pp. 277 ~ 280

1994 IEEE International Symposium on Circuits and Systems, *London, England, 30 May to 2 June*

Design of Motion Compensation Filters of Frequency Scalable Coding - Drift Reduction -

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ABSTRACT

This paper investigates cause of blurring called drift, which is observed in inter-frame predicted and down scaled pictures with scalable video coding system, from multirate stand point of view and proposes a new motion compensation method in decoder for drift reduction.

1. INTRODUCTION

In the last couple of years, considerable effort has been directed towards emerging digital video coding system based on discrete cosine transform (DCT) and inter-frame prediction with motion compensation [1,2]. In addition to that, multiresolution decomposition is also required to attain compatibility between various resolutions of displays [3]. Therefore DCT based scalable coding system (SC system) which converts the scale of video data has attracted a great deal of attention [4-6].

Our concern is to consider quality of decoded and down-scaled pictures through the SC system. The first question to be discussed is degree of "*aliasing*" error caused by the scaling. An answer for this question can be found in [7] which says that "absolutely no perceptible impairment were observed by experts" in case of 2:1 decimation. We also evaluated degree of aliasing error theoretically to support this answer [8]. The second question is "*quantization*" error. It is observed in trade off between compression ratio and picture quality [1,2]. The third question is, so called, "*drift*" error [4,5,10]. The drift is characterized by the fact that it is observed only in inter-frame predicted and scaled pictures. Although some researchers have proposed some drift reduction methods [6,9], little is known about cause of the drift.

The purpose of this paper is to investigate cause of the drift and to propose a new method which can reduce the drift. First of all, we describe signal processing in the SC system from multirate stand point of view. Secondly, we investigate cause of the drift in z-domain and conclude that mismatching of frequency characteristics of motion-compensated signal between encoder and decoder brings about the drift [9]. Finally, we propose a new method for drift reduction and confirm its effectiveness with some experiments.

2. FREQUENCY SCALABLE CODING

This section explains coding and scaling procedure in the SC system and the drift problem.

2.1 CODING AND SCALING The SC system compresses data volume of input frame signal and outputs reconstructed signal which is down-scaled through the system. This procedure is explained as follows.

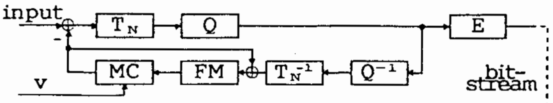
Denoting input signal in a block at time t and at two dimensional location $\mathbf{n}$ by $x(t,\mathbf{n})$ one of the signals;

$$p_I(t,\mathbf{n}) = x(t,\mathbf{n}) , \tag{1}$$

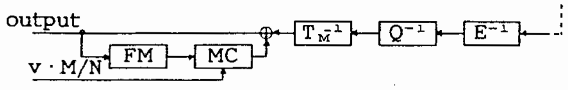
$$p_P(t,\mathbf{n}) = x(t,\mathbf{n}) - y_c(t-1,\mathbf{n}) , \tag{2}$$

$$p_B(t,\mathbf{n}) = x(t,\mathbf{n}) - \{y_c(t-1,\mathbf{n}) + y_c(t+1,\mathbf{n})\}/2 , \tag{3}$$

is fed into DCT where $y_c(t,\mathbf{n})$ indicates motion-compensated signal of $x(t,\mathbf{n})$ and it is produced so that energy of predicted signal $p_x(t,\mathbf{n})$ becomes less than that of $x(t,\mathbf{n})$ [1,10]. Here I, P and B denote type of frame. After that the signal is quantized, entropy coded and transmitted to the scalable decoder as a bit stream (**see Fig.1**).



a) Encoding procedure for full scale image.



b) Decoding procedure for M/N down scaled image.

T_N; N point DCT
Q ; quantization
E ; entropy coding
FM; frame memory
MC; motion compensation
v; motion vector

Fig.1 Scalable video coding system. (M<N)

The decoder, on the other hand, decodes the bit stream and reconstructs frame signal $z^*(t,n)$ by adding motion-compensated signal y_d^* to the predicted signal p^*, namely,

$$z^*_I(t,n)= p^*_I(t,n), \tag{4}$$

$$z^*_P(t,n)= p^*_P(t,n)+ y^*_d(t-1,n), \tag{5}$$

$$z^*_B(t,n)= p^*_B(t,n)+\{y^*_d(t-1,n)+y^*_d(t+1,n)\}/2, \tag{6}$$

where "*" denotes quantized and scaled version. The scaling is achieved applying MxM point inverse DCT (IDCT) to low frequency area of coded NxN point DCT coefficients (M<N) [2,8,10]. Therefore the reconstructed signal contains *"aliasing"* error and *"quantization"* error in general.

2.2. DRIFT PROBLEM As a result of experiments, the other blurring called *"drift"* is observed in reconstructed frames [4,5,9,10]. The first purpose of this paper is to examine cause of the drift error which is characterized by

[A] Drift is observed in scaled B and P frames ; and
[B] High frequency components (e.g. edge, texture) in the frame are suppressed.

[A] implies that the problem is due to producing y^*_d in eq.(5) and (6) which is performed by MC with scaling. Hence we shall confine our attention to procedure of producing motion-compensated signal y_e and y^*_d next.

3. MOTION COMPENSATION (MC)

This section addresses signal processing of MC in the existing SC system in detail.

3.1 MC IN ENCODER In encoder of the system, MC is performed with half pel (1/2 pel) precision [10] which means that a motion vector "v" is defined over n/2 where n is an integer. Subsequently motion-compensated signal $y_e(n)$ in eq.(2) and (3) is produced by

$$y_e(n)=x_{i/2}(n+v-i/2),\ \text{if } 2v \bmod 2 = i,\ \text{for } i=0,1, \tag{7}$$

where

$$\begin{bmatrix} x_{0/2}(n) \\ x_{1/2}(n) \end{bmatrix} = 1/2 \begin{bmatrix} 2 & 0 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} x(n) \\ x(n+1) \end{bmatrix} . \tag{8}$$

Notice that (1) we continue our discussion using one dimensional location variable "n" instead of two dimensional one "n" and omit time variable "t" for simplification of notation: and (2) MC is applied to each block which is a divided part of input signal [1,10].

In this paper we treat eq.(8) as a convolution of frame signal and MC filters, namely,

$$x_{i/2}(n)=f_{i/2}(k) * x(n),\ \text{for } i=0,\ 1, \tag{9}$$

for later discussion. This convolution is expressed in z-domain by

$$X_{i/2}(z)=F_{i/2}(z)\cdot X(z),\ \text{for } i=0,1, \tag{10}$$

where

$$\begin{bmatrix} F_{0/2}(z) \\ F_{1/2}(z) \end{bmatrix} = 1/2 \begin{bmatrix} 2 & 0 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ z^{-1} \end{bmatrix} . \tag{11}$$

3.2 MC IN SCALABLE DECODER In the scalable decoder, on the other hand, not only frame signal is scaled down but also each motion vector is multiplied by M/N (M<N) [5,9,10]. In case of M=N/2, MC is performed with quarter pel (1/4 pel) precision to retain full precision available at full size. Then the motion-compensated and down scaled signal $y^*_d(n)$ is produced with down scaled motion vector v^* (=v/2) by

$$y^*_d(n) =x^*_{i/4}(n+v^*-i/4),$$

$$\text{if } 4v^* \bmod 4 = i,\ \text{for } i=0,1,2,3, \tag{12}$$

where

$$x^*_{i/4}(n)=f_{i/4}(k) * x^*(n)\ ,\ \text{for } i=0,1,2,3. \tag{13}$$

Expressing in similar way to eq.(11) MC filters of existing scalable decoder are given by

$$\begin{bmatrix} F_{0/4}(z) \\ F_{1/4}(z) \\ F_{2/4}(z) \\ F_{3/4}(z) \end{bmatrix} = 1/4 \begin{bmatrix} 4 & 0 \\ 3 & 1 \\ 2 & 2 \\ 1 & 3 \end{bmatrix} \begin{bmatrix} 1 \\ z^{-1} \end{bmatrix} . \tag{14}$$

Then the drift occurs.

4. MC AS A MULTIRATE SIGNAL PROCESSING

In this section we derive motion-compensated signals y_e and y^*_d in z-domain to investigate cause of the drift.

4.1 MC IN ENCODER Signal processing in eqs.(7)-(11) can be interpreted as that in **Fig.2**, which is expressed in z-domain by following equations:

$$A_e(z)= X(z^2) \tag{15}$$

$$B_e(z)= A_e(z)P(z) \tag{16}$$

$$C_e(z)= B_e(z)z^{-2v} \tag{17}$$

$$Y_e(z)= [C_e(z^{1/2})+C_e(-z^{1/2})]/2. \tag{18}$$

Combining eqs.(15)-(18) motion-compensated signal in the encoder is given by

$$Y_e(z)= [P(z^{1/2}) + (-1)^{2v}P(-z^{1/2})]X(z)z^{-v}/2 . \tag{19}$$

Next, we derive P(z) in eq.(19) as follows. Considering that $B_e(z)$ in eq.(16) is also given by

$$B_e(z)= X_{0/2}(z^2) + X_{1/2}(z^2)z , \tag{20}$$

we can get relation between $F_{i/2}(z)$ and P(z) by

$$P(z)= F_{0/2}(z^2) + F_{1/2}(z^2)z . \tag{21}$$

Substituting eq.(11) into eq.(21) P(z) becomes

$$P(z)= (z+2+z^{-1})/2 . \tag{22}$$

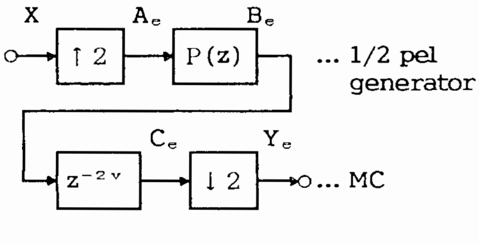


Fig.2 MC in encoder with 1/2 pel precision. (v=n/2, n∈integer)

4.2 MC IN SCALABLE DECODER On the other hand, eqs.(12)-(14) can be interpreted as the signal processing in **Fig.**3 which is expressed by following equations:

$$A_d(z)= X^*(z^2) \tag{23}$$

$$B_d(z)= A_d(z)Q(z) \tag{24}$$

$$A'_d(z)= B_d(z^2) \tag{25}$$

$$B'_d(z)= A'_d(z)R(z) \tag{26}$$

$$C_d(z)= B'_d(z)z^{-2v} \tag{27}$$

$$\begin{aligned} Y^*_d(z)= [&C_d(z^{1/4})+C_d(-z^{1/4}) \\ &+C_d(-jz^{1/4})+C_d(jz^{1/4})]/4 \ . \end{aligned} \tag{28}$$

Combining eqs.(23)-(28) motion-compensated signal in the scaling decoder is given by

$$\begin{aligned} Y^*_d(z)= [\ &Q(z^{1/2})+R(z^{1/4}) \\ &+(-1)^{2v}Q(z^{1/2})+R(-z^{1/4}) \\ &+(-j)^{2v}Q(-z^{1/2})+R(-jz^{1/4}) \\ &+(j)^{2v}Q(-z^{1/2})+R(jz^{1/4})]X^*(z)z^{-v}/4 \ . \end{aligned} \tag{29}$$

Next, we derive Q(z) and R(z) in eq.(29) as follows. Considering that $B'_d(z)$ in eq.(26) is also given by

$$\begin{aligned} B'_d(z)= &X_{0/4}(z^4) +X_{1/4}(z^4)z \\ &+X_{2/4}(z^4)z^2+X_{3/4}(z^4)z^3 \end{aligned} \tag{30}$$

we get relation among $F_{i/4}(z)$ and Q(z) and R(z) by

$$\begin{aligned} Q(z^2)R(z)= &F_{0/4}(z^4) +F_{1/4}(z^4)z \\ &+F_{2/4}(z^4)z^2+R_{3/4}(z^4)z^3 \ . \end{aligned} \tag{31}$$

Substituting eq.(14) into eq.(31) we get

$$\begin{aligned} Q(z^2)R(z)&= (z^3+2z^2+3z+4+3z^{-1}+2z^{-2}+z^{-3})/4 \\ &= (z^2+2+z^{-2})/2\cdot(z+2+z^{-1})/2 \ . \end{aligned} \tag{32}$$

Therefore we can find that

$$Q(z) = R(z) = (z+2+z^{-1})/2 \ . \tag{33}$$

4.3. CAUSE OF THE DRIFT Considering eq.(1)-(6) we can see that $Y^*_d(z)$ must be equal to $Y^*_e(z)$ so that reconstructed signal z* is equal to scaled version of input signal x*. However this is not satisfied in the existing system. This can be confirmed by calculating

$$d^*(z) = Y^*_d(z) - Y^*_e(z) \tag{34}$$

where $Y^*_d(z)$ and $Y^*_e(z)$ are down scaled version of $Y_d(z)$ and $Y_e(z)$ respectively. In this paper we omit aliasing error and quantization error to focus our discussion on the drift error. In this case equations:

$$Y_e^*(z) = Y_e(z^{1/2})/2 \ ; \text{and} \tag{35}$$

$$X^*(z) = X(z^{1/2})/2 \tag{36}$$

are satisfied. From eqs.(35),(19) and eqs.(36),(29), $Y^*_e(z)$ and $Y^*_d(z)$ in eq.(34) become

$$\begin{aligned} Y^*_e(z)= [\ &P(z^{1/4}) \\ &+(-1)^{2v} P(-z^{1/4})]X(z^{1/2})z^{-v}/4 \end{aligned} \tag{37}$$

$$\begin{aligned} Y^*_d(z)= [\ &Q(z^{1/2})R(z^{1/4}) \\ &+(-1)^{2v}Q(z^{1/2})R(-z^{1/4}) \\ &+(-j)^{2v}Q(-z^{1/2})R(-jz^{1/4}) \\ &+(j)^{2v}Q(-z^{1/2})R(jz^{1/4})]X(z^{1/2})z^{-v}/8 \end{aligned} \tag{38}$$

Substituting eq.(37) and eq.(38) into eq.(34) mismatching of frequency characteristics of motion- compensated signals between encoder and scalable decoder is obtained by

$$\begin{aligned} D^*(z)= [\ &\{Q(z^{1/2})R(z^{1/4}) -2P(z^{1/4})\} \\ &+(-1)^{2v}\{Q(z^{1/2})R(-z^{1/4}) -2P(-z^{1/4})\} \\ &+(-j)^{2v} Q(-z^{1/2})R(-jz^{1/4}) \\ &+(j)^{2v} Q(-z^{1/2})R(jz^{1/4})]X(z^{1/2})z^{-v}/8 \end{aligned} \tag{39}$$

where Q(z), R(z) and P(z) satisfy eq.(22) and eq.(33).

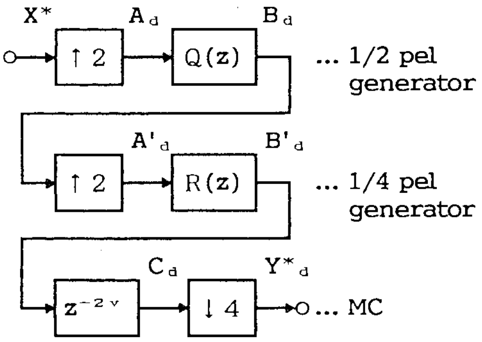


Fig.3 MC in scalable decoder with 1/4 pel precision. (M=N/2)

Comparing eq.(37) and eq.(38) we can also find that, while encoder employs only one low pass filter P(z), the existing decoder uses two low pass filters Q(z) and R(z), namely one more filter than the encoder. This can be the reason of [B] in sec.2.2. On these grounds we have come to the conclusion that the mismatching of motion-compensated signals between encoder and decoder brings about the drift.

5. PROPOSED METHOD

In this section, we propose a new deign method of MC filters in scalable decoder and compare the proposed method with the existing method in effectiveness of drift reduction.

5.1 OPTIMUM DESIGN OF THE MC FILTERS First, we propose to use encoder's MC filter P(z) as one of decoder's MC filters R(z). Then eq.(39) becomes

$$\begin{aligned} D^*(z)= [\ &\{Q(z^{1/2}) -2\}P(z^{1/4}) \\ &+(-1)^{2v}\{Q(z^{1/2}) -2\}P(-z^{1/4}) \\ &+(-j)^{2v} Q(-z^{1/2}) P(-jz^{1/4}) \\ &+(j)^{2v} Q(-z^{1/2}) P(jz^{1/4})]X(z^{1/2})z^{-v}/8 \ . \end{aligned} \tag{40}$$

Secondly, we propose to use half band filter H(z) [11] as one of decoder's MC filters Q(z). The filter H(z) satisfies

$$\begin{aligned} &H(e^{jw})= 2 \ , \text{ if } 0 \leqq \omega < \pi/2 \ ; \text{and} \\ &H(e^{jw})= 0 \ , \text{ if } \pi/2 < \omega \leqq \pi \ . \end{aligned} \tag{41}$$

It is expressed by

$$H(z) = 1 + S(z^2)z \tag{42}$$

where

$$S(z)= z^{-1/2}\sum_{i=1}^{N} s_i\,(z^{-(2i-1)/2}+z^{(2i-1)/2}) \ . \tag{43}$$

Filter coefficients s_i are determined so that S(z) approximates all pass filter under some criteria [12].

Substituting eq.(41) into Q(z) in eq.(40) we can confirm that eq.(40) becomes zero because eq.(41) implies that $H(z^{1/2})=2$ and $H(z^{-1/2})=0$ for $0\leqq\omega\leqq\pi$ and, therefore, our method can eliminate the drift.

5.2 SIMULATION RESULTS The filter coefficients "s_i" in eq.(43) obtained with Parks-Mclellan's algorithm [12] are indicated in **Table 1**. As a result of the procedure described above the MC filters are given, instead of eq.(14), by

$$\begin{pmatrix} F_{0/4}(z) \\ F_{1/4}(z) \\ F_{2/4}(z) \\ F_{3/4}(z) \end{pmatrix} = 1/2 \begin{pmatrix} 2 & 0 \\ 1 & 1 \\ 0 & 2 \\ z^{-1} & 1 \end{pmatrix} \begin{pmatrix} 1 \\ S(z) \end{pmatrix} \qquad (44)$$

In case of N=1 our method is as exactly same as the existing decoder in eq.(14).

Fig.4 illustrates energy of difference between scaled original signal and reconstructed signal. **Table** 2 indicates the energy in average of 150 frames. Input data are compressed with MPEG2 algorithm at 4Mbps [10]. Structure of frames is expressed by BBI BBP BBP ... and I frame appears at interval of 12 frames. It indicates that the drift decreases as N increases and we have confirmed that H(z) becomes close to all pass filter as N increases. Therefore we can conclude that the proposed optimization of MC filters is reasonable. The effectiveness of our method is also confirmed by subjective test.

Table 1 Filter coefficients of S(z).

	existing	proposed		
N	1	2	3	4
s1 s2 s3 s4	0.500000	0.620558 -0.120558	0.603249 -0.135697 0.032448	0.614736 -0.151865 0.047350 -0.010221

Table 2 Energy of difference between decoded signal z* and scaled original signal x*. [dB]

	existing	proposed		
N	1	2	3	4
flower	27.05 (0.00)	28.66 (+1.61)	28.94 (+1.89)	29.10 (+2.05)
mobile	26.45 (0.00)	28.42 (+1.97)	28.69 (+2.24)	28.93 (+2.48)

x* is produced with 8 point DCT and 4 point IDCT.

6. CONCLUSIONS

We proposed a new motion compensation (MC) technique which reduces blurring called "drift" in decoded and down scaled moving pictures with scalable decoder. Cause of the blurring was analyzed and the method was introduced as a solution to the problem. We also confirmed effectiveness of the new method compressing moving pictures with MPEG2 algorithm.

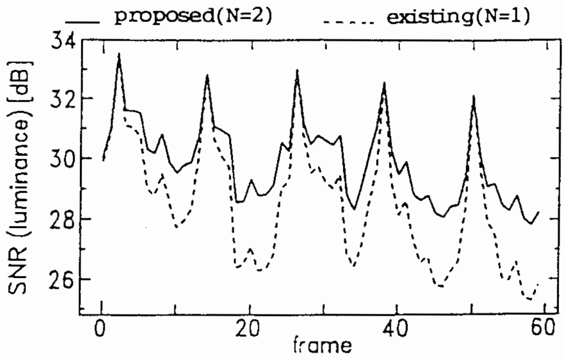


Fig.4 Energy of difference between decoded signal z* and scaled original signal x* for MPEG test sequence called "flower and garden".

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