초저속 전송 네트웍을 위한 웨이브릿 변환을 이용한 비디오 코딩

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요 약

최근 초저속 전송 매체용 비디오 코딩 기법에 대한 관심이 높아지고 있다. 그러나 기존의 블럭을 기반으로하는 변환 코딩기법들은 비트율 제한으로 인해 블럭화 현상 등으로 화질 열화가 심하다. 본 논문에서는 초저속 전송 매체를 위하여 웨이브릿 변환과 다중해상도 움직임 추정 및 보상 기법을 이용하는 비디오 코딩 시스템을 제안한다. 제안된 시스템은 non-stationary 신호를 적응적으로 표현하며, 인간 시각 특성을 잘 반영하는 웨이브릿 변환을 사용한다. 웨이브릿 변환된 계수들은 움직임 추정 및 보상후 예측 오차의 크기에 따라서 다양한 모드로 코딩된다. 이와 함께 일정한 화질을 유지하기 위하여 간단한 버퍼 제어 기법을 사용한다. 실험을 통하여 제안된 기법은 블럭화 현상이 줄어들며, 기존의 블럭을 기반으로하는 변환 코딩 기법보다 복원 영상의 화질이 좋음을 보였다.

Video Coding Using Wavelet Decomposition for Very Low Bit-rate Networks

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ABSTRACT

The video coding for very low bit-rate has recently received considerable attention, but the conventional coding schemes with block based transform suffer from the blocky effect for the constraints of limited bit-rate. In this paper, we present a video coding system based on wavelet transform and multiresolution motion estimation/compensation for very low bit-rate video. The proposed scheme uses the wavelet transform which is flexible to represent non-stationary image signals and adaptable to the human visual characteristics. The wavelet transformed coefficients are coded by various coding modes in accordance with the sum of absolute error after motion estimation/compensation in wavelet decomposed domain. And simple buffer control technique is applied to handle constant image quality. It is shown that the presented scheme has more acceptable image quality without blocky effects than conventional block based transform video coding.

1. Introduction

In recent years, it is tried that many video applications are served on the already established networks such as conventional telephone networks, mobile communication lines. But the existing standards such as the MPEG, H.261 do not meet the bit-rate of these networks which is restricted below 64Kbps. The requ-

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irements of the problem dictate at least an order of magnitude improvement in coding efficiency[14].

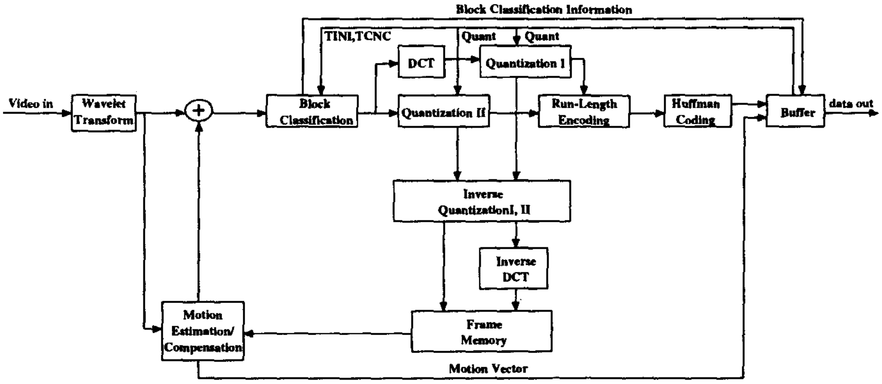
Nowadays, many researchers have been studied the coding system for very low bit-rate. Those results are categorized into four classes: transform technique based video coding, object-oriented based video coding, model-based video coding, and fractal based video coding[14]. As we consider time complexity and the amount of generated data of coding algorithm, an enhanced transform based coding algorithm will be a solution in a few years under the current technologies. The wide spread video coding system using transform technology is H.26x*p* which is composed of block based motion estimation/compensation in spatial domain, discrete cosine transform, and variable length entropy coding[12][13]. The major problem of the coding scheme for very low bit-rate communication networks is the degradation of reconstructed image quality in terms of peak signal-to-noise ratio(PSNR) and/or subjective quality caused by block artifact and mosaic effects between blocks.

To remedy of the problems, we proposed a new coding system based on wavelet transform, which is known that it has good adaptability and flexibility to represent non-stationary image signals[1][8], multiresolution motion estimation/compensation techniques specially designed for very low bit-rate video transmission. The coding system cooperates with the quantizer and the buffer controller to achieve constant bit-rate transmission and good picture quality at a given bit-rate.

The description of image decomposition with wavelet transform, multi-resolution motion estimation/compensation, various coding modes, and simple buffer control of suggesting video coding system are discussed in section 2. In section 3, we show some experimental results to evaluate our system. Then we conclude with the summary of the system and lists of further works.

2. Proposed Video Coding Scheme

In this section, we describe the video coding scheme using wavelet transform and multiresolution motion estimation/compensation for very low bit-rate. As shown in (Fig. 1), the system is composed of discrete wavelet transform, multiresolution motion estimation/compensation, variable length coder(quantizer, run-length coder, and huffman coder), and buffer controller. To obtain high compression ratio without great loss of image quality, we use wavelet transform that is well known as good representation tool of non-stationary signal and motion estimation/compensation in wavelet transform domain, which uses the similarity



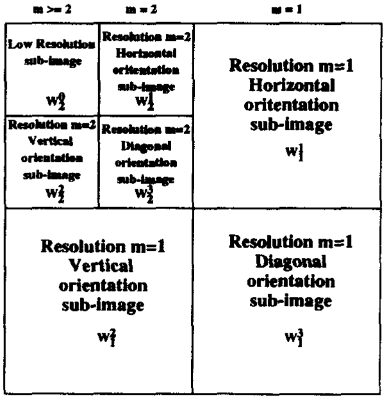
(Fig. 1) Block diagram of the proposed video coding scheme which uses wavelet transform and multiresolution motion estimation/compensation of motion structures between sub-bands with same direction[9]. And accounting for bit-rate and activity of input signal, we introduce four classes of coding mode. The detailed explanation of each component is given in the following subsections.

2.1 Wavelet Transform

Wavelet transform has been paid considerable attention to in the area of image signal representation due to its flexibility to represent image signal and adaptability to human visual characteristics(HVC), since human visual system(HVS) is insensitive to degradation in high frequency region of image signal[1]. Most of the conventional video coding systems take block based DCT to reduce correlation among pels in the same video frame. The block based schemes cause critical blocky effect by quantization noise in case of very low bit-rate, so the degradation of image quality cannot be allowed. But wavelet transform decomposes the image signal into more stationary in spatial and frequency domain, thus the decomposed signal is more adaptable to the HVS and can be coded efficiently.

In our video coding system, we use Daubechies's biorthogonal 9-7 filter[8] to transform the video frames. In term of energy compaction and entropy, biorthogonal 9-7 filter has better performance than orthogonal D-4, D-6, or biorthogonal 9-3, 5-7 filters. That is, biorthogonal 9-7 filter shows the characteristics of symmetry which increases regularity. Thus we can encode wavelet transformed coefficients with low bit-rate. After the wavelet transformation, many coefficients of high frequency components would be zero. (Fig. 4-(b)) and 4-(d) show sample wavelet transformed images. There are a low frequency level sub-image on the top-left of the image and some high frequency details which show high frequency components of the image.

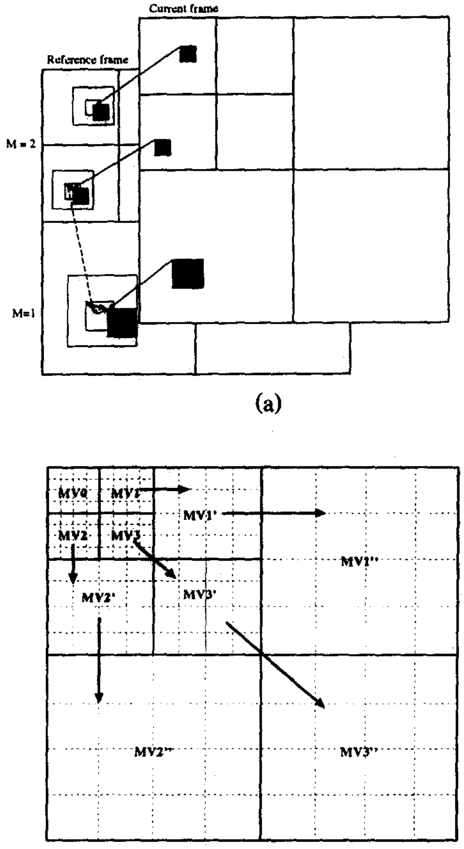
The coefficients of each band of wavelet decomposed have different properties. As shown in (Fig. 2), low-passed band W_2^0 preserves the original image characteristics but high-passed bands have direction sensitive high frequency components in original image such as horizontal orientation in W_i^1, vertical orientation in W_i^2, and diagonal orientation in W_i^3. In this video coding scheme we use the properties of each band to improve video quality under the restricted bit-rate.



(Fig. 2) Image decomposition using successive wavelet transform at low-passed sub-band

2.2 Motion Estimation and Compensation

The motion compensated coding that exploits temporal redundancies in image sequences is one of the most popular image coding techniques. As shown in (Fig. 3-(a)), multiresolution motion estimation/compensation is used at the wavelet decomposed domain in our video coding scheme. Each layer of the wavelet decomposed image has similar motion activity according to the orientations and layers. Based on this fact multiresolution motion estimation/compensation is suggested by Zhang[9]. The motivation of using the multiresolution motion estimation/compensation approach is the inherent structure of the wavelet decomposition. This scheme significantly reduces the searching and matching time to find a motion vector. And it gives smooth motion field due to the prediction of motion vector between successive layers at the same orientations.



(a)

(b)

(Fig. 3) (a) Multiresolution motion estimation and prediction of initial motion vector in each sub-band, (b) An example of motion estimation and prediction

Multiresolution motion estimation/compensation works as follows in m-successive decomposed frame. At first, to get motion vector in wavelet decomposed frame, where W_j^i means a sub-band image at i layer j direction, let the low-passed sub-band W_m^0 be segmented into $N \times N$ blocks. They are compared to displaced candidate blocks of the reference frame which is stored in frame memory. The reference frame, of course, is already decomposed by wavelet transform. The offset between the best matched blocks of the reference frame and matching block in current frame corresponds the motion which is denoted by a displacement vector $v(x, y)$, that is called motion vector. The search is limited to the maximum displacement p in both direction around the position of the block in current frame. In block matching, mean square error or mean absolute error are the most widely used as matching criteria. Formally speaking, we can write as the following equations.

$$s(\vec{D}) = \sum_{i=1}^{N} \sum_{j=1}^{N} Dist(I(z, t), I(z-\vec{D}, t-1)) \tag{1}$$

where $z=(i, j), \vec{D}=(x, y), -p \leq x, y \leq p$

$u = \min_{x,y} s(\vec{D})$

$v = (x, y)|_u$

where $s(\vec{D})$ is the sum of difference between two blocks, $Dist(\cdot)$ is a distance measure function, and v is a motion vector of the block with (x, y) component, which has the smallest sum of distance among the candidate blocks. Secondly, the motion vectors v_m^j for the sub-band, W_m^j where $j=1, 2, 3$, that are in the same layer as W_m^0, are obtained by block marching algorithm as described above. In one lower layer sub-band, then, we can get motion vector for each direction sub-band $W_{m-1}^{1 \text{ or } 2 \text{ or } 3}$ with similar method. But the initial motion vector of each sub-band was predicted using one above layer's motion vector as $v_j^i = 2 \cdot v_{i+1}^j$. That is, at each layer except for top most one we make use of one above layer's motion vector as initial displacement, and then refine it so as to accurately search the motion field. The procedure described above is repeated until $m=1$. The processing of prediction and refining motion vector exploit the motion structure at the wavelet decomposition domain.

The example of the proposed motion estimation scheme is illustrated in (Fig. 3-(b)). Where we decompose input video sequence into 7 sub-bands($m=2$) applying two successive wavelet transform to original image and low-passed sub-band. The arrows depicted in the figure show which sub-bands are used as initial motion vector. The block size in successive lower bands becomes twice as well as sub-band itself compared with that layers.

2.3 Coding Modes

After motion estimation, we classify the block into 4 classes according to the sum of absolute distance of the block. Since each block has different characteristics such as containing only backgrounds, new objects, and only translational moving objects, etc., we must make use of it to obtain good image quality while low bit-rate. That is to say, the blocks having different properties have to be coded with their own ways. In our approach all of the blocks are classified into four classes: no coded mode(MODE 1), inter one motion vector mode(MODE 2), inter one motion vector and coding predicted error mode(MODE 3), and intra-mode(MODE 0) by considering the buffer status and channel capacity.

〈Table 1〉 Block classification algorithm

MV: Motion vector which is composed of x, y components
SAE: Sum of absolute error after motion estimation/compensation of a block
TCNC: Threshold for coding or not coding of a block
TINI: Threshold for intra or non intra coding mode

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IF ($MV=(0, 0)$ AND $SAE \le TCNC$) THEN
    MODE1: Coding a block using No Coded Mode
ELSE IF ($MV \ne (0, 0)$ AND $SAE \le TCNC$) THEN
    MODE2: Coding a block using Inter, One Motion Vector Mode
ELSE IF ($TCNC < SAE \le TINI$) THEN
    MODE3: Coding a block using Inter, One Motion Vector and Coding Predicted Error Mode
ELSE IF ($SAE > TINI$) THEN
    MODE0: Coding a block using Intra-Mode
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〈Table 1〉 shows the block classification algorithm which accounts for motion vector and predicted error of blocks. Where SAE represents sum of absolute error between two blocks, TCNC represents the threshold whether the block is coded or not, and TINI for threshold of whether a block is inter-mode or not. TINI and TCNC are adaptively changed during coding operation of video frames by rate control algorithm with observation of remaining buffer size and bit-rate of transmission lines.

〈Table 2〉 Coding informations and methods of each coding mode

MODE	Coded information	Coding method
MODE1	Block classification information	Fixed length coding
MODE2	Block classification information Motion vector	Fixed length coding Variable length coding
MODE3	Block classification information Motion vector Block difference	Fixed length coding Variable length coding Quantization +Raster scanning and run-length coding +huffman coding
MODE0	Block classification information Block information	fixed length coding if low-pass band, DCT +quantization +Zigzag scanning and run-length coding +huffman coding otherwise, quantization +raster scanning and run-length coding +huffman coding

MODE 1: In this mode, we assume that the block can be rebuilt with acceptable image quality from previous frame which is stored in frame memory. When a block has no motion and does not contain any new objects or the remaining buffer size, channel bandwidth is not enough, we can coding the block as MODE 1 with only sending block classification information. So the amount of data is very small.

MODE 2: To construct the block, the block classification information and the motion vector are required. A block, so to speak, has objects with only translational motion from reference frame. So we can get the block from reference frame using motion vector that is displacement of the two blocks. It is desirable to code motion vector with variable length coder such as huffman coder since they have statistical redundancies, that is, motion vectors of adjacent blocks are very close at each direction.

MODE 3: Block classification information, motion vector, and coded data of predicted error after motion compensation are needed to reconstruct blocks for this mode. An object within block have some motion but it is not exactly represented by motion vector, thus the difference of two blocks must be coded. The motion vector coded by the same way of MODE 2, and the block difference is coded through quantization, run-length coding, and huffman coding. In contrast to intra-mode, quantization is performed in its error block itself. The execution of DCT in this mode does not compact energy since each pels of a block has already decorrelated.

MODE 0: There is no prediction in intra-mode. With the motion estimation we cannot get any prediction gain because this block does not correlate any blocks of reference frame. Thus block classification information and block data itself must be transmitted to receiver. In this mode, a block is coded through DCT, zig-zag scanning and run-length coding, and huffman coding if the block lies in low-passed sub-band, or raster line scanning and run-length coding, huffman coding if in otherwise bands. This coding mode generates a lot of data as well as takes more computing time than other modes. As many as blocks coded with this mode the quality of reconstructed image is the better at the cost of bit-rate.

A block of which coding mode is determined is coded with its own way. Quantization and run-length coding are needed to code the MODE 0 and MODE 3. All of data to be transmitted are came from the above two modes. So it is required careful treatment of quantization to accomplish good quality of reconstructed image under the constraint of very low bit-rate.

2.4 Quantization, Variable Length Coding and Buffer Control

The wavelet decomposition decorrelates the pels values of the original image and concentrates the image information into relatively small number of coefficients[13]. The coefficient distribution of wavelet transformed image has a lower entropy than the original image, thereby more compression is possible. Based on rate distortion theory we can eliminate the coefficients with small magnitudes without occurring of significant distortion in the reconstructed image. The elimination of small valued coefficients can be accomplished by applying a threshold function.

$$T(x) = \begin{cases} 0 & \text{if } \ |x| < \text{threshol } t \\ x & \text{otherwis} \end{cases} \tag{2}$$

we call the range $-t<x<t$ as dead zone. And the amount of compression obtained can be controlled by varying the threshold parameter t.

Higher compression ratios can be obtained by quantizing the non-zero wavelet coefficients before they are encoded. A quantizer is a many-to-one function $q(x)$ that maps many input values into a smaller set of output values. Quantizer is a staircase function characterized by a set of numbers $\{d_i,\ i=0,\ \cdots,\ N\}$ called decision points and a set of numbers $\{r_i,\ i=1,\ \cdots,\ M\}$ called reconstruction levels. An input value x is mapped to a reconstruction level r_i if x lies in the interval $(d_i,\ d_{i+1})$.

To accomplish the high compression ratio without significantly loss of information we used different range of dead zone and quantization step size for each sub-band. At each band, quantizer has uniform step size. Quantization is perform as follows for each band W.

x: input value
y: output value
$T(x)$: threshold function

$$y = \frac{T(x) + \dfrac{Quant^{j}_{i,k}}{2.0}}{Quant^{j}_{i,k}} \tag{3}$$

where $Quant^{j}_{i,k}$ means a quantization step size for jth orientation, ith layer, at \$k\$th frame. It is adaptively changed for constant quality and bit-rate in coding processing.

After the quantization the coefficients of block is coded through zero run-length coder with raster line scanning when MODE 3 or zig-zag scanning when MODE 0. During the scanning process non zero coefficient is occurred, then we mark runs and the coefficient as (number of zero run, non zero coefficient) pairs which is called 2-D run-length encoding, and then continue the scanning process. The following process of run-length encoding is huffman coding that are well known. After all, in the process of quantization, information loss is occurred.

When the block classification and quantization are being executed, the buffer control algorithm is performed at the same time. The buffer control techniques take an important role in video coding systems. Because each of video frame generates different amount of data according to its activity, it is needed that buffer control schemes handle the generating bit-rate to preserve constant image quality. In our system, only quantization step size(Quant), threshold of coding a block or not(TCNC), threshold to determine whether a block is coded with intra-mode or inter-mode(TINI) are considered. To determine quantization step size, we use similar algorithm used in H.26*p*[12]. Quantization step size $Quant^j_i$ for each band is determined as the equation (4).

$$Quant^j_{i,k} = Quant^j_{i,k-1} + \alpha \cdot \frac{B_{i-1} - \bar{B}}{\bar{B}} + \beta \cdot \frac{B_{i,bl} - \frac{bl}{7} \cdot \bar{B}}{R} \tag{4}$$

Where $Quant^j_{i,k}$ is the quantizer step size for jth orientation, ith layer at kth frame, B_{i-1} means the number of bits spent for the previous picture, $\bar{B}$ is the expected number of bits per picture, bl is the present sub-band layer, $B_{i,bl}$ means the number of bits spent until now for the picture, R is bit-rate of transmission line, and α and β are constants. The equation (4) tells that the quantization step size of current frame is determined by considering the previous frame quantization step size, bit-rate of previous frame, and bit-rate until now for that frame. If previous frame have generated a lot of bit-rate, then in terms of the buffer status control we increase the quantization step size to reduce bit-rate for current frame. To adaptively change the threshold values, buffer fullness is also considered. Buffer_fullness is defined as ratio of remaining buffer size to total buffer size, that is, buffer_fullness=(remaining_buffer_size)/(total_buffer_size). As increasing buffer_fullness, the TINI, TCNC is increasing with the rate of buffer_fullness.

To control the TCNC and TINI, the buffer fullness is used so as to allow constant buffer rate and to maintain acceptable video quality. The initial TCNC, TINI, is already set for classification of block before coding process as 10%, 80% of mean SAE of block at first frame, respectively. Which are determined by analyzing the several simulations results. In the course of coding process TCNC, TINI is changed in accordance with buffer_fullness as follows.

$$\begin{aligned} TCNC &= TCNC + (buffer\_fullness - 0.5) \times TCNC \\ TINI &= TINI + (buffer\_fullness - 0.5) \times TINI \end{aligned} \tag{5}$$

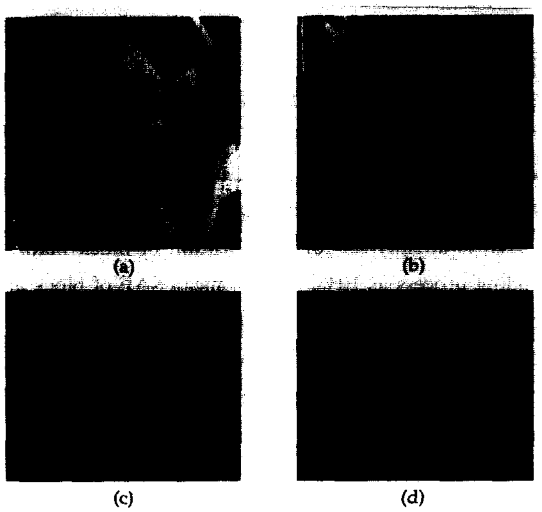
3. Experimental Results

In this section, we show the experimental results to evaluate our video coding system for very low bit-rate. As a distortion measure, we take the PSNR, which is defined as

$$PSNR = 10 \cdot \log\left(\frac{255^2}{MSE}\right) \tag{6}$$

where MSE is the mean square error of the compressed image[7]. Although PSNR does not completely correspond to subjective visual qualification of image, it is a commonly used measure for the comparison of the different coding techniques. There is no distortion measure yet which models the working of the human visual system in a proper way.

Miss America video sequence is used to evaluate the performance of the video coding system, and Lenna image to analyze only intra-mode coding. The frame rate is 5 frames/sec, size of a frame of the video sequence is 176 pels/line, 144 lines/frame, QCIF 4:2:0 format. (Fig. 4) shows Lenna and a single frame of Miss America original image and their wavelet transformed images respectively.


(a) (b)
(c) (d)

(Fig. 4) Test image and single frame of video sequence : (a) Lenna(256×256, 8bits/pel) original image for testing only intra-mode, (b) Wavelet decomposed image of Lenna, (c) One frame of Miss America(QCIF, 4 : 2 : 0 format, luminance component) (d) Wavelet decomposed image of Miss America

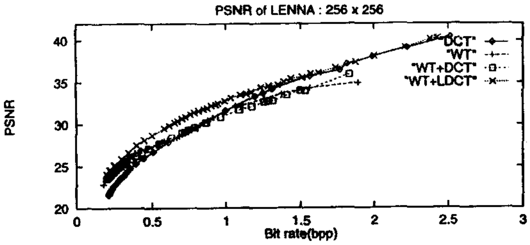
For performance evaluation of the coding scheme, we considered the analysis of the intra-mode coding performance and the entire system performance, respectively. First, we compared the results of four types of coding methods that are DCT, WT, WT +DCT, and WT +LDCT to analyze intra coding mode. Each method of intra coding mode uses the techniques described below to encode image data.

DCT : DCT→quantization→zigzag scanning, run-length encoding→huffman coding

WT : wavelet transform→scanning, run-length coding→huffman coding **WT +DCT** : wavelet transform →DCT→quantization→zigzag scanning, run-length encoding→huffman coding

WT +LDCT : wavelet transform→(DCT→zigzag scanning, run-length encoding→huffman coding if low-passed band or scanning, run-length coding→huffman coding otherwise)

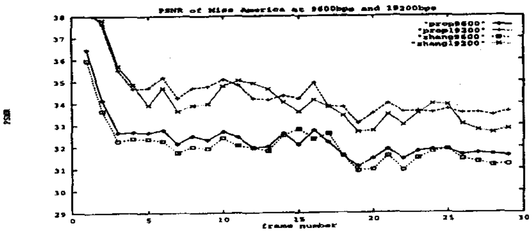
(Fig. 5) and 7 show the result of intra-mode coding. At high compression ratio(below 0.25bpp), WT + LDCT has better performance than others. The decoded image with WT, WT +LDCT is more acceptable than that of DCT which shows significant degradation of image quality caused by blocky effect. The proposed system, after classification of block coding mode, used WT +LDCT scheme to improve the performance.



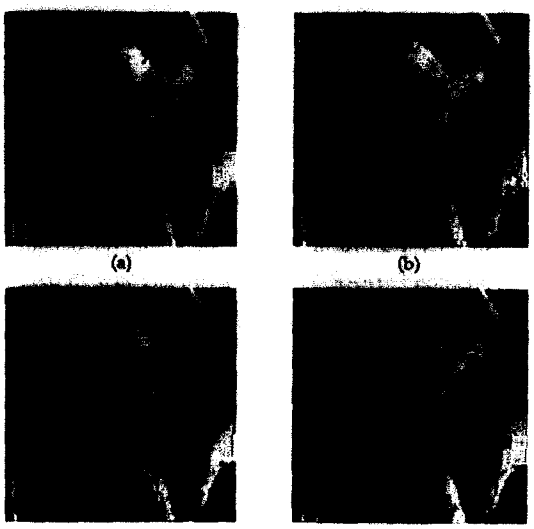
(Fig. 5) PSNR vs. bit-rate for intra-mode with DCT, WT, WT + DCT, WT + LDCT

〈Table 3〉 Average performance of codec with Miss America video sequence

Bit-rate	Method	Frame rate	PSNR or Y	PSNR of Cb	PSNR of Cr
9.6Kbps	Zhang[?]	5 frame/sec	31.9501	33.0760	28.6415
	Proposed	5 frame/sec	32.3087	33.4816	29.2755
19.2Kbps	Zhang[?]	5 frame/sec	33.8271	34.8130	29.7312
	Proposed	5 frame/sec	34.4375	35.3216	30.4224



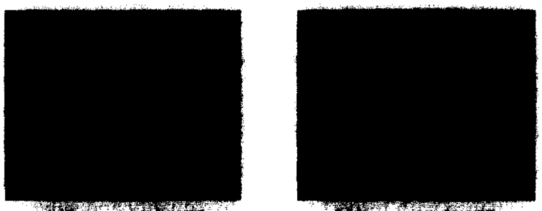
(Fig. 6) PNSR vs. frame number of Miss America at 9.6 kbps and 19.2kbps, where 'prop' means the proposed method and 'Zhang' means the method suggested by [9]

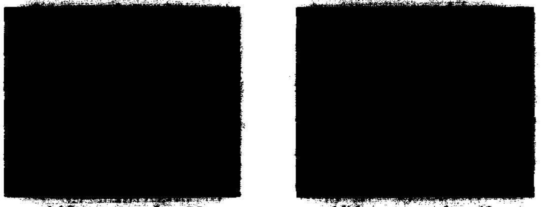

(a) (b)
(c) (d)

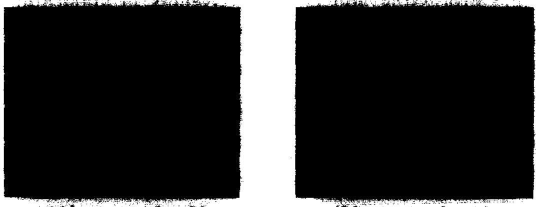
(Fig. 7) Performance of intra-mode coding with Lenna at 0.21bpp : (a) DCT, (b) WT, (c) WT+DCT (d) WT +LDCT

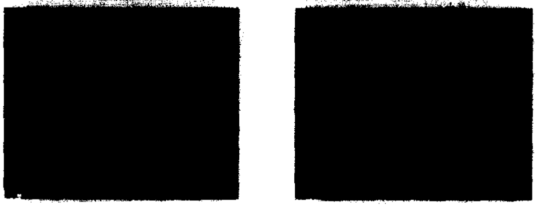
In ⟨Table 5⟩ and (Fig. 7), we present the comparative results to show the average performance in terms of PSNR when transmitted at both 9.6kbps and 19.2 kbps with Miss America video sequence. To compare the performance of our system, we use the video coding system suggested by Zhang[9] which uses the multiresolution motion estimation/compensation and vector quantization for residual signals. At 9.6Kbps and 19.2Kbps transmission bit-rates, the average PSNR of luminance component of Miss America video sequence is 32.3087 dB, 34.4375 dB at 5 frames per second respectively. From the ⟨Table 3⟩, the presented system has better PSNR performance than that of Zhang's scheme at low bit rate by 0.5dB or so.

Some selected reconstruction images at 19.2kbps bit-rate are shown in (Fig. 8) (only luminance component is printed here). The decoded image quality is acceptable with no blocky effects which would result if block based DCT and motion estimation in spatial domain are used. But the coding system has at least one frame delay for reconstruction of received data since wavelet transform is applied to whole single frame.


(a)frame number 10 (b)frame number 20


(c)frame number 30 (d)frame number 40


(e)frame number 50 (f)frame number 60


(g)frame number 70 (h)frame number 80

(Fig. 8) Reconstructed video sequence of Miss America at 19.2kbps

4. Conclusion

This paper described a new video coding scheme using wavelet transform and multiresolution motion estimation/compensation. The wavelet transform used here attempts to exploit the HVS, yielding encouraging result compared with the block based waveform coding techniques. And multiresolution motion estimation/compensation took advantage of motion structure of wavelet decomposed image using prediction between layers. Bit-rate was controlled by quantization step size, coding modes of blocks by considering the remaining buffer size and amount of generated data.

The result of video coding system with Miss America video sequence at 9.6Kbps and 19.2Kbps transmission bit-rates is that the average PSNR of luminance component is 32.3087 dB, 34.4375 dB at 5 frames per second respectively. The coding system has out-performance with respect to objective quality and subjective quality comparing to block based transform coding scheme because it has removed the blocky effects.

Further research should be needed to optimize the proposed video coding scheme with the consideration of the effects of the wavelet transform to the HVS, and to reduce the complexity of algorithm for real-time processing and cost effectiveness in application of very low bit-rate video.

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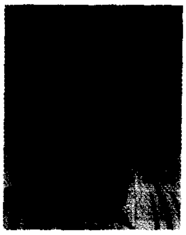

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