QUALITY AND COMPLEXITY COMPARISON OF H.264 INTRA MODE WITH JPEG2000 AND JPEG

Aravind AL*, Bindu P. Rao*, Sudhir S. Kudva *, Sreenu Babu†, Sumam David, SMIEEE*, and Ajit V. Rao, MIEEE†
† Multimedia Codecs Group, Texas Instruments (India) Ltd., Bangalore, India
* Dept. of E&C Engg., National Institute of Technology Karnataka, Surathkal, India

ABSTRACT

The recently proposed H.264 video coding standard offers significant coding gains over previously defined standards. An enhanced intra-frame prediction algorithm has been proposed in H.264 for efficient compression of I-frames. This paper investigates the scope of the intra-frame coder of H.264 for image coding. We compare the quality of this coder and the complexity of its decoder with the commonly used image codecs (JPEG and JPEG2000). Our results demonstrate that H.264 has a strong potential as an alternative to JPEG and JPEG2000.

1. INTRODUCTION

The recently standardized ITU-T recommendation H.264 and ISO/IEC international standard MPEG-4 AVC (a.k.a MPEG-4 Part 10) [1] represents the third generation of video coding standards after MPEG1/2 and MPEG4. H.264 has been confirmed to offer better coding gains than its predecessors (ex. MPEG-4 Part 2) [2].

The intra coding algorithm of H.264 exploits the spatial and spectral correlation present in an image. Intra prediction removes spatial redundancy between adjacent blocks by predicting a block from its spatially adjacent causal neighbors. A choice of coarse and fine intra prediction is allowed on a block-by-block basis. Coarse prediction uses 16x16 blocks for uniform background area with four possible "directions" for prediction. Fine prediction uses 4x4 blocks for fast changing picture areas and allows 9 directional modes. An integer transform on the prediction residual eliminates any spectral redundancy. These features and new entropy coding methods provide efficient compression of the intra frames. A de-blocking filter improves the signal-to-noise ratio (SNR) of the image and provides excellent subjective quality.

H.264 achieves excellent compression performance in the intra mode. In this paper, we demonstrate that the intra codec has excellent performance and complexity characteristics even when compared against the standard image codecs (JPEG and JPEG2000). Objective quality comparison results substantiate the earlier work done in this regard [3],[4]. However in these works the test images used were the video sequences. In our work we have used standard still test images to analyze the potential of H.264 intra mode as a image codec. Complexity analysis for baseline profile for H.264 has been done earlier [5]. Hence we concentrate on the main profile. Apart from objective quality and complexity analysis we have also done the subjective analysis, results of which confirm with the objective quality results and prove the superiority of H.264.

Note that the H.264 standard has three "profiles" - baseline, main and extended. In this work, we focus on the main profile. Also, our experiments are based on the JM-7.3 reference code [6] and our comparisons are against Jasper version 1.700.5 [7] of the JPEG2000 standard and IJG version 6b [8] of the JPEG standard.

The rest of this paper is organized as follows: The objective and subjective comparison of the H.264 intra frame coder with JPEG and JPEG2000 is described in Section 2. Section 3 presents complexity comparisons between the codecs. Finally, in Section 4, we summarize the conclusions drawn from our experiments.

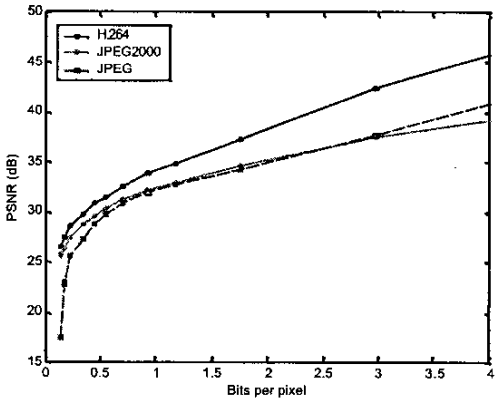

Fig. 1 Objective Quality

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2. PERFORMANCE ANALYSIS

We have quantified the objective and subjective quality of the H.264 intra coder for various bits per pixel (bpp) values on standard images and compared the results against the JPEG and JPEG2000 standards. The test images used for both the analysis are Lena, Mandrill, Monalisa, Barbara, and Peppers.

2.1. Bits per pixel ratio control

While explicit control on the bits per pixel ratio is not possible in H.264 and JPEG, these codecs allow the manipulation of "tuning" parameters that control the bpp ratio. These are the "quality" parameter of JPEG and quantization parameter of H.264. However explicit rate control is possible in JPEG2000. To compare the performance of the three codecs at the same values of bpp, we varied the tuning parameters such that the bit rate achieved as a result was within 1% from each other.

2.2. Objective quality comparison

The objective quality of images coded using the three standards were compared in terms of peak signal-to-noise ratio (PSNR). Specifically, the average PSNR was calculated at different bit rates for each codec over the 5 standard test images mentioned earlier and compared.

The plot in Fig.1 compares the PSNR achieved for the H.264 intra coder against both standards at various values of bpp for the average of the five standard test files. We note that H.264 has a quality gain of around 3dB compared to JPEG at almost all bit rates. However, compared to JPEG2000, quality gain of H.264 varies with the bpp ratio. The gain is as high as 5dB for 4 bpp, but less than 1dB at 0.16 bpp. In contrast, the work in [3] demonstrated that the H.264 intra coder gains more substantially over JPEG2000 at lower bit rates for image frames that are part of a video sequence. Overall, the H.264 intra mode consistently outperforms JPEG and JPEG2000 in PSNR.

We believe that the superior performance of H.264 on the PSNR scale is mainly due to the flexible intra-frame prediction. The option to choose coarse or fine intra prediction as well as prediction directions for each block allows the codec to achieve superior coding gains. Neither JPEG nor JPEG2000 exploit inter-block redundancies in an equally powerful manner.

2.3. Subjective quality comparison

Subjective quality analysis was done for the standard test images mentioned above. 15 subjects in the age group of 20-50 years were asked to evaluate the above pictures encoded using each of the H.264 intra, JPEG2000 and JPEG coders at various bit rates. The subjects were allowed to

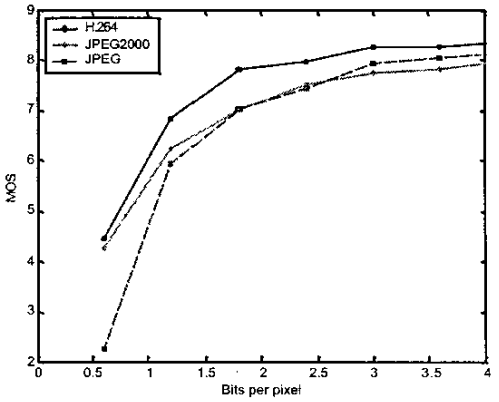


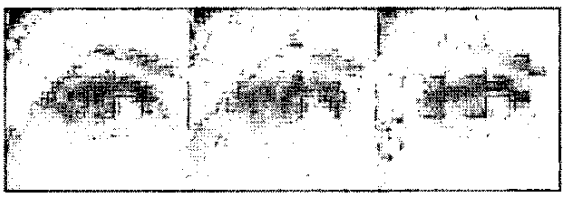
Fig. 2 Subjective Quality

assign a rating on a scale of 0-10 for each file. A mean of all the ratings was taken for the three codecs (H.264, JPEG2000 and JPEG) and is presented in the form of graph in Fig. 2. The results obtained correlate with the objective results thereby proving the superiority of the H.264 intra coder.

As compared to JPEG, H.264 has an average gain of 0.25 MOS at higher bit rates of 4 bpp which increases at low bit rates, to as high as 2 MOS at 0.6 bpp. With respect to JPEG2000, H.264 has an average gain of 0.5 MOS at 4 bpp, which reduces to around 0.2 MOS at 0.6 bpp.

We believe that the superior subjective quality of H.264 is particularly due to its use of the adaptive de-blocking filter. An informal study of images coded using the H.264 intra coder with and without the de-blocking filter confirms this hypothesis.

A visual illustration of the qualitative difference between the three codecs is shown in Fig. 3 . Here, the standard Lena image is coded at a bit rate of 0.4 bpp for H.264, JPEG2000 and JPEG. Expanded view of the right eye of Lena image where the visual quality difference is clearly visible is shown in Fig.3. Note that the H.264 intra coder offers superior quality even at very low bit rates. It is clear that the JPEG2000 image has several ringing artifacts while the JPEG image has blocking artifacts.



H.264 JPEG2000 JPEG

Fig. 3 At a bit rate of 0.4 bpp

Table I COMPLEXITY (NO. OF OPERATIONS) FOR IMAGE LENA (256x256)

Major function	Unit	Mem copy cycle/Call	Add/ Sub / Call	Logical operations / Call	Multiply/ divide/ Call	Function calls/ frame	Total no. of operations per frame
Inverse transform	4x4 block	168	207	293	3	2745	1841106
Intra prediction	16x16 or 4x4 block	99	126	159	102	3738	1809462
De-block	16x16 block	2826	5725	3080	0	256	2977576
Cabac	1 bit	6017	2870	9267	1610	19769	3166519

3. COMPLEXITY ANALYSIS

We analyzed the JM 7.3 implementation, main profile of the H.264 decoder in terms of cycle and memory complexity. For cycle complexity analysis, we computed the total number of basic operations in the decoder. In memory complexity analysis, we measure the total memory needed in terms of constants, global and heap.

3.1. Code Modifications

We made a few code modifications to the H.264 JM7.3 reference code. Specifically, the video decoder was customized as an image decoder and irrelevant / redundant parts of the code were eliminated.

3.2. Cycle Complexity

Table I shows the cycle complexity of the H.264 intra decoder in terms of number of arithmetic, logical and memory copy operations of the major modules. The complexity is calculated for image Lena of size 256x256 compressed with a quantization parameter of 28 (.9 bpp) for the JM7.3 implementation. Each 256x256 frame requires 10 MOPS (million operations) for the major modules mentioned in the table while the total including all other modules and control loops is 13 MOPS.

The entropy coder for main profile, namely Context adaptive Binary Arithmetic coding (CABAC) is particularly complex consuming 3.2 MOPS. This is mainly because it requires several bit-level operations to be performed sequentially. Other particularly heavy contributors to CABAC complexity include the updating of context models and the arithmetic decoding process.

The adaptive de-blocking filter accounts for about 3 MOPS. Here the complexity is due to small block size and the adaptive nature of the filter. There are computationally intensive conditional checks to determine if each pixel has to be processed depending on its neighbors.

The Inverse transform and intra prediction modules consume around 1.8 MOPS each. A significant contributor is the planar prediction mode for 16x16 blocks. In the 4x4 prediction, the diagonal modes are very complex.

TABLE II COMPLEXITY OF JPEG2000

Major function	Operations per frame
Entropy decoding (Ebcot)	4629151
Wavelet Decompression	7373853
Dequantization	2005959

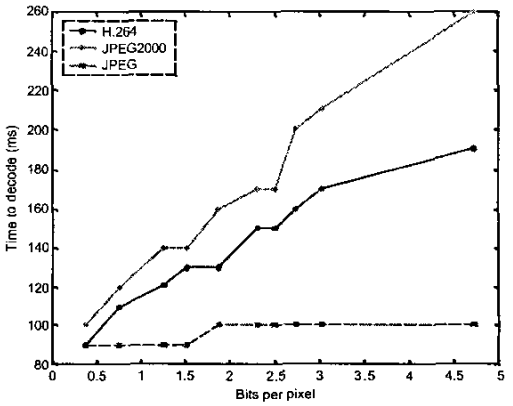


Fig. 4 Time to decode

Table II gives the cycle complexity of major modules of JPEG2000 for the Jasper implementation. Here, important contributors to the MOPS are arithmetic coding (4.6 MOPS) and wavelet decompression (7.4 MOPS). Note that the complexity of the wavelet decoder depends on the number of resolution levels used to decompose the image. In the above analysis, we assume a resolution level of 6. The total complexity of the JPEG2000 decoder including all modules is approximately 14 MOPS. JPEG's computational complexity is about one-third that of JPEG2000 [9] and hence would be the lowest of the three codecs (H.264, JPEG2000, JPEG).

We also calculated the time needed on a PIII, 600MHz processor to run each of the three decoding algorithms. The comparison was done at various values of bpp and for various sized images. JPEG consistently offers the lowest complexity amongst the three codecs. The H.264 intra decoder is between 1-2.5 times more complex than JPEG depending on the bit rate. JPEG2000 has the highest

complexity (approximately 1.5 times the H.264 intra decoder). Fig. 4 plots the decoding time for the three algorithms for various values of bpp on the standard Lena image of size 256x256.

3.3. Memory Complexity

Table III compares the memory consumption of the H.264 intra coder against JPEG and JPEG2000. We note that the context related tables in CABAC consume 50% of the constant memory. Also significant memory is required to store information on the surrounding macro blocks for intra prediction.

In summary, the memory and complexity requirements of the H.264 intra coder are more than JPEG but significantly less than JPEG2000.

TABLE III COMPARISON OF MEMORY REQUIREMENTS OF H.264 INTRA, JPEG AND JPEG2000

Memory(KB)	H.264 Intra	JPEG	JPEG2000
Constant	45.0	11.0	25.1
Global & static	6.5	0.08	66.2
Heap	66.4	28.2	2670.1
Total	117.8	39.3	2761.4

4. CONCLUSION

It is evident from our analysis that the H.264 intra mode outperforms JPEG and JPEG2000 in terms of objective and subjective quality. However the H.264 intra decoder has significantly higher complexity than JPEG. At the same time, it is significantly faster than the JPEG2000 decoder (Jasper implementation) at all bit rates.

We conclude that the H.264 intra coding algorithm is ideal for still image compression although it has been proposed as a component of the latest video coder. If standardized as an image codec, H.264 offers strong advantages to consumers as well as silicon and software manufacturers. These advantages include higher quality, reduced system cost for image/video systems and a faster time-to-market.

5. ACKNOWLEDGEMENT

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