video sequences are composited into one, five videos being decimated by 3, and the other decimated by a rational number, 2/3. In both cases, we obtain better results by using the DCT-EZT coding than by using the conventional DCT encoder. For conventional DCT encoder we use four different Quantization Parameters (QP), which are QP=3, 5, 8, and 10. We also use syntax based adaptive arithmetic coder to encode the symbols obtained from the conventional DCT encoder. These symbols in the block layer are the combination of (LAST, RUN, LEVEL), namely TCOEFs (Transform Coefficients), and individually, LAST, RUN, LEVEL, SIGN for both intra- and interframe, and INTRADC for intraframe. The LAST symbol is the indication of the remaining non-zero coefficients in a DCT block. If LAST is 0, there are more non-zero coefficient(s) in the DCT block, if 1, it means that this is the last non-zero coefficient in the block, thus there is no need to look further for the other coefficients in the block. The RUN symbol stands for the number of successive zeros preceding the coded coefficient. The LEVEL is the non-zero value of the quantized coefficient. These symbols and the initial cumulative frequencies for adaptive arithmetic coding were taken from video coding standard H.263 recommendation in [14]. For the most commonly occurring events a table of combinations of (LAST, RUN, LEVEL), which are called TCOEFs, were used. Unlike Huffman coding, the predetermined variable length codes (VLC) of each TCOEF with fixed length, which are supplied in [14], are not used in the adaptive arithmetic coding case. Consequently, adaptive arithmetic coding results in better performance. For the remaining combinations of LAST, RUN, and LEVEL, they are coded separately. Thus for each of them different histograms are used to track the changing probabilities of the symbols. The signs of the coefficients, SIGN, and the intraframe DC coefficients, INTRADC are also encoded in the same way by using their own histograms.

Average PSNR values for the composited videos with four subframes and with six subframes are shown in Table 2 and 3, respectively. Some of the reconstructed composite video frames with six subframes from each conventional DCT and DCT-EZT encoder systems are shown in Figure 5.

As seen from both PSNR comparisons and subjective tests of video frames the proposed DCT compositing with DCT-EZT encoder outperforms the DCT compositing system with the conventional DCT encoder using regular scalar quantizer. In Figure 5, one can easily see the degradations at the reconstructed video sequences of the conventional DCT coder. This becomes more visible at lower bit rates.

Table 2. Average PSNR values for composited videos with four subframes (N=2)

Conventional DCT Encoder	QP=3	QP=5	QP=8	QP=10
	39.0713 dB	36.5549 dB	34.3038 dB	32.8692 dB
DCT-EZT Encoder	40.9160 dB	38.7932 dB	36.8879 dB	35.4929 dB

Table 3. Average PSNR values for composited videos with six subframes (N=3, 2/3)

Conventional DCT Encoder	QP=3	QP=5	QP=8	QP=10
	38.5867 dB	35.5643 dB	33.0410 dB	31.5754 dB
DCT-EZT Encoder	40.4920 dB	37.9544 dB	35.1252 dB	34.0327 dB

6. CONCLUSIONS

The composited videos are encoded efficiently by using the DCT-based embedded zerotree coder. To use the zerotree coder with DCT coefficients they are rearranged into a hierarchical structure similar to the wavelet subbands. Adaptive arithmetic coding is used to encode the symbols obtained from dominant and subordinate passes considering the usefulness of the arithmetic coding when dealing with sources with small alphabets. We also use the advantage of the embedded bit stream property of the zerotree coding. As each symbol is encoded by adaptive arithmetic encoder, the number of the bits at the output is counted, so when the desired bit budget is reached the coding is terminated. We obtain better results by using the DCT embedded zerotree coder than conventional DCT encoder that uses regular scalar quantizer. The improvement of the composited videos is 1-2.7 dB on average.

ÖZET

Bu makalede çok noktalı video konferans için birleştirilmiş videoların DCT tabanlı gömülü sıfır ağacı kodlaması gerçekleştirilmiştir. Sıfır ağacı kodlama, bir video veya görüntüyü artan ayrıntıyla bit dizinine kodlayan ilerici bir kodlama yöntemidir. Gömülü olma özelliği, aynı görüntü veya videonun düşük bit oranlarında hedef bit oranına ulaşmak için bütün kodlamasının bit dizininin başlangıcından itibaren yerleştirilmiş olmasıyla elde edilir [9]. Sıfır ağacı kodlamanın kullanılmasıyla birleştirilmiş videolarının kalitesi geleneksel kodlayıcılara göre iyileştirilmiştir.

ANAHTAR KELİMELER: Video kodlama, video birleştirme, çok noktalı video konferansı, gömülü sıfır ağacı kodlama, ardışık yakınlaştırma nicemlemesi.

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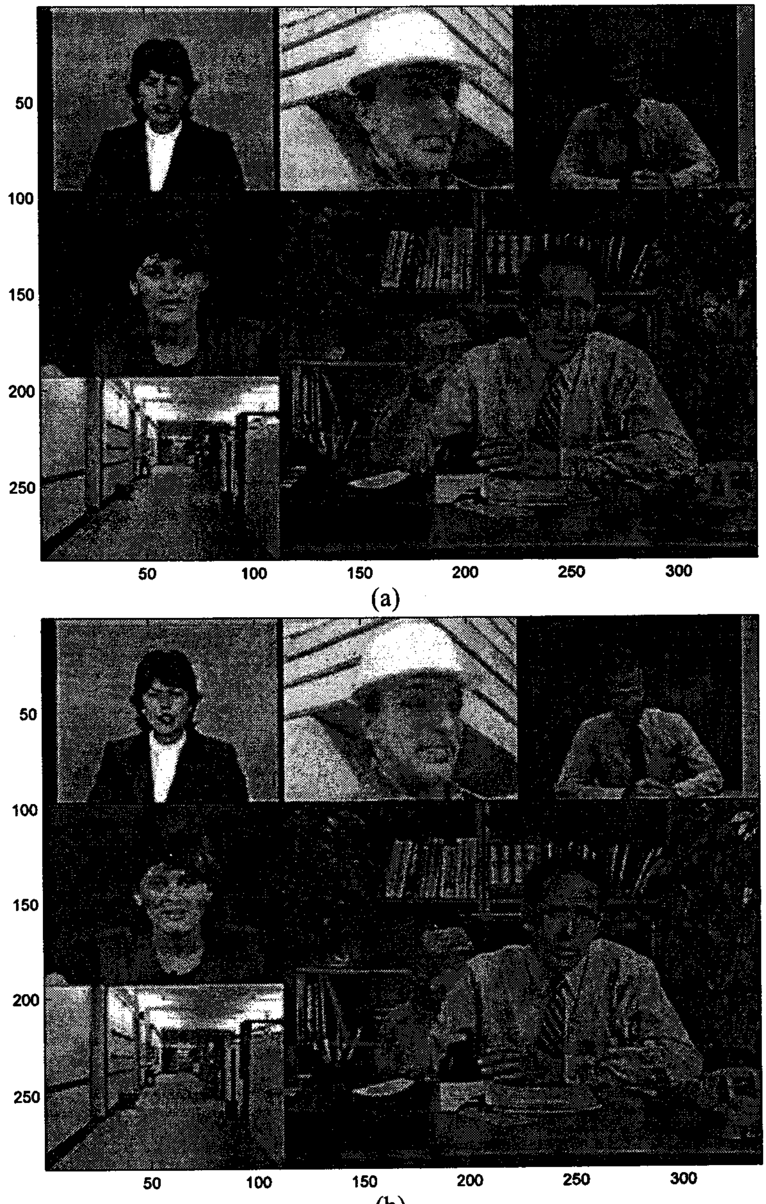

Figure 5. Samples of reconstructed composite videos with six subframes from the conventional DCT and the DCT-EZT codings at 33959 bits, (a) Conventional DCT with PSNR=32.1421 dB, (b) DCT-EZT with PSNR=34.7676 dB

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