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STATISTICAL ANALYSIS OF H.264/AVC DEBLOCKING FILTER

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The latest video coding standard, H.264/AVC uses in-loop deblocking filter for suppression of blocking artifacts at low bit rates. The deblocking filter can effectively suppress the blocking artifacts due to low bit rate video coding, however it is highly computationally complex. This paper describes statistical analysis of H.264/AVC deblocking filter for various QCIF sequences. The deblocking filtering phenomenon can be divided into two steps: decision to apply filter (no filter/strong filter/normal filter) and application of filter. Number of operations: additions, shifts and comparisons spent in deblocking filter are measured. Moreover, frequency of usage of strong and normal filter for various video sequences is computed. It has been found that 88.49% of average number of operations is spent to take decision about type of filter (no filter/normal filter/strong filter) whereas11.51% of average number of operations is spent for filtering of samples for various QCIF video sequences.

Keywords : H.264/AVC, Deblocking filter, Computational complexity, Statistical analysis

1. Introduction

H.264/AVC (Advanced Video Coding) is the latest video coding standard developed by Joint Video Team (JVT) that includes experts from Motion Picture Expert Group (MPEG) and ITU-T Video Coding Expert Group (VCEG) [1]. H.264/AVC supersedes previous video coding standards in almost every aspect. It can be used in wide range of applications that can be categorized as: (1) Broadcast over cable, satellite communication, cable modem, DSL, terrestrial communication, etc. (2) Storage on optical and magnetic devices, DVD etc. (3). Conversational services important networks. (4) Video-on-demand (5) multimedia streaming services over IDSN, cable mode, DSL, LAN, wireless Network etc. and multimedia messaging services over ISDN, DSL, Ethernet etc [2]. Performance analysis of H.264/AVC has shown its superiority over other existing standards like H.263 and MPEG-4 [3-4].

H.264/AVC like other video coding standards use block base transform coding method to exploit spatial redundancy. The basic approach is to divide the whole image into blocks, transform each block using discrete cosine transform, quantize and entropy coded [5]. Quantization step divides transformed coefficients by quantization table and are rounded to an integer. At low bit rates, high-order DCT coefficients are more severely quantized (usually to zero), which results in loss of correlation occurs between adjacent blocks. This produces visually disturbing discontinuities along the block edges, known as blocking artifacts.

H.264/AVC uses adaptive in-loop deblocking filter for the reduction of blocking artifacts [6]. Performance analysis of deblocking filter has shown its effectiveness for suppression of blocking artifacts [7]. However, it is highly computationally complex as it takes one-third of computing resources of the decoder as it takes one-third of computational resources of the decoder according to an analysis of run-time profiles of decoder sub-functions [8]. The proposed research describes in-depth statistical analysis of H.264/AVC deblocking filter with respect to computing complexity. The main objective of proposed research is to find out the cause of computational complexity of H.264/AVC deblocking filter. Various operations like additions, shifts and comparisons are computed during execution of deblocking filter to find out the rationale for high computing complexity of H.264/AVC deblocking filter. The proposed analysis is platform independent as number of

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operations executed during operation of deblocking filter remains same irrespective of platform to be used. Rest of paper is organized as follows: section 2 elaborates the brief working of H.264/AVC deblocking filter. The simulation results are discussed in section 3 while section 4 concludes the paper.

2. Overview of H.264/AVC Loop Deblocking Filter

H.264/AVC employs loop deblocking filter to suppress the blocking artifacts. The filter is applied within the coding loop after the inverse transform block in H.264/AVC encoder as shown in Figure 1.

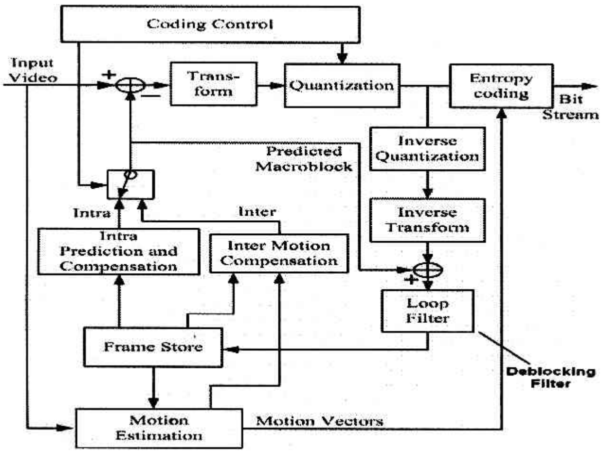

Figure 1. In-loop deblocking filter position in H.264/AVC encoder.

The filter is applied at macroblock level by processing pixels in vertical edge followed by horizontal edge pixels. The vertical and horizontal block edge pixels in a macroblock are shown in Figure 2. The application of deblocking phenomenon is decided with the help of a parameter called boundary strength (bS) and is assigned an integer value from 0 to 4 [2]. Various parameters like macroblock type, motion vector, quantization parameter, gradient of samples across edges, are used for computation of boundary strength [2, 5]. The decision to apply deblocking filter is also dependent on another condition in addition to non-zero boundary strength. The main reason for inclusion of additional condition is to distinguish between occurrence of real edges in video and edges due to compression phenomenon. As a result, the edge pixels p_0, p_1, p_2, p_3 and q_0, q_1, q_2, q_3 are filtered on the fulfillment of conditions elaborated in Eq. (1) and Eq. (2).

$$bS > 0 \tag{1}$$

$$|p_0 - q_0| < \alpha \,\&\&\, |p_1 - q_1| < \beta \,\&\&\, |q_1 - q_0| \le \beta \tag{2}$$

where α and β are the thresholds defined in standard [standard]. The process of deblocking filter can be divided into two steps: (1) decision to apply filtering or no filtering (2) application of filter. Two types of filter: strong and normal filter are used for deblocking of artifacts. On fulfillment of condition in Eq. (2) and bS =4, strong filter is applied while normal filter is applied for 1 ≤ bS ≥ 3 and condition of Eq. (2).

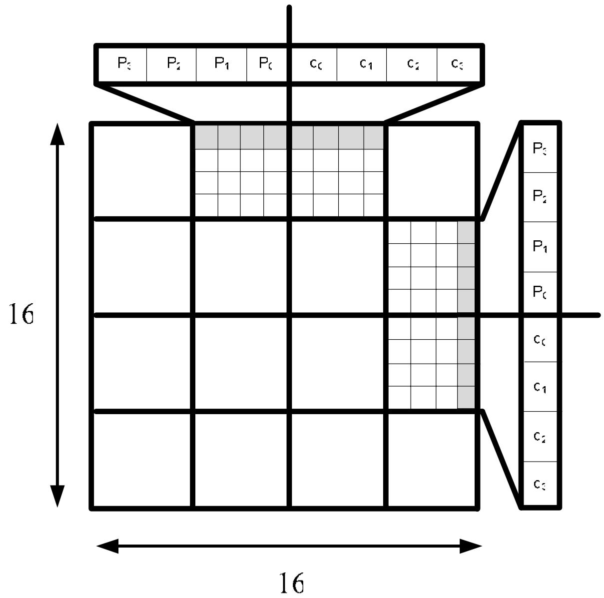

Figure 2. Filtering of pixels in a macroblock.

The strong filter modifies the horizontal edge pixels p_0, p_1 and p_2 to produce P_0, P_1 and P_2 according to Eq. (3) through Eq. (5) [2]

$$P_0 = (p_2 + 2p_1 + 2p_0 + 2q_0 + q_1 + 4) >> 3 \tag{3}$$

$$P_1 = (p_2 + p_1 + p_0 + q_0 + 2) >> 2 \tag{4}$$

$$P_2 = (2p_3 + 3p_2 + p_1 + p_0 + q_0 + 4) >> 3 \tag{5}$$

Similarly vertical edge pixels q_0, q_1 and q_2 are modified by replacing p with q in Eq. (3) through Eq. (5). The normal filter modifies the horizontal

Table 1. Various parameters for experimental environment.

Reference software version	JM 10.2
Video format	176 x 144
Total frames	150
Frame rate	15
Profile	Main
Intra Period	0 (only 1st frame)
Max search range	16
GOP structure	IPPP
Hadmard Transform	Used
Transform 8x8 mode	Not used
No. of reference frames	1
Frame skip	0
Inter search	16x16, 16x8, 8x16, 8x8, 8x4, 4x8, 4x4
B frames	Not used
Entropy method	CABAC
Rate distortion optimization	Not used

edge pixels p_0, p_1 and vertical edge pixels q_0, q_1 according to Eq. (6) through Eq. (9) [2].

$$P_0 = p_0 + \Delta_0 \quad (6)$$

$$Q_0 = q_0 - \Delta_0 \quad (7)$$

where $\Delta_0 = (4(q_0 - p_0) + (p_1 - q_1) + 4) >> 3$

$$P_1 = p_1 + \Delta \quad (8)$$

$$Q_1 = q_1 + \Delta \quad (9)$$

where $\Delta = (p_2 + ((p_0 + q_0 + 1) >> 1) - 2p_1) >> 1$

Literature review indicates that H.264/AVC deblocking filter is highly computationally complex. The proposed research in this paper performs in-depth statistical evaluation of deblocking filter by analyzing frequency of occurrence of various operations like additions, shifts and comparisons during execution of filter.

3. Results and Discussion

H.264/AVC reference software model JM 10.2 is used for statistical analysis of deblocking filter [9]. The analysis conducted in proposed research is operations dependent and not platform dependent, therefore the cost in terms of time delay, hardware requirements and memory calls is not considered. The Quarter Common Intermediate Format (*QCIF*) sequences used for experimentation are HALL, SALESMAN, NEWS, CARPHONE, and FOREMAN [10]. The other parameters used for analysis are elaborated in Table 1.

The source code of deblocking filter in reference software of H.264/AVC is modified to insert flags at pixel level, macroblock level and frame level for statistical analysis. Table 2 describes average comparison of the total number of various operations like additions, shifts and comparisons during execution of deblocking filter. The multiplication is considered as equivalent to performing shift and addition and is counted towards additions and shifts. The average total number of operations spent for decision to apply filter and application of filter are described in Table 3.

Table 2. Various operations in QCIF sequences .

Sequence	Additions	Shifts	Comparisons
Hall	39,287,968	42,061,490	123,216,435
Salesman	35,902,147	40,511,946	150,930,703
News	53,790,851	49,066,148	163,898,224
Foreman	51,547,739	48,376,735	163,081,086
Carphone	56,005,167	50,454,945	154,271,124

Table 3. Total operations spent on various QCIF sequences

Sequence	Total operations spent for decision to apply filter	Total operations spent for filtering of edge samples
Hall	196,089,707	20,617,213
Salesman	202,239,999	13,175,349
News	203,219,613	17,687,001
Foreman	205,395,868	20,798,789
Carphone	206,447,135	23,755,877

Table 4. Frequency of strong and normal filter usage in various QCIF sequences.

Sequence	Strong Filter Usage	Normal Filter Usage
Hall	5,800	22,715
Salesman	5,685	26,049
News	6,263	17,919
Foreman	4,840	26,360
Carphone	9,296	29,669

Table 4 describes the frequency of strong and normal filtering usage for various QCIF sequences in H.264/AVC Deblocking Filter encoded at 30 Kbps. It can be seen that application of strong filter is significantly less than that of normal filter.

Figure 3 shows the graphical comparison of addition, shift and comparison operations (average) spent in deblocking filter for various QCIF sequences. It can be observed that comparison operations supersede addition and shift operations in all sequences.

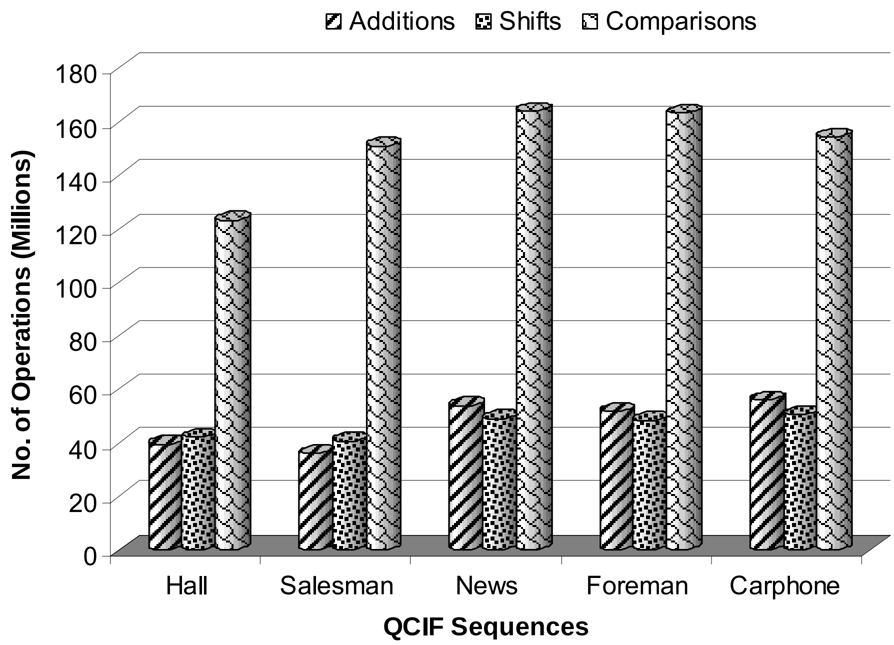

Figure 3. No. of additions, shifts and comparisons operations spent during execution of H.264/AVC deblocking filter for various QCIF Sequences

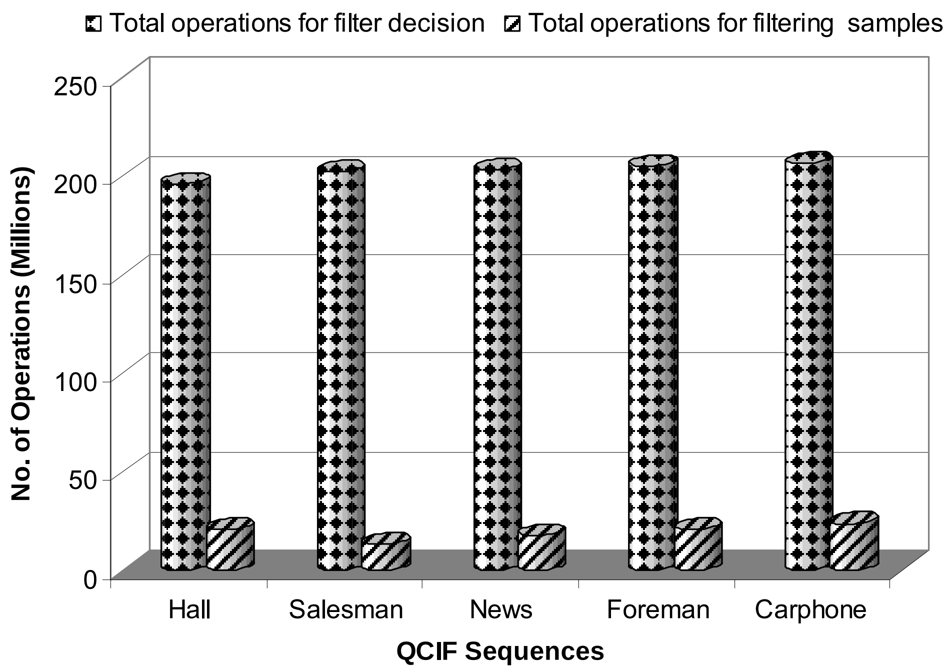

Figure 4. Total operations spent during execution of H.264/AVC deblocking filter for various QCIF Sequences

Figure 4 demonstrates the comparison of total number of operations (average) spent for decision to apply filter and application of filter for various QCIF sequences. The number of operations spent for decision to apply deblocking filter or not are significantly higher than that of actually applying the filter.

The average number of operations spent on decision for filter (no filter/normal filter/strong filter) are computed for various QICF sequences used in experimentation and are added together to get the total number of operations. Similarly number of operations spent during application of filter is computed. The percentage is computed by dividing the respective operations with total number of operations. As a result, it has been found that 88.49% of average number of operations is spent to take decision about type of filter whereas11.51% of average number of operations is spent for filtering of samples for various QCIF video sequences. Therefore, it is concluded that the computing complexity of H.264/AVC deblocking filter mainly comes from operations done to decide about application of filter or not.

4. Conclusion

We have described an in-depth statistical analysis of deblocking filter for latest H.264/AVC video coding standard. The source code of filter is annotated to count various operations during coding of various QCIF sequences. It has been found that main computational complexity of H.264/AVC deblocking filter is due to significant number of operations spent during decision to apply filter (no filter/strong filter/normal filter). Moreover, it is found that frequency of strong filter is substantially less than that of normal filter for various QCIF sequences used in experimentation.

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