Superimposed Boundary Strength Matrix Method for Decision Process of In-Loop Deblocking Filter

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***Abstract*—This paper presents the so-called "superimposed boundary strength matrix method" for the decision process for an in-loop deblocking filter. In this paper, we reduce the number of branch operations so as to cope with computational complexity, and such as pipeline stalls. Our method is compared with e.g. JM reference software, and verified that our method meets the specification of JM reference such as boundary strength values and PSNR. Simulation results show that the proposed method can achieve performance enhancement, ranging from 64.4% to 80.3%, within reasonable processing time. In addition to this, highly parallelized processing components can be obtained, and if the proposed method is applied to the parallel processing hardware implementation, performance enhancement will be apparent by exploiting parallelism included in our superimposed BS matrix method.**

I. INTRODUCTION

The ITU-T/ISO/IEC Joint Video Team (JVT) proposed H.264/AVC (Advance Video Coding), with twice the compression rate of H.263 and MPEG (Moving Pictures Experts Group) [1] However, this enhanced compression requires appreciably more processing power than previous compression techniques [2]. The main features of H.264/AVC are the following:

1) Introduction of advanced motion estimation,
2) Improvement of entropy coding such as CAVLC (Content Adaptive Variable Length Coding) and CABAC (Content Adaptive Binary Arithmetic Coding),
3) Advancement of the Deblocking filter [3].

The deblocking filter reduces the blocking artifacts that are produced by block-based video coding but in the previous version, this was not standardized. In H.264, the deblocking filter is positioned in a prediction loop to increase coding efficiency and improve video quality but this increases the computational complexity in the encoding and decoding processes.

Block based motion estimation and motion compensation introduce the blocking artifact in the edges between the blocks. The block based integer cosine transform, which is used to remove spatial redundancy, also makes a visible block structure in the image [4]. H.264/AVC has adopted an in-loop deblocking filter to reduce these blocking artifacts. Also, by applying the deblocking filter adaptively, H.264 could enhance the subjective and objective quality of the video without increasing the bit rate. [2]

However, the highly adaptive in-loop deblocking filtering process requires considerable computational complexity; in fact the in-loop deblocking filter accounts for almost 33% of the computational complexity in the H.264/AVC decoder [5]. The boundary strength (BS) decision part of the deblocking filter represents a high conditional complexity [6]. To determine the BS for a specific edge, coding information is considered, such as the reference pictures, the motion vectors for the blocks, and whether the intra-coded mode is used on the current macroblock or not. There are a lot of branch conditions in the BS decision process, which makes implementation of the deeply pipelined architecture difficult.

BS is mainly used to determine whether a special filter is applied to the edges, or if a normal filter should be applied to them. The BS is related to the intermediate parameters used in the deblocking filter as a primary factor [1]. Not only are image samples required, to be filtered, but many related parameters are also required to start the deblocking filter process so that the earlier the BS is decided, the more lower the latency time.

To reduce the complexity of the deblocking filter process, pre-judging of the BS method has been proposed [7]. This method reduced the complexity of the boundary strength by pre-judging the macroblock partition mode and by using the similarity property among the image samples in the edges of 16x16 or 16x8 or 8x16 macroblock partitions. However, this method does not consider below 8x8 sub macroblocks and partitions of the sub-macroblocks. Moreover, there is still some redundancy induced by using edge to edge processing order equal to the JM reference [8].

This paper proposes a superimposed matrix method that is used to decide the BS more efficiently. The similarity property is exploited further to minimize the number of branch conditions and the complexity.

The organization of this paper is as follows. Section 2 presents some issues related to the algorithms of BS decisions and Section 3 introduces the proposed superimposed BS matrix method. Then, experimental results are compared with the JM reference in Section 4 and finally, concluding remarks are given in Section 5.

II. Background of Boundary Strength Decision

The BS has to be decided for all these 4x4 block edges using many branch operations, which leads to high computational complexity and normal pipeline hazards. To reduce this complexity in the BS decision process, a pre-judging BS method has been proposed [7], which reduces the complexity of the BS decision process by pre-judging the macroblock coding mode, and exploiting the similarity property as mentioned above. Each 16x16 macroblock is coded with an intra-mode or an inter-mode in the H.264/AVC. If an inter-mode is used on the current macroblock, the motion estimation and compensation in the encoder, or the motion compensation in the decoder, determines the composition of the macroblock's partitions. One macroblock is divided into one 16x16 or two 16x8 or two 8x16 largely. Otherwise it is divided into four 8x8 sub-macro blocks where each of the four sub-macroblocks are further divided into one 8x8 or two 8x4 or two 4x8 or four 4x4.

The motion estimation and motion compensation, used in the H.264/AVC, operates based on macroblock partitions and 4x4 blocks, which are inside a larger partition, have the same reference picture and motion vectors. Therefore, the edges of the blocks inside the large macro-block partition have a BS value of zero and the zero-valued edges can be omitted during the deblocking filtering. The pre-judging BS method has applied this policy to 16x16, 16x8, 8x16 large partitioned modes to reduce the complexity in the BS decision making process. However, this method does not consider sub-macroblock below 8x8. Moreover, there is still some redundancy induced by using edge to edge processing order which is equal to the JM reference.

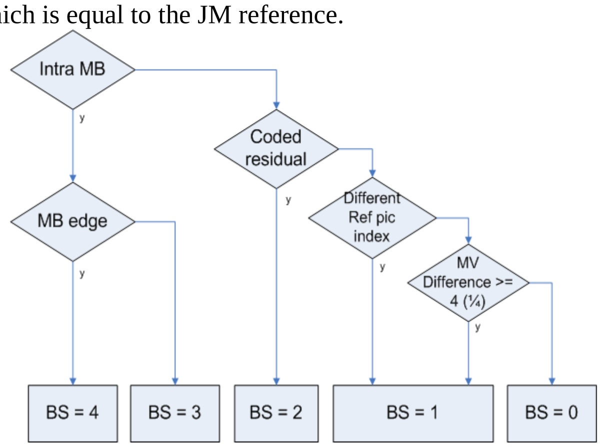


Fig. 1 Branch intensive BS derivation process used in the JM reference.

According to the ITU-T standard, if either or both of the blocks are intra-coded, and an edge between these blocks is a macroblock edge, then the BS is equal to 4. Otherwise, if the condition of the macroblock edge is not satisfied among the above two conditions, then the BS is equal to 3. A BS value of 3 or 4 is related wholly to the intra-mode. If one macroblock is coded within the intra-mode, any edges between the two blocks that are chosen in the internal macroblock satisfy the condition of a BS value of 3, as previously mentioned. The BS is set to 4 for any edge on the intra-coded macroblock boundary and this point can easily be seen since it is determined based on 16x16 macroblock units to decide whether a block is I type or P type. The JM reference processes the deblocking filtering edge to edge. The vertical edge is filtered first, from left to right, followed by the horizontal edge, filtering from top to bottom.

The BS decision making part also operates using this processing order so that by using this edge to edge method, there are many redundant branch operations. For every four vertical and four horizontal edges, two redundant branch operations are computed repeatedly, which depends on whether the block is intra-coded or it is on the macroblock boundary.

III. Our Proposed Method

A. *Overview of our method*

In this section, our so-called "superimposed BS matrix method" is proposed which is used to operate the BS decision making process more efficiently by maximizing the parallelism and reducing the complexity occurred by the branch operations. In the superimposed matrix method, four BS matrices are used where one is related to the intra-mode and the others are related to the inter-mode, coded transform coefficient, Left most and Top macroblock edges, respectively. For convenience these have been named the intra BS matrix, the inter BS matrix, the coded residual BS matrix, and the neighbor BS matrix. Each BS matrix consists of two 4x4 arrays as these represent four vertical edges and four horizontal edges. The BS matrix contains a total of 32 BS values, corresponding to the specific 32 4x4 block edges. The similarity property is exploited to decrease the BS matrix size, and to reduce the computational complexity. Each BS value in the matrix is used in four samples on the same 4x4 block edge equally.

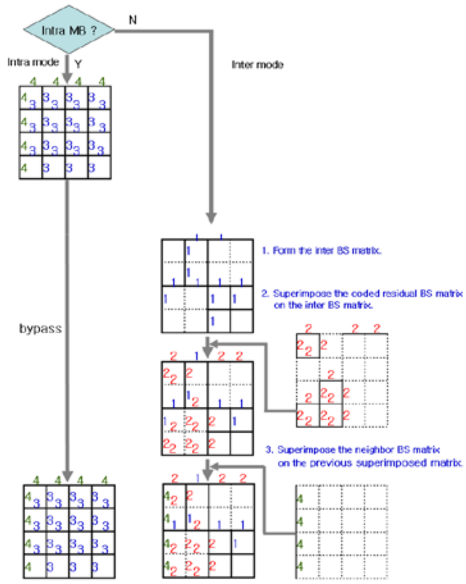


Fig. 2 BS decision process in a superimposed BS matrix method.

B. Procedure of the superimposed BS matrix method

The superimposed BS matrix method is proceeding as in the following four cases.

1) In the case of the intra-coded block: The intra BS matrix is used. If the decision of the BS can be performed with one branch operation (especially in case of the intra-coded mode), a large amount of branching operations can be reduced. This method directly writes the BS values on the intra BS matrix. Once the intra-coded mode is treated, the whole value of the macroblock is known. Therefore the BS can be determined for one 16x16 intra-coded macroblock at once.

2) In the case of inter-coded block: the inter BS matrix is used where reference picture and motion vectors are compared for every 32 edges repeatedly in the JM reference. However, the complexity associated with the inter-coded mode can be reduced if the similarity property is exploited, as mentioned above. Comparisons have been made between the reference picture and the motion vectors for some partitions to form the BS result on the inter BS matrix. Furthermore, 8x8 sub-macroblocks, and partitions of the sub-macroblock are used to exploit the similarity property up to this level.

When performing the BS decision process for the sub-macroblock, the new method, known as “fractal cross”, is applied and consists of one large cross and four small crosses for the 8x8 blocks. P-type macroblock partitions have only one reference picture which is used in one macroblock partition and it may differ from the reference picture of another macroblock.

However, in the case of sub-macroblock partitions such as 8x4, 4x8, 4x4, the reference picture is all the same if these are in the same 8x8 sub-macroblock unit [3]. In other words, the minimum reference picture unit in the baseline profile is 8x8 sub-macroblock. This fact and the similarity property are combined to obtain high efficiency. The large cross is performed first, comparing the reference picture and motion vectors fully, followed by performing the small crosses with the motion vectors only.

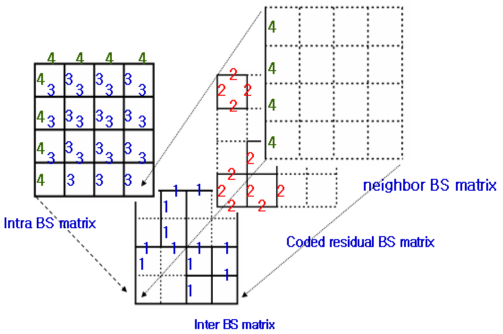


Fig. 3 Concept of superimposition.

3) A coded residual BS matrix: It is used for the coded transform coefficient. According to the ITU-T standard, the BS is set to 2 when either or both of the blocks contain coded residuals. This process seems more efficient if it is operated with the existing edge to edge method. Because there are no useful patterns that can be used to skip edges, just like in the case of the inter-mode. The existence of the coded transform coefficient is checked for every 32 edges, as in the JM reference.

4) The Neighbor BS matrix: It is used for the Left most edge and the Top edge. The BS decision process of the two edges is separated from the intra-mode or inter-mode BS decision process to exploit regularity and to improve the similarity property in the inter-mode. Two edges are extraordinary among the edges of the macroblock, because two edges are located on the macroblock’s boundary and information about the neighbor macroblock is needed. The Left most edge and the Top edge are related to the left neighbor macroblock, and the above macroblock, respectively. There also exist two cases, one where the neighbor block is intra-coded and the other where it is not. If the left neighbor macroblock is intra-coded, the Left most line of the neighbor BS matrix is filled with the BS value of 4, or the BS decision process in the inter-mode is performed on the four 4x4 block edges repeatedly. The BS decision Process for the Top edge is the same as the process for the Left most edge.

These four BS matrices are combined to produce the superimposed BS matrix. The four BS matrices are stacked in the sequence of the inter BS matrix, the coded residual BS matrix, the neighbor BS matrix, and the intra BS matrix. The inter BS matrix is placed on the ground and values of other matrixes are superimposed on this foundation. This is something like etching pictures on copperplate print by means of acid or a sharp tool, or drawing pictures step by step on the copperplate print. The BS value of zero is not overwritten on the foundation matrix and it is treated like transparent matrixes where the only meaningful values ranging belong one to four are overwritten.

IV. Experiment Results

This superimposed BS matrix method was simulated on an Intel Pentium4 Processor 2.40GHz and 1,024MB memory hardware environment. The QCIF format (176×144) was chosen, that was encoded with the baseline profile. All of the experiments were tested with six sequences (200 frames): i.e., foreman, coastguard, container, mother and daughter, news and silent.

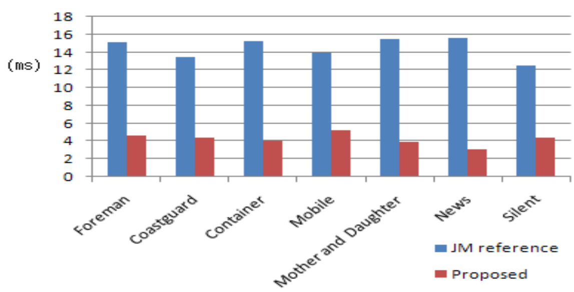


Fig. 4 Processing time comparison between the proposed method and the JM reference.

Since the JM reference has significant redundancy due to this fact, the code was extracted only for the baseline profile from the JM reference to make fairer comparisons. Performance time comparison between the proposed method and JM reference is shown in Fig. 4.

Fig. 5 shows the center area pixel value's variation for more exact comparison. Since the BS decision process was modified only, it is verified, indirectly, that the BS values of the proposed method is the same as those of the JM reference.

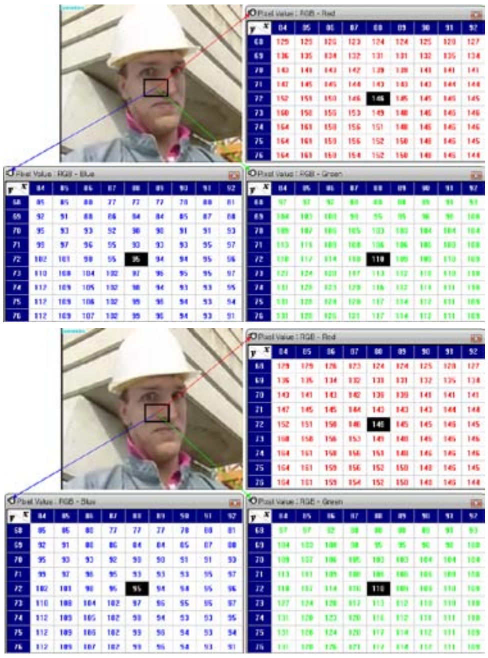
(a)
(b)


Fig. 5 The center area pixel value's variation of image (a) The JM software <reference> (b) A superimposed BS matrix method.

TABLE I
COMPARISONS BETWEEN THE OUR METHOD AND THE JM REFERENCE

Sequence Name	Speedup ratio	PSNR for the JM reference	PSNR for new method	PSNR difference
Foreman	69.0 %	37.12 db	37.12 db	0 db
Coastguard	67.2 %	34.77 db	34.77 db	0 db
Container	73.0 %	36.17 db	36.17 db	0 db
Mobile	62.4 %	34.22 db	34.22 db	0 db
M & D	74.4 %	37.66 db	37.66 db	0 db
News	80.3 %	37.13 db	37.13 db	0 db
Silent	64.4 %	36.19 db	36.19 db	0 db

Performance enhancement in the processing time is shown in TABLE I where the PSNR difference between the proposed method and the JM reference is also listed. Compared with the JM reference software, the processing time is decreased by looking at the speedup ratio which has increased from 64.4% up to 80.3%. On the other hand, as shown in the right most column of Table.1, there is no difference in the PSNR where it can be seen that the RGB of two pictures is exactly of the same value.

V. CONCLUSIONS

In this paper a new superimposed BS matrix method has been proposed for the deblocking filter in H.264/AVC baseline profile. The BS decision process has been changed from an existing edge-based method to the proposed matrix-based method. The similarity property was exploited furthermore by using a fractal cross approach to below 8x8 sub-macroblocks so that the number of conditional branch operations is decreased in the proposed method to reduce the computational complexity and the pipeline stalls. The method has been verified with the JM reference software.

The BS values and the PSNR of the proposed method are exactly the same as those obtained by the JM reference, while the speedup is increased from 64.4% up to 80.3%. In addition to this, parallelism was maximized in the proposed method. A highly parallelized processing component has been obtained. If the proposed method is applied to parallel processing hardware implementations, the performance enhancement will be apparent by exploiting the similarity property and the parallelism included in the superimposed BS matrix method.

ACKNOWLEDGMENT

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