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Research paper

Development of the best prediction matrix mode algorithm for-intra prediction in h.264 encoder

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Abstract

The video compression techniques began to impose themselves on the ground in recent years, as it can provide sending the videos using less transmission bandwidth or stored in less storage space. One of these innovative compression techniques is the H.264 standard which has huge significance in terms of technology. Thus attracted our interest as researchers since a few years ago and prompted us to propose a new efficient intra prediction scheme and it has been termed the Best Prediction Matrix Mode (BPMM). This novel prediction technique had achieved impressive results for each of compression ratios, bit rates, and PSNR. In this paper, we discuss how we can develop our predic-tion scheme to mitigate some of its major challenges concerning the relatively large encoding overhead and make it more realizable. Namely using entropy coding, the encoding overhead could be appreciably reduced to the level of the conventional intra-coding techniques. We have utilized hardware description language VHDL to evaluate the performance of our proposed prediction scheme. The results show that superior interceding performance could be achieved without scarifying space for encoding overhead. We would like to recommend our intra-prediction algorithm, BPMM, in the ITU reference design of H.264.

Keywords:*Best Prediction Matrix Mode(BPMM); Compression Efficiency; H.264/AVC; Huffman Coding; Intra Prediction.*

1. Introduction

Video compression is one of the priority areas that attracted Many researchers as it has been considered a promising solution to meet the rapidly growing use of Video communication. On one hand, Video compression can support many applications such as digital camcorders, video telephony, broadcasting, video conferencing and video surveillance[1].

On the other hand, many video coding standards fall within the definition of video compression. Advanced video coding standard, which is named H.264 or MPEG4 Part-10, has advanced features than other standards. Perhaps the most salient feature of this standard is markedly improved video coding efficiency[2].

Figure1 illustrates the hardware architecture realization of the H.264 encoder. In the beginning, a raw video is awarded to RAM. After the system is reset, a stream of bits is fetched to the circular buffer through a data bus. The circular buffer works as an interface between RAM and the encoder. In the circular buffer, each frame is partitioned into 16×16 blocks luma pixel size, known as a macroblock (MB).

The encoder has two essential paths of data, encoding and reconstruction path. The encoding path consists of Intra Prediction, Transform, Quantize and Entropy encoder blocks. The prediction block is responsible for creates a prediction of the current macroblock depended on an earlier coded macroblock. Calculating a residual by subtracting predicted macroblock from the current macroblock. This residual is transformed, quantized and encoded using Entropy Coder to get finally coded bitstream (NAL)[3]. Concurrently, in the reconstruction path, we can get the residual macroblock.

After the process of inverse quantized and inverse transformed was applied for the quantized coefficients.

Reconstructed block results from the adding of prediction macroblock with a residual macroblock. This is necessary to predict the following current block of intra frame[4].

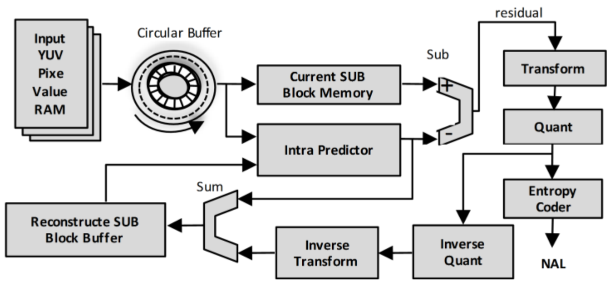

Fig. 1: The Hardware Architecture of the H.264 Encoder.

The authors proposed a new mode of prediction few years agotitled Best Prediction Matrix Mode (BPMM), that combines the vertical, horizontal, and DC modes. BPMM achieved better compression ratios, bit rates and PSNR relying on improving the intra prediction scheme of H.264 and reducing the residual information by selecting best values for each pixel[5,6].

In this paper, while we refer to our earlier work and the promising results that was achieved, unfortunately, several practical constraints arise when dealing with realizing Best Prediction Matrix Mode (BPMM). Nonetheless, it is possible to overcome these obstacles so the authors are motivated by offeringthat goal in this article.

1.1. Related work

The (BPMM) is a candidate blueprint for the enhancement of intra-frame coding. Several recent studies have corroborated that the utilization of predicted pixel that's closer to the coding pixel which results in reduce the predicted error. This can enhance each of PSNR, compression ratio, execution time and reduce bit-rate accordingly. Therefore, fast intra-prediction instead of traditional intra-prediction has attracted the attention of researchers[1], [7-15]. For instance, one of the fast algorithms was introduced in[7]. This study based on block variance estimation, the pre-decision algorithm is to classify the coding image and to select the possible block size with five coding regions. Another study[8]employs the prediction directions and the Sum of Absolute Transformed Difference (SATD) of the reconstructed surrounding pixels and the block content to remove the less likely prediction modes from the Rate Distortion Optimization (RDO) computation. This study aimed to improve performance. The study[9] proposed an approach to the intra mode decision problem based on Laplacian. In this study, the algorithm depend on detects edges and then selects the best mode for the block.Similarly, a novel pipeline schedule for ahardware-based high-profile intraprediction scheme is also proposed in[10]. In which 8 × 8 prediction is performed in Stage 1 and 4 × 4, 16 × 16and chroma predictions are executed during Stage 2. While [11] exploit the gravity center vector of the block to determine the best candidate prediction mode for intra coding. The study in[12] presented an improved gravity center method proposed in[11] based on center of mass and two subsampling techniques. An efficient intra block size decision for H.264/AVC encoding optimization scheme is proposed in [13]. It makes use of the spatial homogeneity characteristics of the macroblock.Another approach[1] is to enhance the method proposed in[13] by implements a texture complexity based fast and efficient intra block mode decision Algorithm For H.264/AVC. The authors in[14] demonstrated a gradient based fast intra prediction mode selection method for 4x4 and 16x16.In another study[15], the authors considered a projection based approach, which employs the reconstructed surrounding pixels and block content to compute the predicted block residuals as the intra-prediction mode decision mechanism.

The aforementioned research[1], [7–13] works have tried to reduce the computational complexity using different approaches. but, result in slight PSNR degradation, because those cannot always decide the best mode and bit-rate increase. Similarly, the algorithms proposed in [14-15] reduced the computational complexity but without improving the bit rate and PSNR.Consequently, the motivation of our research concentrates on achieved impressive results for each of compression ratios, bit rates, PSNR, and the execution time.

This paper is organized as follows: Section 2 gives a brief overview of the intra prediction as an essential component in the H.264 encoder. The Best Prediction Matrix Mode methodology is outlined in the 3rd Section. Section 4 investigates the question of challenges and recent results. A new methodology is described in the 5th Section. Section 6 contains the evaluation of our development in BPMM and summarizes the results of this work. Finally, in Section 7, we draw out conclusions.

2. An overview of h.264 intra prediction

Realization compression within a frame continued to be the main objective of the intra prediction algorithms. Comparable values of the adjoining pixels within the picture frame have utilized a reduction of spatial redundancy[7]. The prediction process relies on the reconstructed pixels of previous sub-block values. We have two block sizes that can be achieved by the intra frame prediction of the luminance component. One is the I16MB, and it has four prediction modes that can be utilized for the total 16 × 16 MB. The other one is the I4MB, which relies on nine prediction modes applicable to the sixteen blocks of 4 × 4 sub blocks which buildthe MB. In addition, there are also four available modes to predict Cr and Cb blocks of the chrominance component[8].

The types of the 4 × 4 intra prediction modes, rely on the neighboring pixels left or above of a 4 × 4 block to get luma samples weights. Each 4 × 4 blocks included 16 pixels designated from 'a' to 'p' as illustrated in Figure 2. The pixels labeled A-M acquired from the neighboring blocks play a key role to calculate a prediction value of P block. If the vertical mode was decided, this leads to each pixel value in each vertical row is identical to the vertical edge. In the same way, if the horizontal mode was decided, this leads to each pixel value in each horizontal column is identical to the horizontal edge[16]. The DC prediction mode differs from its predecessors by substituting whole pixels in the current block by the mean value of pixels labeled from 'A' through 'L'[5], [6].

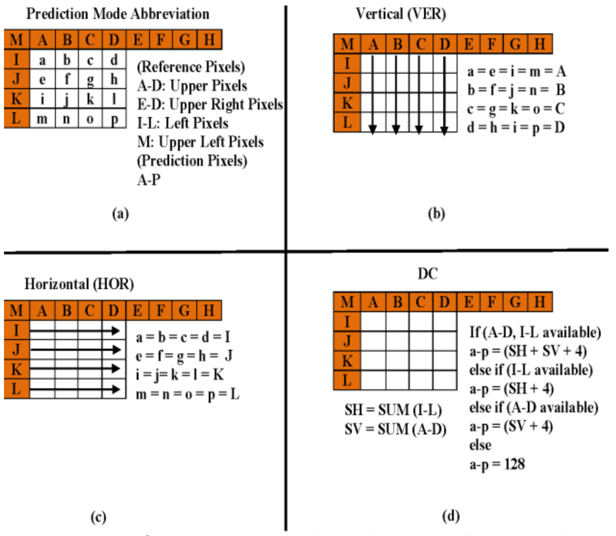

Fig.2: Equations of Luma 4 X 4 Mode Prediction Pixels (Vertical, Horizontal, and DC) [16].

3. The best prediction matrix mode

All The proposed new technique is discussed in this section. It has been considered as a promising solution to improve the compression ratio, PSNR, and the bit rate. Statistics show that the use of both DC, vertical and horizontal modes are more frequent than others. That is due to thepredicted pixels are close to the coding pixels[17].

This motivated us to design our BPMM, where the key idea of the proposed technique is to integrate the DC, vertical and horizontal modes to the new one intra 4 × 4 prediction mode.

As shown in Figure 3, our BPMM calculation depends on values swaps between four matrices: DC, vertical, horizontal andupper-left corner matrices. If these swaps have consisted, we can get the construction matrix.

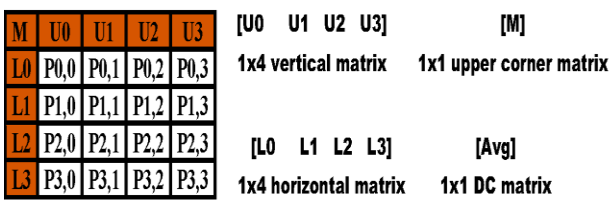

Fig. 3: Construction Matrices of Our BPMM Intrapridiction Algorithm.

Figure (4) illustrates our new proposed intra predictiontechnique. $P_{i,j}$denotes the pixel to be predicted in the ithrowandjth column of the current 4 × 4 block where 0 <= i, j <= 3,U_j and L_i denote the reference samples reconstructed fromupper and left blocks respectively.

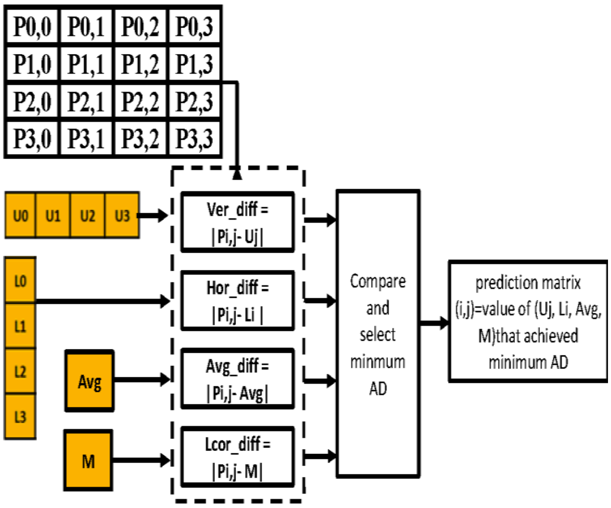

Fig. 4: The Proposed Intraprediction Technique.

Algorithm onesummarizesthe procedure for generating the best prediction matrix.

Algorithm 1 Pseudo code for computing BPMM

1: Read original intra 4x4 block ;
2: Prepare construction matrices;
3: Compute the absolute difference as follow:
4: for (i , j = 0 : 3) do ► step = 1
5: Ver_diff= $|P_{i,j}- U_j|$; Hor_diff = $|P_{i,j}- L_i|$;
6: Avg_diff =$|P_{i,j}- Avg|$; Lcor_diff = $|P_{i,j}- M|$;
7: Find the minimum value of the absolute differences;
8: Put the value of one of (U_j, L_i, Avg, M) that Corresponds to this minimum in the prediction matrix (i,j).
9: end for
10: Get the best prediction matrix.

We can explain the new proposed intra prediction scheme through the numerical example demonstrated in Figure 5. More details can be found about the proposed algorithm in [5,6].

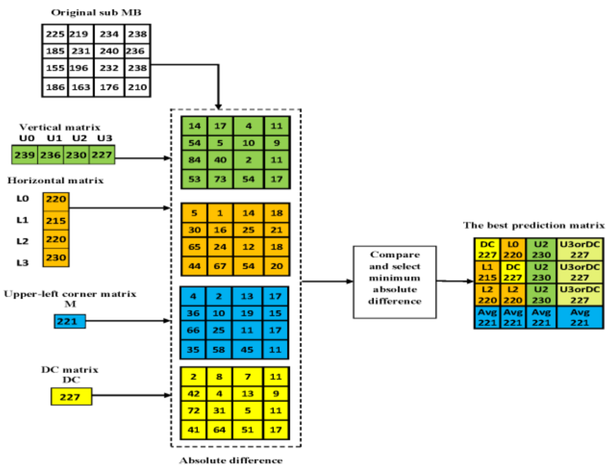

Fig. 5: Numerical Example of Applying the BPMM.

4. Challenges and recent results

Once the intra prediction modes for each 4 × 4 luma sub-block are identified the decoder should receive these modes. But this may consume a huge number of bits. There is a known fact that the neighboring 4 × 4 luma sub-blocks in the same macro block are highly correlated especially for their modes. For further explanation, Figure 6 presents sub-block Z as a current block to be coded and mode 2 is an outcome of the prediction to previously encoded sub-blocks X andY. It may be probable that the best mode for block Z is mode 2 also. Consequently, the predictive coding uses this advantage to expect 4 × 4 sub-blocks modes in the following way: one of the core functions of the encoder and decoder is a computation of the most probable prediction mode to current 4 × 4 sub-block, set as the smallest prediction modes among X and Y. In the absence of these neighboring blocks, DC prediction mode will be selected[18].

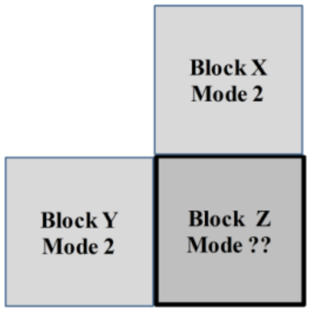

Fig. 6: Intra Mode Prediction Example[18].

The H.264 standard specifies two flags for each 4 × 4 sub-block, prev_intra 4 × 4 pred mode (one bit), and rem_intra 4 × 4 pred mode (three bit) which used to signal intra modes. If the most probable prediction mode uses the prev_intra 4 × 4_pred_mode flag is set to 1. On the other hand if this flag is 0, it suggests that there's a change in mode, then the rem_intra 4 × 4_ pred_mode flag is set by the newest one.

Based on the above, we have found that if the sixteen sub-blocks which forms the MB have the sameprediction modes at best the overhead bits for defining the modes will be:

$$\overbrace{1\left(bit/sub\ block\right)}^{prev\_mode\_flag}\times 16\left(sub\ block/MB\right)=16\left(bits/MB\right) \qquad (1)$$

But in the worst case if the whole sixteen sub-blocks modes are different from one another the overhead bits are then:

$$\left(\overbrace{1\left(bit/sub\ block\right)}^{prev\_mode\_flag}+\overbrace{3\left(bits/sub\ block\right)}^{rem\_mode\_flag}\right)\times 16\left(sub\ block/MB\right) = 64\left(bits/MB\right) \qquad (2)$$

The basic advantage offered by this conventional approach relies on having only one prediction mode for the whole sub-block.

In contrast, in our proposed technique, each pixel in the sub-block has its own mode. So, for each sub-block, there are sixteen modes that must be signaled to the decoder and this could definitely require a large number of bits.

For more clarity, if the whole sixteen pixels forming the sub-block have the same prediction modes at best the overhead bits will be:

$$\overbrace{16\left(bit/sub\ block\right)}^{prev\_mode\_flag}\times 16\left(sub\ block/MB\right)=256\left(bits/MB\right) \qquad (3)$$

However, in the worst case if the whole sixteen pixels modes are different from one another the overhead bits are then:

$$\left(\overbrace{1\times 16\left(bit/sub\ block\right)}^{prev\_mode\_flag}+\overbrace{3\times 16\left(bits/sub\ block\right)}^{rem\_mode\_flag}\right)\times 16\left(sub\ block/MB\right) = 1024\left(bits/MB\right) \qquad (4)$$

Given these aforementioned facts, realizing Best Prediction Matrix Mode (BPMM) in practice is not a trivial task. The main challenging problem is that we have a high overhead, in each sub-block mode carries there are from 240 to 960 extra bits that would cause a high loss of line bandwidth.Therefore, the reduced overhead is a bottleneck for Best Prediction Matrix Mode (BPMM) in practice.

5. Proposed methodology

Previous sections discussed theBest Prediction Matrix Mode (BPMM) and its high overhead bits problems that are required in prediction mode signaling. Literature survey reveals some methodologies to solve the high overhead issues in (BPMM). The proposed method involves reduced overhead by using variable length coding algorithm, namely, the Huffman Encoding algorithm.

5.1.Huffman algorithm

Huffman coding is a lossless compression algorithm which pursues the best coding based on the probability of characters. Huffman coding falls within a lossless compression algorithm which depends primarily on the repetition rate of the characters in a target text to be compressed[19], [20]. The essential step is to build a Huffman tree. Symbols that have high weights are assigned prefix codeword with the shortest length than another one with low weights. It designates prefix codeword so that no two symbols will have an identical adjustment of the binary coding and no extra information is needed to determine the beginning and the end of the message coding[21-23]. This inspires us to suggest Huffman coding to achieve the following objectives, there should be header information for a decoder to know each pixel predicted mode. Also, It should be clearly explained how bit rate of each block header information did not increase even we coded each pixel with different modes which expectedly causes to increase in bit rate.
This part includes the description of Pseudo code that has been applied to code the prediction mode information for every pixel using Huffman coding. Pseudo code is provided in Algorithm 2.
The proposed alternative of the encoding process is provided in four stages as follows:

Algorithm 2 Pseudo code for computingHuffman coding
1: After we calculate the best prediction matrix of 4 × 4 sub-block, then we get sixteen 4 × 4best prediction matrices for each MB are being combined to construct the best prediction matrix with 16 × 16 dimensions, 2: Determine the repetition of unique 16 × 16 best prediction matrices, 3: Arrange the unique 16 × 16 best prediction matrices indescending order according to its repetition, and 4: Generate a Huffman code dictionary based on theprobability of each 16 × 16 best prediction matrix that's where assigned fewer numbers of bits to the most frequent symbol.

There is no similarity in the Huffman encoded code words for each macro block. Consequently, the code words can be inserted in the h.264 bit stream and transmitted together easily without additional prefix codeword.
Moreover, this optimization has resolved the overhead challenges, so that signalling prediction modes for each MB have code words within a range of 8 to 15 bits, in comparison with the h.264 standard that needs from 16 to 64 bits to signal prediction mode for each MB. Thus, our procedure is a clear improvement in providing a less number ofbits for the prediction mode overhead.

6. Experimental results

In this section, we evaluate the performance of our new intraprediction technique as a result of the proposed method of Huffman encoding based on three aspects: First, VHDL implementation of our new intra prediction technique through H.264 hardware encoder of Henson [24] as the platform of testing our proposal. Second, a series of trials are performed by applying video quality measurement methods to several input test sequences. Lastly, we discuss the results of evaluating our prediction approach in the following respects PSNR, compression ratio, time and bit rates.

6.1. Huffman encoder architecture realization

The hardware architecture of the proposed method of Huffman design is presented in Figure7. The Huffman encoder architecture is realized depending on five main modules, namely Current MB Buffer to store the Current MB Pixels mode, Huffman Dictionary Buffer in which the generated Huffman Dictionary is stored,comparator, controller and counter. We have also “STROBE”and“READY” as handshaking signals.
The mainfunction of the Huffman encoder is to get the Huffman code of each MB Pixels mode to be encoded. When READY signal is set high, a request is sent to ram that holds the best Prediction matrix with 16×16 dimensions to output Current MB Pixels mode, and load them in theCurrent MB Buffer.
Then the Huffman encoder has two outputs: One is the Huffman code, and the other is ”STROBE” signal.A comparison process will happen between the loaded current MB Pixels Mode and the stored MB Pixels Mode in Huffman Dictionary Buffer. If they are both identical”STROBE” signal set by "1" to indicate that Huffman code is considered as valid.

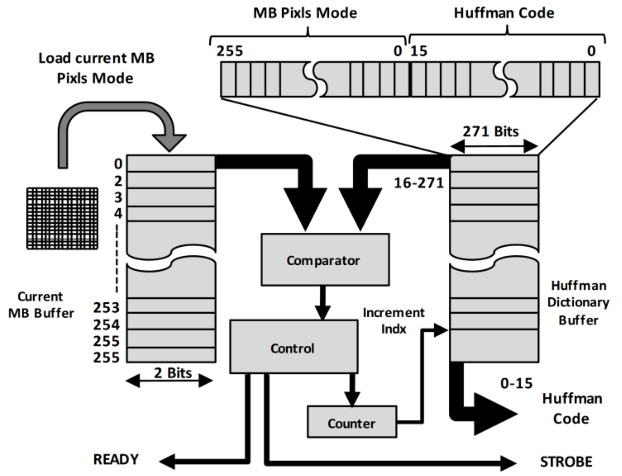

Fig. 7: The Hardware Architecture of Proposed Huffman Encoder.

On the other side If bothcurrent MB Pixels Mode and the stored MB Pixels Mode in Huffman Dictionary Buffer is radically different then the controller increments the counter to access next addressing of Huffman Dictionary Buffer looking for Huffman code.

6.2. Performance evaluation of our proposed approach

This part of the paper provides validation of our proposed technique, so we compared the performance of the standard prototype of H.264 with our intra prediction algorithm that had been developed using the proposed method of Huffman design.
(QCIF) and (CIF) format video sequences are used for testing and the comparison is based on three CIF videos namely Water, Crew, and City as well as four QCIF videos namely Silent, Mother-Daughter, Foreman, and Salesman. For fair comparison and evaluation, we used the same hardware and set quantization parameter from 20 to 45 with a step of 5 to encode each video, one with standard H.264 intra frame coder, and the other using our best prediction matrix mode.
In Figure8 there is a clear trend of improving the compression ratio on average by 52.54 % and as a result, there is a reduction on average by 27.203 % in the bit rate while the PSNR is marginally increased on average by 0.6dB and slightly decrease in execution time on average by 0.082 %for the Silent QCIF video. In a similar manner, the remainder QCIF videos follow the same tendency in enhancing the compression ratio and correspondingly the bit rate decreasing while the PSNR is slightly increased and finally there is slight decrease in execution time as shown in Figs 9-11.
For signifying the results, the tests of new proposed prediction technique was repeated again using CIF video. The results indicate that a pronounced increase in the compression ratio on average by 56.198 % and this contributed significantly to bit rate reduction on average by 29.506 % while the PSNR increasesslightly on average by 0.6 dB and the execution time is slightly reduced on the average by 0.0072 for the Water CIF video. The behaviour of the pre-

dictor repeats itself for the other CIF videos as depicted in Figs 12-14.

Table 1 demonstrates that the BPMM developed using the Huffman design yielded a number of improvements in terms of increasing the compression ratio on average by 53.14%, decreasing the bit rate by an average of 28.42 %, increasing the PSNR by an average of 0.63 dB while the execution time slightly decreased.

Table 1: Experimental Results of DevelopedBPMM Compared to Henson [24]

Video	PSNR increase (dB)	Comp. Ratioin-crease %	Bit rate decrease %	Time %
Water Cif	+ 0.6	56.198	29.506	- 0.007
Crew Cif	+0.71	40.625	29.399	- 0.001
City Cif	+ 0.6	55.9	26.932	- 0.044
Silent Qcif	+ 0.5	52.54	27.203	- 0.082
Mother-Daughter Qcif	+ 0.7	48.648	29.096	- 0.012
Foreman Qcif	+0.68	54	27.859	- 0.142
Salesman Qcif	+0.63	64.102	28.96	- 0.136
Average	+ 0.63	53.14	28.42	- 0.06

7. Conclusions

In this paper, we have debated one of the promising Intra Prediction algorithms of the H.264 standard. That is the Best Prediction Matrix Mode BPMM. An unexpected interesting development was achieved by this prediction scheme but the mode information overhead is the biggest obstacle to realize this approach. So, we have proposed an effective solution based on Huffman coding. The usefulness of this method is motivated by sending the prediction mode for each pixel instead of each block while maintaining the compression ratio while taking care to avoid the overhead. Finally, we have an accurate judgment of our method based on a complete comparison between our developed prediction scheme and H.264 prediction standard. The researchers noted that our new intra prediction mode so-called BPMM, that it was developed based on Huffman coding yielded the best compression ratios, bit rates, PSNR and execution time for both (QCIF) and (CIF) video formats and over all the QP values under test. Above all, we were able to overcome the overhead challenge. Because of its superior performance we recommend including our intraprediction algorithm in the reference design of H.264.

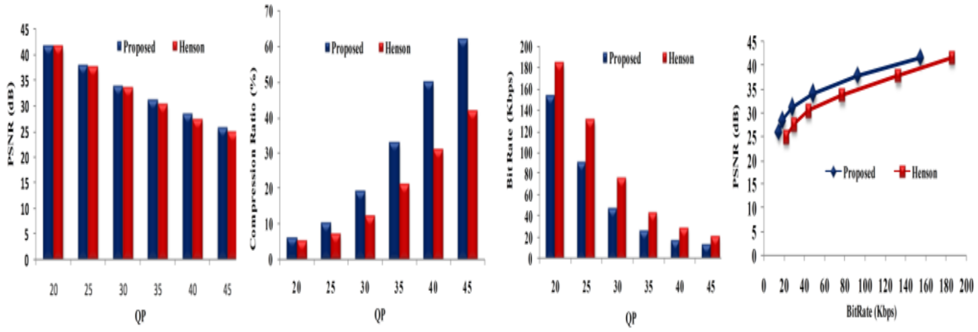

Fig. 8: Evaluation of Developed BPMM Using Silent QCIF Video.

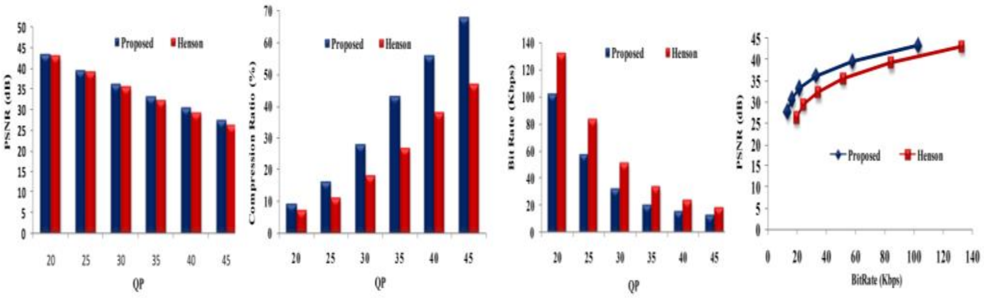

Fig. 9: Evaluation of Developed BPMM Using Mother-Daughter QCIF Video.

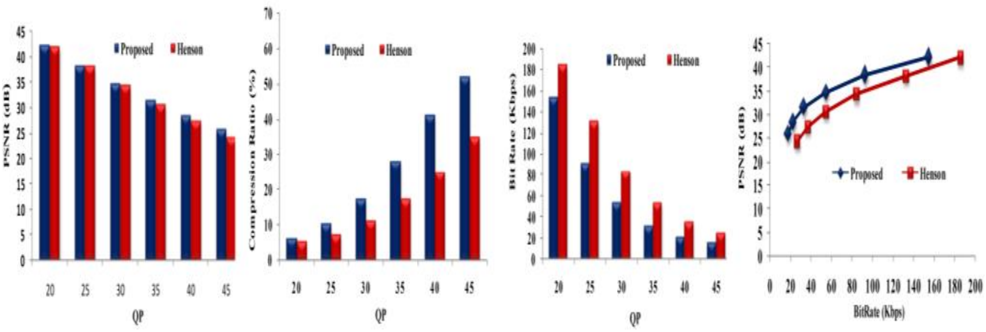

Fig. 10: Evaluation of Developed BPMM Using Foreman QCIF Video.

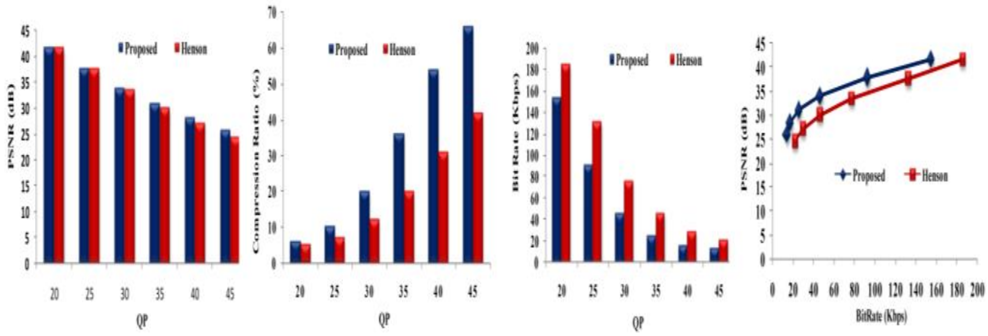

Fig. 11: Evaluation of Developed BPMM Using Salesman QCIF Video.

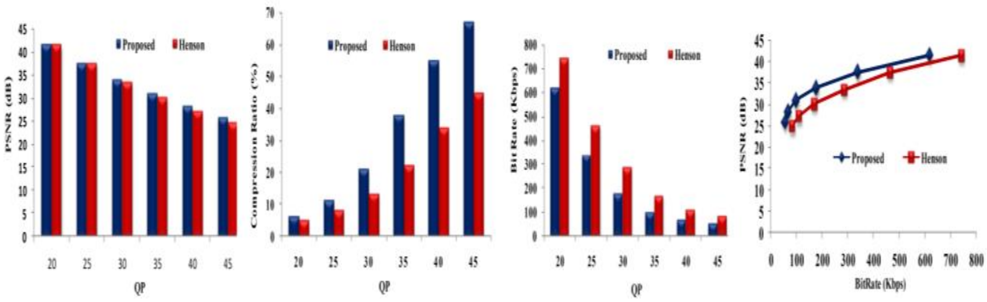

Fig. 12: Evaluation of Developed BPMM Using Water CIF Video.

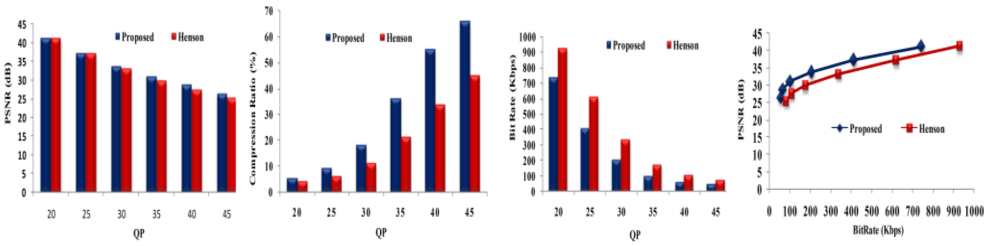

Fig. 13: Evaluation of Developed BPMM Using City CIF Video.

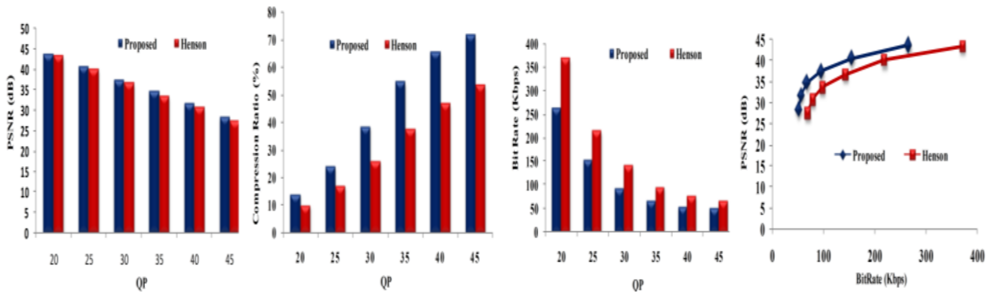

Fig. 14: Evaluation of Developed BPMM Using Crew CIF Video.

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