NEW CAVLC DESIGN FOR LOSSLESS INTRA CODING

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ABSTRACT

The context-based adaptive variable length coder (CAVLC) in H.264/AVC is not appropriate for lossless video coding because it was designed for lossy video coding. Since statistical characteristics of residual data in lossy and lossless coding are quite different, we design a new VLC table for the number of non-zero coefficients and an adaptive scheme for VLC table selection in level coding for lossless intra coding. Experimental results show that the proposed CAVLC scheme provides approximately 10% bit saving, compared to the original CAVLC scheme in H.264/AVC.

Index Terms— H.264/AVC, lossless intra coding, CAVLC

1. INTRODUCTION

Recently, lossless coding has been actively studied for a medical image, a digital documentation and a digital cinema. JPEG lossless (JPEG-LS) [1] is the well-known lossless image coding method and was adopted as an international lossless image coding standard. Although the H.264/AVC standard was developed originally for lossy coding, it can also support lossless image coding.

Lossless intra coding employs prediction and entropy coding because transform and quantization are not used. It is controlled by a transform-bypass lossless mode [2] in the fidelity range extensions (FRExt) [3]. Recently, in order to increase coding performance for lossless intra coding, the sample-wise *differential pulse-code modulation* (DPCM) [4], [5] were developed. However, their coding performance is not good. When residual errors are entered into the entropy coding part, H.264/AVC still employs context-based adaptive variable length coding (CAVLC) which is designed mainly for DCT-based lossy coding.

For lossless intra coding, the original sample values are coded by intra prediction and entropy coding without transform and quantization. For lossy coding, quantized transform coefficients are coded. Hence, statistical characteristics of residual errors from lossy and lossless intra coding are very different. It means that there is still some room for improving coding performance in H.264/AVC by modifying the entropy coding part.

In this paper, we propose new entropy coding methods based on sample-wise DPCM for lossless intra coding. We design a better VLC table for the number of non-zero coefficients and an adaptive method for level VLC table selection.

2. OVERVIEW OF CAVLC IN H.264

Context-based adaptive variable length coding (CAVLC) was designed to take advantage of several characteristics of residual data in lossy coding:

1) After transform and quantization, sub-blocks typically contain many zeros in high frequency regions.
2) The levels of non-zero coefficients tend to be larger toward the low frequency regions.
3) The levels of the highest non-zero coefficients tend to be as small as one.

Therefore, considering the above characteristics, we have five coding steps in CAVLC.

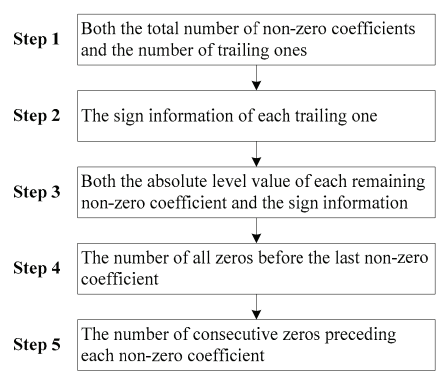

Fig. 1. Encoding step of CAVLC

In Step 1, four VLC tables, used for encoding the number of non-zero coefficients (*numcoeff*) and the number of trailing ones (*numtrailingones*), are comprised of three variable-length code tables (*Num-VLC0*, *Num-VLC1* and *Num-VLC2*) and one fixed-length code table (*FLC*). The choice of the VLC table depends on *numcoeff* in the previously coded upper and left sub-blocks. Thus, based on the predicted *numcoeff*, an appropriate VLC table for the current sub-block is selected.

In Step 3, each absolute level value (*abs_level*) is encoded by a VLC table selected from seven VLC tables (*Lev-VLC0* to *Lev-VLC6*). Selection of the VLC table depends on the recently encoded *abs_level*.

3. PROPOSED CAVLC SCHEME

3.1. Analysis of the Statistical Characteristics of Residual Data in Lossless Coding

In lossless coding, residual data does not represent quantized transform coefficients, but rather the differential pixel values between the original and predicted pixel values. Therefore, the statistical characteristics of residual data in lossy and lossless coding are very different.

Characteristics of residual data in lossless coding are as follows. First, the occurrence probability of non-zero coefficients is independent of the scanning position (Fig. 2). Second, the occurrence probability of trailing ones is not so high (Table 1). Third, *numcoeff* in lossless coding is generally larger than *numcoeff* in lossy coding (Fig. 4). Finally, *abs_level* does not decrease as the scanning position increases (Fig. 5).

Figure 2 shows the occurrence probability of non-zero coefficients as a function of the scanning position. Table 1 lists the occurrence probability of trailing ones in terms of the quantization parameter (QP). As expected, we can observe significant differences in the statistics between residual data of lossy and lossless coding.

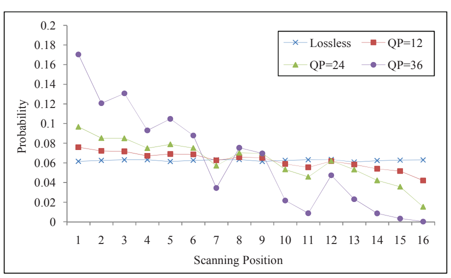

Fig. 2. Probability of non-zero coefficients ('Mobile', CIF)

Table 1. Occurrence probability of trailing ones

Sequence \ QP	0 (Lossless)	12	24	36
Foreman	0.258	0.760	0.903	0.958
Silent	0.232	0.817	0.923	0.955
Mobile	0.222	0.636	0.837	0.929
Football	0.144	0.792	0.908	0.955
Paris	0.275	0.747	0.866	0.936

In order to reflect the different statistical characteristics of residual data in lossy and lossless coding, we propose a new CAVLC algorithm for lossless intra coding in H.264/AVC by modifying Step 1, Step 2 and Step 3 of CAVLC, as shown in Fig. 3.

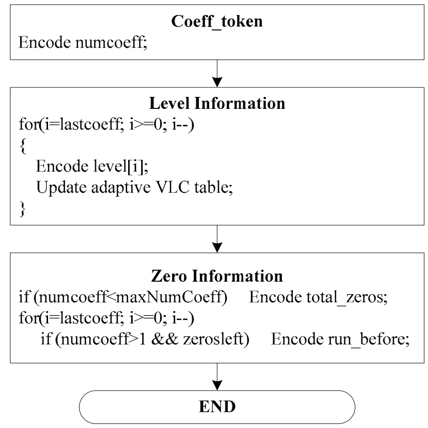

Fig. 3. Encoding structure of the proposed method

3.2. Coding the Number of Non-zero Coefficients

In Step 1 of the proposed CAVLC scheme, we encode *numcoeff*. However, we do not encode *numtrailingones* by considering the occurrence probability of trailing ones. In the original CAVLC in H.264/AVC, the VLC table is selected based on the predicted *numcoeff*. If the predicted *numcoeff* is larger than seven, the *FLC* table is selected.

Figure 4 shows the cumulative probability distribution function of the number of non-zero coefficients. In lossless coding, since *numcoeff* is generally larger than seven, the *FLC* table is selected frequently. From our extensive experiments on lossless intra coding with various test sequences, we observe that the *FLC* table is selected about 95%. Therefore, we could remove three VLC tables (*Num-VLC0*, *Num-VLC1* and *Num-VLC2*) in Step 1.

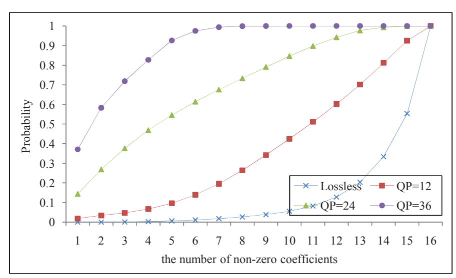

Fig. 4. Cumulative probability distribution of the number of non-zero coefficients ('Foreman', QCIF)

The *FLC* table consists of four bits for *numcoeff* and two bits for *numtrailingones*, except for chroma DC. Since *numtrailingones* does not need to be considered, only four bits for *numcoeff* are kept. However, instead of using the *FLC* table which assigns four bits uniformly for all *numcoeff*, we design a new VLC table considering the statistical characteristics of *numcoeff* in lossless coding.

In our proposed VLC table, we assign 4-bit and 2-bit codewords to *numcoeff* from 0 to 12 and 13 to 16 in our proposed VLC table, respectively. However, it is not efficient to assign four bits uniformly for *numcoeff* from 0 to 12 because the occurrence probability of *numcoeff* is likely to increase as *numcoeff* increases. Thus, we use the phased-in code [6] which is a slight extension of fixed length code. The phased-in code consists of codewords with two different lengths. Therefore, we assign 4-bit and 3-bit codewords to *numcoeff* from 0 to 9 and 10 to 12, respectively. In order to avoid ambiguity at the decoder, we insert a check bit into the prefix of each codeword.

For chroma DC, CAVLC employs a special VLC table to encode chroma DC residual data according to the color format, such as 4:2:0, 4:2:2 and 4:4:4. In our research, we also design a new VLC table for chroma DC data by considering the statistical characteristics of residual data. Chroma DC data has up to four coefficients in the 4:2:0 color format. In the proposed VLC table for chroma DC, we insert a check bit into the prefix of the codeword to assign the unique codeword and distinguish between *numcoeff*>0 and *numcoeff*=0. Table 2 represents the codeword table for *numcoeff*.

Table 2. Codeword table for '*numcoeff*'

numcoeff	Codeword			
	Except for Chroma DC		Chroma DC	
	Check bit	Bits	Check bit	Bits
0	1	1111	1	×
1	1	1110	0	00
2	1	1101	0	01
3	1	1100	0	10
4	1	1011	0	11
5	1	1010	-	-
6	1	1001	-	-
7	1	1000	-	-
8	1	0111	-	-
9	1	0110	-	-
10	1	010	-	-
11	1	001	-	-
12	1	000	-	-
13	0	00	-	-
14	0	01	-	-
15	0	10	-	-
16	0	11	-	-

Note that since trailing ones are treated as normal coefficients, they should be coded in the level coding step. Therefore, we removed Step 2, which is a coding stage of the sign information of each trailing one.

3.3. Level Coding

For level coding, *abs_level* of each non-zero coefficient is adaptively encoded by a VLC table selected from the seven predefined VLC tables in the reverse scanning order. Each VLC table is designed for efficient encoding in a specified range of *abs_level*. Selection of the VLC table for level coding is based on the expectation that *abs_level* is likely to increase toward the low frequency regions. Hence, selection of the VLC table is monotonically increases according to the previously encoded *abs_level*. However, *abs_level* in lossless coding is independent of the scanning position, as shown in Fig. 5. Therefore, we have designed an adaptive method for VLC table selection that can decrease or increase according to the previously encoded *abs_level*.

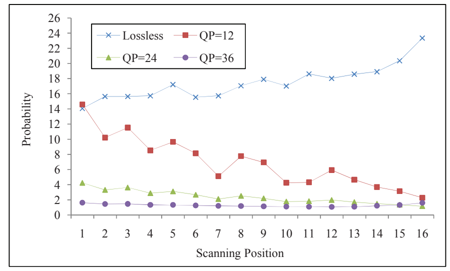

Fig. 5. Distribution of average absolute level value according to scanning position ('Mobile', CIF)

In lossy coding, the original level coding scheme typically determines the smallest VLC table in the range of possible VLC tables based on the assumption that the next *abs_level* to be coded is going to be larger. However, since the next *abs_level* does not necessarily increase at lower frequency regions in lossless coding, we cannot assume that the next *abs_level* is always larger than the current *abs_level*. Therefore, the VLC table for each *abs_level* should be selected by considering the previously encoded *abs_levels* because we cannot predict whether or not the next *abs_level* will increase.

In order to determine the appropriate VLC table, we assign the weighting value to the previously encoded *abs_levels*. The decision procedure of the VLC table for *abs_level* is described as follows.

$$avg_i = \frac{1}{(lastcoeff - i + 1)} \left\{ \sum_{k=lastcoeff}^{i} abs\_level_k \right\}, \tag{1}$$

$$T(abs\_level_i) = \frac{1}{a_i + 1} \{ a_i \cdot avg_i + abs\_level_i \},$$
$$a_i = \begin{cases} 0, & i = lastcoeff \\ 1, & i = lastcoeff - 1,\ lastcoeff - 2 \\ 2, & \text{otherwise} \end{cases}, \tag{2}$$

where a_i and abs_level_i are the i-th weighting coefficient and the i-th *abs_level* value, respectively. $T(abs\_level_i)$ represents a threshold value for selecting the corresponding VLC table used to encode the next *abs_level* ($(i-1)$-th *abs_level*). *lastcoeff* indicates the position number of the last non-zero coefficient. Note that *abs_level* is encoded in the reverse order.

In Table 3, we represent the VLC table for level coding with respect to new threshold values. From extensive experiments on lossless intra coding, we determine the optimal threshold value for the level VLC table.

Table 3. New threshold values for selection of the VLC table

VLC tables	$T(abs\_level_i)$
Lev-VLC0	0
Lev-VLC1	2
Lev-VLC2	4
Lev-VLC3	9
Lev-VLC4	19
Lev-VLC5	39
Lev-VLC6	> 39

In Fig. 5, we observe that the last scanned *abs_level* is quite different between lossy and lossless coding. In lossy coding, level encoding starts with *Lev-VLC0* or *Lev-VLC1* because the last scanned *abs_level* is likely to be small; however, in lossless coding, the last scanned *abs_level* is not small enough to use *Lev-VLC0 or Lev-VLC1*. From our extensive experiments on lossless intra coding using various test sequences, we find that the average value of the last scanned *abs_level* in the chroma DC sub-block and other sub-blocks are approximately 6.79 and 10.70, respectively. Therefore, we initialize the VLC table as *Lev-VLC3* and *Lev_VLC4* for both cases, respectively.

4. EXPERIMENTAL RESULTS AND ANALYSIS

We have implemented our proposed CAVLC scheme in the H.264 reference software version JM 13.2 [7]. In order to verify the validity of the proposed CAVLC scheme, we have performed experiments on several video sequences of the YUV 4:2:0 format with QCIF and CIF resolutions. The encoding parameters for the reference software are

1) *ProfileIDC*: 244 (High 4:4:4)
2) *IntraPeriod*: 1 (only intra coding)
3) *QPISlice*: 0 (lossless)
4) *SymbolMode*: 0 (CAVLC)
5) *QPPrimeYZeroTransformBypassFlag*: 1

In order to evaluate coding performance of the proposed CAVLC scheme, we have compared bit-rate percentage differences and compression ratio differences by

$$Compression\ Ratio = \frac{Original\ image\ size}{Bitrate_{proposed}} \quad (3)$$

$$\Delta Saving\ Bits(\%) = \frac{Bitrate_{original} - Bitrate_{proposed}}{Bitrate_{original}} \times 100 \quad (4)$$

From Table 4, we notice that the proposed CAVLC scheme provides improved coding performance for lossless intra coding by approximately 10% bit saving, compared to the original CAVLC in the H.264/AVC FRExt high profile.

Table 4. Performance comparison

Sequence (Original Size)	Method	Total Bits (bits)	Comp. Ratio	ΔSaving Bits (%)
Foreman (45619200)	Original	21119320	2.16	0
	Proposed	19336368	2.36	8.44
Silent (45619200)	Original	22109864	2.06	0
	Proposed	20099328	2.27	9.09
Mobile (182476800)	Original	110168736	1.66	0
	Proposed	95493056	1.91	13.32
Football (182476800)	Original	101325088	1.80	0
	Proposed	90326256	2.02	10.85
Paris (182476800)	Original	89998496	2.03	0
	Proposed	81372000	2.24	9.59
Average	Original		1.94	0
	Proposed		2.16	10.26

5. CONCLUSIONS

In this paper, we propose an improved context-based adaptive variable length coding (CAVLC) scheme for lossless intra coding in H.264/AVC. Considering the statistical characteristics of residual data in lossless intra coding, we design a new CAVLC scheme in H.264/AVC. Experimental results show that the proposed CAVLC scheme provides approximately 10% bit saving, compared to the H.264/AVC FRExt high profile.

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REFERENCES

[1] M.J. Weinberger, G. Seroussi, and G. Sapiro, “The LOCO-I lossless image compression algorithm: principles and standardization into JPEG-LG,” *IEEE Trans. Image Processing*, vol. 9, no. 8, pp. 1309–01324, Aug. 2000.

[2] S. Sun, Intra Lossless Coding and QP Range Selection, ISO/IEC JTC1/SC29/WG11 and ITU-T Q6/SG16 Joint Video Team Document JVT-C023, May 2002.

[3] G.J. Sullivan, P. Topiwala, and A. Luthra, “The H.264/AVC Advanced Video Coding Standard: Overview and Introduction to the Fidelity Range Extensions,” SPIE conference, Special Session on Advances in the New Emerging Standard: H.264/AVC, Aug. 2004.

[4] Y.L. Lee, KH. Han, and G.J. Sullivan, “Improved lossless intra coding for H.264/MPEG-4 AVC,” IEEE Trans. Image Processing, vol. 15, no. 9, pp. 2610–2615, Sept. 2006.

[5] N. Krishnan, R.K. Selvakumar, P. Vijayalakshmi, and K. Arulmozhi, “Adaptive Single Pixel Based Lossless Intra Coding for H.264/MPEG-4 AVC,” IEEE ICCIMA ’07, vol. 3, pp. 63–67, Dec. 2007.

[6] I.E.G. Richardson, H.264 and MPEG-4 Video Compression. WILEY, 2003.

[7] http://iphome/hhi.de/shehring/tml/download/old_jm/jm13.2.zip, Joint Video Team, Reference Software Version 13.2.