Perceptually enhanced INTRA video encoder for high definition/quality services

M. Martínez-Rach, O. López, P. Piñol, M. Perez Malumbres[1] and
J. Oliver [2]

Resumen— **Although inter video coding gets the highest R/D for general video coding, intra encoders are of particular interest for some applications. We propose a simple perceptually enhanced intra-mode video encoder (PM-LTW) based on the Contrast Sensitivity Function (CSF) that gets good performance by allowing a gracefully quality degradation as compression rate increases. We evaluated the performance in terms of perceptual quality, memory consumption and complexity with H.264/AVC intra, Motion-JPEG2000 and Motion-SPIHT. We employed the Visual Information Fidelity (VIF) image Quality Assessment Metric (QAM) as video quality metric. The results show that the proposed encoder is competitive with respect to H.264/AVC at low to medium compression rates, and as video resolution increases, it outperforms H.264/AVC. In addition it requires much less memory and exhibits fast encoding rates.**

Palabras clave— **High Definition Video Coding, Perceptual Coding, Contrast Sensitivity Function**

I. INTRODUCTION

ALTHOUG the use of motion-estimation (inter-frame coding) achieves much better R/D when compared to intra-frame coding, there are several applications that requires a intra-frame coding approach. Most of the television content productions require recordings in HD to maintain high quality of picture even though the final transmission is in SD (standard definition) format and after professional video editing processes, where random and frequent frame access and edition is performed. Intra-frame coding is desirable as well in many other applications like video archiving, high-quality high-resolution medical and satellite video sequences, applications requiring simple real-time encoding like video-conference systems where very low delay is desirable or even for professional or home video surveillance systems [1] and Digital Video Recording systems (DVR), where the user equipment is usually not as powerful as the headend equipment. So, for these applications, computing capability, limited memory resources and real-time constraints need to be taken into account. Many wireless applications often use intra coding technologies which exhibits an excellent error resilience behavior at the price of higher bit-rates. The strength of an intra-video coding system relies on the ability to efficiently exploit the spatial redundancies of each video sequence frame avoiding complexity in the design of the encoding/decoding engines.

In the context of image and video compression, the most reliable way of measuring the perceived quality is by performing subjective quality tests. Such subjective tests were standardized by the Video Quality Experts Group (VQEG) [2]. The Mean Opinion Score (MOS) is a subjective quality metric obtained from a number of human observers, has been regarded for many years as the most reliable form of quality measurement, and the procedure for doing such experiments has been standardized [3]. However, the MOS method is too cumbersome, slow and expensive for most applications.

Many research has been done in order to obtain objective image and video image QAM based on the knowledge of how our Human Visual System (HVS) perceives quality. QAM are valuable because they provide video encoder designers and standard organizations with means for making meaningful quality evaluations without convening viewer panels. The most commonly used quality metric is the PSNR since it is simple and fast to calculate. However PSNR does not always capture the distortion perceived by the HVS. In terms of correlation to human perception it would be preferable to use the MOS value as QAM when performing R/D comparisons but it would be too cumbersome. Some studies begin to present their results by means of quality assessment metrics like MSSIM [4] and VIF [5].

Image and video encoders have included much of the knowledge of our HVS in the way they process in order to obtain a better perceptual quality of the compressed sequences. The most widely used characteristic is the contrast adaptability of the HVS. HVS is more sensitive to contrast than to absolute luminance. The Contrast Sensitivity Function (CSF) relates the spatial frequency with the contrast sensitivity.

We propose a intra perceptual video encoder, PM-LTW, based on LTW image codec [6] with the inclusion of CSF in the wavelet transform stage, optimized and tuned to work at moderate to good video quality levels. We propose the use of a CSF weighting matrix applied to wavelet subbands that preservers a very good balance between bit-rate and perceptual quality in all the quantization range. As quality metric for R/D comparisons, we propose to use the VIF (Visual Information Fidelity) QAM [7] which has been proven [8] [9] to have a better correlation with subjective perception than other metrics that are usually used for this types of comparisons [10] [4]. We perform a comparison of the PM-LTW perceptual performance with other intra tuned coding proposals

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[1] Departament of Physics and Computer Engineering, Miguel Hernandez University - Elche - Spain, e-mail: {`mmrach,otoniel,pablop,mels`}`@umh.es`.

[2] Department of Computer Engineering, Polytechnic University of Valencia - Spain, e-mail: `joliver@upv.es`

like H264/AVC, Motion-JPEG2000, Motion-SPIHT and x264.

The rest of the paper is organized as follows. In section II we introduce some advantages of intra coding, in section III we describe how to include the CSF in the encoding process and in section IV we discuss about the convenience of using quality assessment metrics. In Section V we describe the codec versions included in the comparison against PM-LTW and we explain the methods followed to perform the comparison as well as the results presented, and finally in section VI some conclusions are drawn.

II. Advantages of Intra-Coding

Inter-frame coding uses temporal correlation of pictures to generate lower bit-rates than intra coding schemes, assuming that the content of successive frames is similar. When this assumption fails, for example in videos of "still-camera" strobes, fast motion sport sequences, quick zooms and pans, special effects or sequences with short duration events and high motion, then the bit-rate savings would be reduced, approaching to bit-rates produced by the intra coding option. Furthermore, the compression delay coding in intra mode is much lower than the one produced in inter coding, what should be taken into account for interactive IPTV applications.

In video content editing applications, accessing random frames would be natural for intra coding schemes, while inter coding would require decoding several frames. Moreover, the quality of reconstructed frames depends only of the frame itself avoiding error propagation between frames that would be considerable when previous frames or part of them are lost or with errors. This also leads to a lower degradation of the edited video when multiple editions of the same sequence are done.

Parallel processing is another field where intra coding can take advantage, since inter coding defines more data dependencies that causes parallel programming to be complex and less efficient. Intra only compression is very suitable with parallel processing architectures, i.e. multi core CPUs, or GPUs.

In [11] an experimental study was performed with H.264/AVC and JPEG2000 in order to determine the benefits of the use of inter frame encoding versus intra frame encoding for Digital Cinema applications. Their results draw that the coding efficiency advantages of inter frame coding are significantly reduced for film content at the data rates and quality levels associated with digital cinema. This indicates that the benefit of inter frame coding is questionable, because it is computationally much more complex, creates data access complications due to the dependencies among frames and in general demands more resources. For lower resolutions their experiments confirms that inter frame coding was more efficient than intra frame coding. These results provide a justification for using JPEG2000, or other intra frame coding methods, for coding digital cinema content.

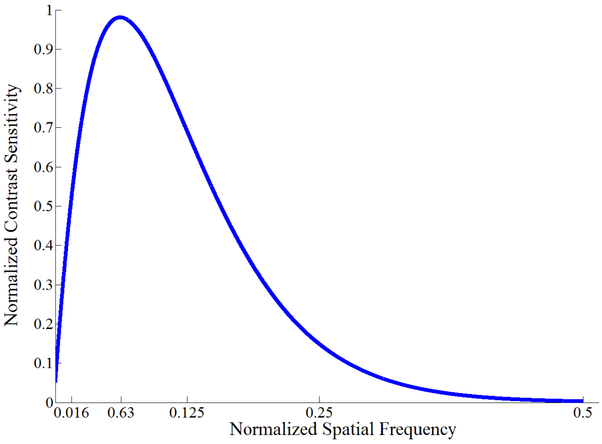

Fig. 1. Contrast Sensitivity Function

III. Contrast Sensitivity Function

HVS research offers mathematical models of human perception. A comprehensive review of HVS-models for quality assessment/image compression is found in [12]. Most of these models account for the varying sensitivity over spatial frequency, color, and the inhibiting effects of strong local contrasts or activity, called masking. Complex HVS-models implement each of these low level visual effects as a separate stage. Then the overall model consists of the successive processing of each stage. One of the initial HVS stages is the visual sensitivity as a function of spatial frequency that is described by the CSF.

A closed form model of the CSF for luminance images [13] is given by:

$$H(f) = 2.6(0.0192 + 0.114f)e^{-(0.114f)^{1.1}} \tag{1}$$

where spatial frequency is $f = (f_x^2 + f_y^2)^{1/2}$ with units of cycles/degree (f_x and f_y, are the horizontal and vertical spatial frequencies). The frequency is usually measured in cycles per optical degree (cpd), which makes the CSF independent of the viewing distance.

Figure 1 depicts the CSF curve obtained with equation 1, it characterizes luminance sensitivity as a function of normalized spatial frequency. CSF is a bandpass filter, which is most sensitive to normalized spatial frequencies between 0.025 and 0.125 and less sensitive to very low and very high frequencies. The reason why we can not distinguish patterns with high frequencies is the limited number of photoreceptors in our eye. CSF curves exist for chrominance as well. However, unlike luminance stimuli, human sensitivity to chrominance stimuli is relatively uniform across spatial frequency. The work of [13] was one of the first where it was demonstrated that the MSE cannot reliably predict the difference of the perceived quality of two images. They propose, by the way of psychovisual experiments, the aforementioned model of the CSF, that is well suited and widely used ([14][15][16][17]) for wavelet based codecs, therefore we adopt this model.

TABLA I

PROPOSED CSF WEIGHTING MATRIX

	LL	LH	HH	LH
L1	1.0	1.1795	1.0000	1.7873
L2	1.0	3.4678	2.4457	4.8524
L3	1.0	6.2038	5.5841	6.4957
L4	1.0	6.4177	6.4964	6.1187
L5	1.0	5.1014	5.5254	4.5678
L6	1.0	3.5546	3.9300	3.1580

The granularity of the correspondence between frequency and weighting value is a key issue. As wavelet based codecs obtain a multiresolution signal decomposition the easiest association is to find a unique weighting value for each wavelet frequency subband. If further decompositions of the frequency domain are done, for example by the use of packet wavelets a finer association could be done between frequency and weights [18]. The most common way of implement the CSF curve in wavelet based codecs is by the use of an Invariant Scaling Factor Weighting [19].

In [20], subjective experiments were performed obtaining a model to express the threshold DWT noise as a function of spatial frequency. Using this model authors obtain a perceptually lossless quantization matrix for the linear-phase 9/7 DWT. By the use of this quantization matrix each subband is quantized by a value that adjust the overall resulting quantized image at the threshold of artifacts visibility. For supra-threshold quantization a uniform quantization stage is afterwards performed.

In [21] authors argued that fixing the quantization matrix for at-threshold visibility and then perform a uniform quantization to reach a desired bit-rate in the supra-threshold range does not guarantee to preserve the best perceptual quality for the resulting image. They propose an iterative rate/distortion process based on the relationship among contrast of resulting image and the MSE. Again subjective supra-threshold experiments were performed for establishing how the overall contrast sensibility is affected by supra-threshold quantization impairments in each individual wavelet subband.

We perform an ISFW implementation of the CSF based on [14] but increasing the granularity at the subband level. So we scale the wavelet coefficients before a uniform quantization stage. We obtain the weighting matrix of Table I directly from the CSF curve (unlike [20] and [21]), by normalizing the corresponding values so that the most perceptually important frequencies are scaled with higher values, while the less important are preserved. This scaling process augment the value of all wavelet coefficients (except LL subband) and therefore the overall bitrate needed for the transmission of the scaled version of the image. Our tests reveal that thanks to the weighting process, the oncoming uniform quantization stage preserves a very good balance between bit-rate and perceptual quality in all the quantization range.

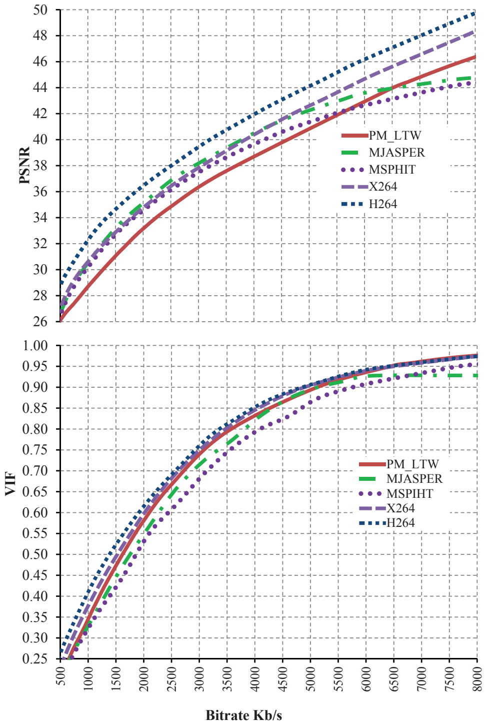

Fig. 2. R/D comparative PSNR and VIF results for Container CIF sequence

IV. THE USE OF QUALITY ASSESSMENT METRICS

Upper panel of Figure 2 show the PSNR R/D results for the Container CIF sequence of all evaluated codecs. While looking at these results, a first conclusion could be that the algorithms or improvements included in the PM-LTW encoder do not perform well and should be discarded because the quality differences are too high for any rate. For example, focusing at 3458.15 Kb/s (1.13 bpp) the difference between H.264/AVC and PM-LTW is up to 3.32 dB. In figure 3 the frame number 20 of the Container CIF sequence is presented at this rate for H.264/AVC and PM-LTW. After having a look at these two frames the difference of 3.32 dB seems too high, that is, one expects more visual difference for a numeric distance of 3.32 dB.

Therefore we can not trust how PNSR ranks quality. We need a quality metric on which rely. Lower panel of figure 2 the quality is measured in terms of the VIF QAM, the previous conclusion that discarded the PM-LTW encoder is compromised. Although quality assessment metrics are not foolproof, the objective quality values for both encoders are not as distant as before, being this distance closer to the perceived one. Assuming that a quality assessment metric is based on a fitting process over a set of MOS values, it is worth to use such a metric for comparisons of different encoder proposals.

V. PERFORMANCE ANALYSIS

All the evaluated encoders working in intra coding mode have been tested on an Intel Pentium Core 2 CPU at 1.8 GHz with 6GB of RAM memory. We have selected H.264/AVC (High-10, JM16.1),

(a) PSNR=37.49 dB Bit-rate=3458.15 Kb/s

(b) PSNR=41.19 dB Bit-rate=3690.42 Kb/s

Fig. 3. Frame 20 of the container sequence encoded with a) PM-LTW and b) H.264/AVC INTRA

TABLA II

Quality levels lower thresholds

Lower Thresholds	CIF & QCIF	ITU & HD
Visually lossless	0.93	0.90
Excellent	0.87	0.85
Good	0.80	0.75
Acceptable	0.70	0.60

Motion-JPEG2000 (Jasper 1.701.0), Motion-SPIHT (Spiht 8.01), x264 (FFmpeg version SVN-r25117, profile High, level 4.0) and our PM-LTW.

The main parameters used for the H264/AVC JM16.1 are: Profile ID: 110; Level ID: 4.1 (for QCIF and CIF) and 5.1 for (ITU and HD1080); IntraProfile: 1; IntraPeriod: 1; IDRPeriod: 1; GrayScale: 1; RateControlEnable: 1; RCUpdateMode: 1; CABAC.

The main parameters used for the X264 Software are: -intra; -pix_fmt yuv420p; -vf ”format=gray”; -fpre ”libx264-hq.ffpreset”

The test video sequences used in the evaluation are: Foreman, Hall, Container, News, Mobile and Pedestrian_area. Resolutions were QCIF, CIF, ITU 576 and HD 1024.

The rates, timing and the distortion values (PSNR) were obtained from the corresponding codec log file. For getting the memory consumption values, we used the VMMap Sysinternals tool. The frame VIF value was obtained with the matlab VIF source code that can be downloaded from authors web page [22].

While comparing encoder proposals it is common to work within a bit-rates and quality working ranges. As we will focus in perceptual qualities stated by users as good and above, first we have to establish the quality working ranges by means of VIF values. We did a simple subjective test with four observers in order to define five quality levels, “Visually lossless”, “Excellent”, “Good”, “Acceptable” and “Bad”. For each sequence, the uncompressed sequence is present as reference to the viewer together with a sequence compressed at a different bit-rate each time. Viewers had no knowledge of the bit-rate being evaluated but they know which one is the uncompressed image. They set for each sequence a value ranging from 0 to 4 with steps of 0.2 points. A value of 0.0 is given when the viewer does not detect any differences between the two sequences. A value of 1 is the lower threshold for the “Excellent” level, being 2 and 3 the corresponding lower thresholds for “Good” and “Acceptable”. When users rank a sequence with a value higher than 3, this means that this sequence is in the “Bad” level. Our study will focus only on the first four levels, from “Visually lossless” to “Acceptable”.

The subjective test to determine the five quality levels was run using different video sequences with different formats and the video codecs defined above. In order to properly choose the video sequences for the test, we used the encoder that offers the best R/D behavior, in terms of the VIF quality metric, for each sequence. After analyzing the resulting data, the VIF value thresholds are obtained for each level. From the raw data, we detected that observers set the thresholds for each level around different VIF values depending on the picture size. For example, when picture size was CIF or QCIF the lower threshold for the “Good” level was set around 0.80 VIF units, but at higher picture sizes it was set around 0.75 VIF units. In the same way, for small size sequences the lower threshold for the “Acceptable” level was set around 0.70 VIF units while for larger sequences it was set around 0.60 VIF units. Table II resume these values.

Figure 4 shows the VIF R/D curve for the HD1080 “Pedestrian area” sequence. Regardless of the codec, points of curves with quality values over 0.90 VIF units could be considered perceptually the same. Focusing on the “Visually lossless” level (above 0.90 VIF units) in figure 4, the key issue is then, at which bit-rate one codec reaches this level and if a bit-rate saving is obtained by using one codec or another. As previously mentioned, for the “Visually lossless” level all the sequences seem to be the same. The raw values told that there is a bit-rate saving (around an 8.9%) when using PM-LTW at 56 Mb/s (0.93 VIF) instead of using X264, because for getting the same VIF quality it needs 61.7 Mb/s. But this, although matematically correct, is not from a perceptual point of view. In this case, if we reduce the bit-rate for the X264 codec up to 56 Mb/s we get a VIF value of 91.6 units, which falls in the same level, being there-

TABLA III

Average bit-rate savings while comparing the use of PM-LTW with studied codecs for each quality level

PM-LTW vs	QCIF	CIF	ITU-D1	HD
M-JPEG2000				
Vis. Lossless	7.32%	9.26%	11.88%	-
Excellent	6.59%	4.03%	10.33%	42.48%
Good	7.58%	2.93%	9.05%	17.59%
Acceptable	9.08%	4.38%	9.02%	4.51%
M-SPIHT				
Vis. Lossless	12.13%	13.76%	19.84%	37.59%
Excellent	12.04%	12.82%	18.28%	36.63%
Good	12.70%	12.58%	16.32%	31.34%
Acceptable	13.15%	12.77%	14.94%	22.87%
x264				
Vis. Lossless	-1.68%	-1.96%	16.11%	12.11%
Excellent	-2.51%	-2.32%	15.41%	14.09%
Good	-3.61%	-2.63%	14.48%	17.02%
Acceptable	-5.04%	-2.94%	13.98%	19.42%
H.264				
Vis. Lossless	-3.04%	-2.05%	12.80%	17.86%
Excellent	-4.97%	-4.05%	6.50%	16.68%
Good	-7.63%	-6.72%	-2.31%	11.23%
Acceptable	-10.59%	-9.27%	-9.06%	2.92%

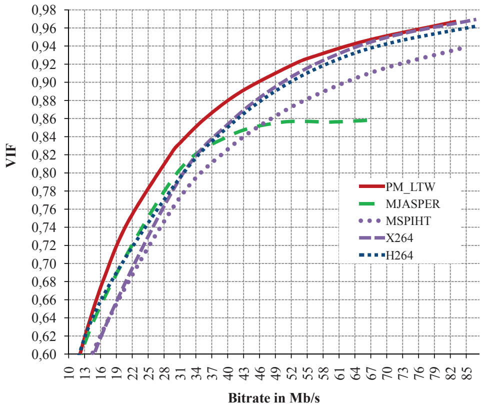

Fig. 4. R/D by means of VIF for the Pedestrian Area HD1080 sequence

fore indistinguishable form the PM-LTW encoded sequence. So, in this case, no advantage of the use of PM-LTW is obtained, because the same saving could be obtained with the x264 encoder. For getting a real bit rate saving in this level by the use of one encoder instead of another, both encoders must reach the "Visually lossless" quality level lower threshold at different rates.

For the rest of levels, the curves corresponding to the different codecs can not be assumed to be perceptually the same, because there were viewers that perceived some differences between values inside the same interval. Table III shows the relative bit-rate savings that in average can be achieved for each of the defined quality levels. When comparing our proposal with Motion-JPEG2000 or Motion-SPIHT and regardless of the frame size and quality level, bit-rate savings are always achieved. The trend is that the saving increases with frame size. When focusing in x264 and H.264 and at QCIF and CIF sizes, their averaged values for all sequences give a better performance for all the defined quality levels, being this savings greater for H.264 than for x264 in all levels. Looking at ITU video size the PM-LTW performance increases as the quality level becomes higher. When comparing with x264, PM-LTW achieve lower bitrate in all quality levels. However, the improvements with respect H.264 are only achieved at "Excellent" and "visually Lossless" quality levels.

TABLA IV

Timing differences between PM-LTW & M-LTW due to Perceptual Enhancement (Average frame time in milliseconds)

D	Wavelet	Coding	Total
PM-LTW			
CIF 3091.9 Kb/s	3.35	12.41	15.76
ITU 9113.8 Kb/s	12.24	37.03	49.27
HD 45471.3 Kb/s	92.38	231.00	323.37
M-LTW			
CIF 3091.9 Kb/s	3.05	13.36	16.41
ITU 9113.8 Kb/s	11.05	41.96	53.01
HD 45471.3 Kb/s	85.64	264.64	350.28
Differences			
CIF 3091.9 Kb/s	0.30	-0.95	**-0.65**
ITITU 9113.8 Kb/s	1.19	-4.93	**-3.74**
HD 45471.3 Kb/s	6.74	-33.64	**-26.91**

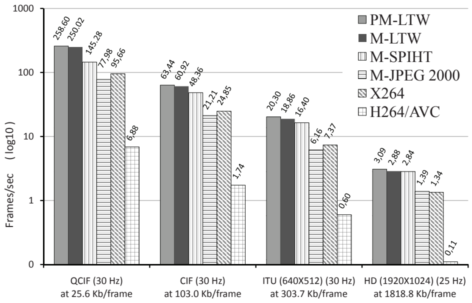

Fig. 5. Maximum frame rates in log scale for the different frame sizes

Figure 5 shows the frame rate obtained by the different encoders being evaluated. As shown, the PM-LTW outperforms the rest of the encoders for any sequence frame size. Regarding memory usage, in Figure 6 we can see the maximum amount in MBytes of the private memory working set needed for each encoder and sequence size. The bit-rate used for each resolution are 769.9 Kb/s, 3091.9 Kb/s, 9113.8 Kb/s and 45471.3 Kb/s for QCIF, CIF, ITU and HD respectively. PM-LTW is by far the one which less memory needs for all frame sizes. As frame size increases these differences are more important. This makes the PM-LTW very suitable to encode at high video resolutions.

VI. Conclusion

PM-LTW intra mode video codec is very competitive in terms of perceptual quality and outperforming the rest of the evaluated encoders for high video resolutions sequences. Since intra frame encoding has some advantages over inter frame encoding for a set of applications the proposed encoder is a very good option for these applications. The use of the VIF QAM instead PSNR in Rate/Distortion com-

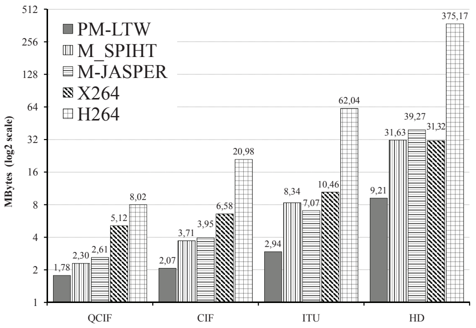

Fig. 6. Memory consumption comparison in MB

parisons, reveals that our proposal performs perceptually very good. This, in turn, verify the fact that using PNSR while comparing encoding proposals in terms of R/D is not recommended, because it could induce to wrong conclusions. Our proposal includes the well known Contrast Sensitivity Function after the wavelet transform stage of our encoder performing a perceptual weighting of the obtained wavelet coefficients. We proposed a weighting matrix that gives a very good R/D behavior in all the bit-rate range. PM-LTW achieves important bit-rate savings for the same perceptual quality when compared with M-SPIHT or M-JPEG2000 for all the evaluated sequence resolutions and quality levels. When comparing with X264 these savings occurs for the ITU resolution but only in the Excellent and Visually lossless quality levels. As resolution increases up to HD our proposal achieves bit-rate savings for all the evaluated quality levels being the highest values for the Visually lossless quality level. PM-LTW requires much less memory than any other encoder being the differences higher as resolution increase. For HD resolution requires near 4 times less memory than M-SPIHT, M-JPEG2000 and X264, and up to 40 times less memory than H.264. In addition PM-LTW is also the fastest of the evaluated encoders being up to 2.3 times as fast as x264 and 28 times as fast as H.264/AVC intra.

This makes PM-LTW a good choice for intra frame coding at high definition/resolution applications.

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