AVC-Intra (H.264 Intra)

Compression

Technical Overview

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Professional AV Systems Business Unit

Panasonic AVC Networks Company

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The Concept and Specification of the Panasonic AVC-Intra(H.264-Intra) HD CODEC

Introduction.

High Definition is now mandated for most television program production. Thankfully, recent technological advances have lowered the cost of HD production and post-production equipment to close to that of yesterday's standard definition hardware. The same advances that make cost effective HD possible have also introduced new creative processes, changed workflows, and all the while enhancing efficiency. HD today has borrowed heavily from the "IT" industry bringing networked data workflows, non-linear HD editing, and the introduction of solid-state field recording and associated tapeless workflows. One example of an IT tapeless system is the Panasonic P-2 format, P-2 uses ultra fast memory to record a variety of SD and HD MXF file based content. The adoption of flexible recording formats like P-2 provides a welcome break from the inherently "locked" formats of tape and other "physical" media.

The advent of high-speed processors and cheap memory has also spurred similar quality and efficiency gains in the area of video compression. Earlier video compression schemes such as MPEG-2, introduced in the early 1990s, although elegant in concept were seriously constrained by the processing capability of the hardware available at the time. Thus elegant data reduction schemes, although well understood could not be realistically implemented. Today however, we can now take full advantage of the power and speed of modern digital processing and leverage that technology to produce more modern and more efficient modern compression schemes such as MPEG-4 AVC/H.264. MPEG4 AVC, more commonly know as "H.264" provides coding efficiencies of two to three times over the older, less efficient MPEG-2 family. Panasonic has expanded the P-2 HD product line with the introduction of a new high quality HD CODEC called AVC-Intra, (AVC-I). The use of H.264 based AVC-I provides production quality HD at bit rates more normally associated with ENG applications, permitting for the first time full resolution, 10 bit field capture of high quality HD imagery in one piece camera-recorders. This white paper will outline the AVC-I concept and introduce some of the AVC-I capable P-2 products.

AVC-Intra, Feature set. Provide ENG and Production Quality CODECs to Satisfy Users demands using the latest compression technology.

The AVC-Intra concept and feature set is shown below in Table 1. With existing recording schemes, e.g. tape, the physical recording format and file / CODEC compatibility is guaranteed by the hardware tape format, this may be considered a closed system. With the more flexible IT file-based systems e.g. P-2, we need to ensure full compression stream compatibility, as this represents the essence of the format itself. To guarantee interoperability it is very important that the stream and compressed file system conforms to internationally recognized standards.

Table 1: Summary of the AVC-I features and Modes

Demands	AVC-I Features
IT affinity / Tapeless	International Standard / P2 file recording
Highly Efficient Compression	MPEG-4 AVC/H.264 @ High10 / High 4:2:2 Profile standard
Editing / Operation	Intra-Frame compression method (I-only compression)
Full Resolution HD mode	100Mb/s mode (1920 x 1080 / 4:2:2 @ 10bit)
ENG / Economy HD Mode	50Mb/s mode (1440 x 1080 / 4:2:0 @ 10bit)

Figure 1.

The evolution of compression technology

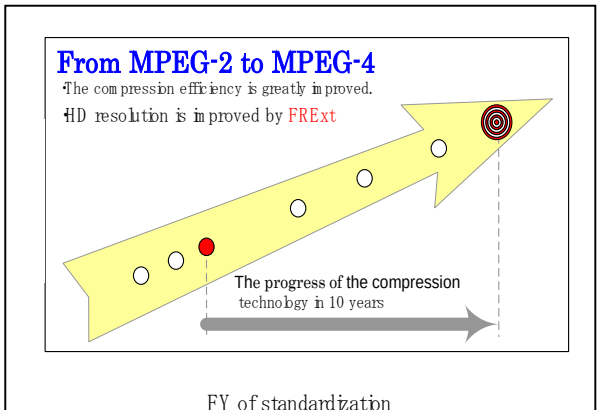
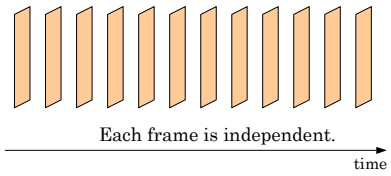
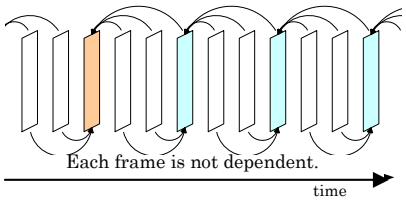


Figure 1 shows the evolution of the various image compression schemes. For the past 10 years, the main target of research and development was the improvement of compression efficiency at the super-low bit rates. MPEG-2 found great success as the recording and the transmission methods of SD DVDs and DTV. Work on more advanced compression then continued leading to MPEG-4 Visual, which later evolved into MPEG-4 AVC. Additional development added High Definition and the FRExt (Fidelity Range Extension) to H.264. Both were subsequently integrated into H.264 by means of the addition of a “High Profile”. The Panasonic AVC-Intra implementation of H.264 is flexible to user demands by virtue of its ability to switch between the AVC-Intra 100 mode and the more economical AVC-I 50 modes. The AVC-I 100Mb/s mode provides full resolution (no-subsampling) HD and fully conforms to High 4:2:2 profile, whilst the more economical AVC-Intra50 mode fully conforms to High 10 Profile. Both CODEC implementations are 10 bits.

The Superiority of INTRA-only Compression.

Video compression may be divided into two basic schemes; INTRA-only compression that completes the compression processing within one frame, and INTER or (Long GOP) compression in which the processing is completed over multiple frames. Both schemes are summarized in Table 2.

Table 2: Features of INTRA compression and Long GOP compression

	Intra (I-only) compression		Long GOP compression	
Compression Scheme	1 frame 		Multiple frames (about 15 frames) 	
Lowering bit rate	Hard	Intra frame correlation only	Easy	Correlation between multiple frames
Delay by processing	Small	1 frame	High latency	Multiple frames
Picture Quality Dependency	Small	Within a frame	Severe	Affects on multiple frames
Editing easiness	Easy	Easy (frame by frame)	Complicated	Complicated (GOP)
Error spread range	Small	Max. 1 frame	Severe	Multiple frames
Dubbing deterioration	Small	Within a frame	Severe	Multiple frames
Parallel processing	Easy	Max. 1 frame	Difficult	Multiple frames

Long GOP compression is able to produce lower bit rate streams than Intra schemes by working on the assumption that the picture content of the adjacent frames is similar. However, there are often many circumstances in which the adjacent frame correlation is simply non-existent or at best very poor. Examples are press events with many “still-camera” strobes, fast motion sports images, camera zooms and pans, special effects or graphics with short duration events and high intensity motion, e.g. animation and Music Videos. The simple, every day “Fade-to-black” is a very severe test for long GOP CODECS, usually resulting in unsightly blocky artifacts for the entire duration of the fade.

AVC-Intra utilizes Intra (I-only) compression specifically to negate the effects of this challenging video content. In doing so, recording, editing and postprocessing are easily accomplished with excellent image quality stability, yet are totally immune to adjacent frame content influence. I-only compression is very suitable for use with parallel processing architectures, i.e. multi core CPUs, it is also suitable for processing with software based CODECs. .

Twice as Efficient as MPEG-2…

In order to improve the compression efficiency of Intra (I-only) compression yet maintain quality and performance, the AVC-Intra CODEC selectively uses some of the H.264’s new compression “tools”. These tools provide the CODEC designer with new algorithms and advanced compression options not present in earlier more primitive CODECs, usually due to the aforementioned hardware limitations.

The designer can thus optimize the CODEC for professional equipment by 'cherry-picking' features from H.264 standard, and optimizing the balance of the compression performance and the circuit complexity. Such optimization methods can improve the efficiency by up to 30% using each of the new compression options. Thus, if more than one such option is utilized, the efficiency improvement becomes twice ($0.7^2<0.5$) with merely two methods combined. Even small compression mode efficiency choices compound, e.g. if the designer can improve the CODEC by a modest 5% with a "tweak", 14 such "modest" improvements when added become $0.95^{14}<0.5$ and are able to achieve to double the efficiency. Even with I-only compression, H.264 – an aggregation of the various efficiency improvement methods can compress twice as efficiently as MPEG-2. Two specific compression "tools" that provide a major increase in efficiency are:

1. The use of correlation between adjacent pixels, known as Intra Prediction
2. Entropy encoding improvement, specifically CABAC:（Context Adaptive Binary Arithmetic Coding）

Intra prediction, Generating Image information from Adjacent Pixels.

Figure 2 shows the various modal options for 4x4-block intra prediction. Basically the scheme predicts and generates the pixel value in a 4x4 block from adjacent pixel value that has already been encoded. H.264 provides the user with nine modes for Luminance signal prediction and four modes for color. The key point of the effective improvement is to select the proper prediction mode for each block. The AVC-Intra implementation not only decides the best prediction mode with minimum processing requirements but also uses the mode optimization algorithm to prevent flicker and any generational dubbing deterioration.

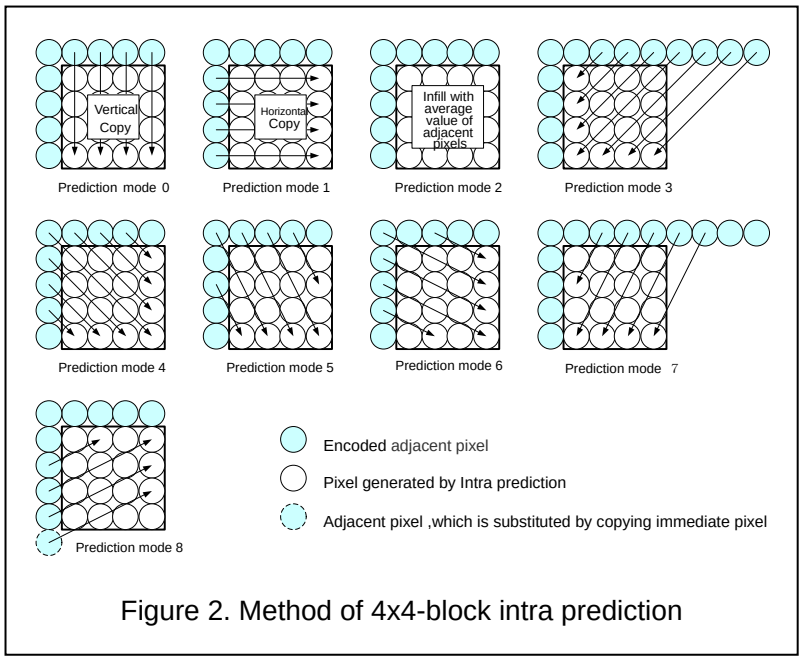


Figure 2. Method of 4x4-block intra prediction

Figure 3 shows the original encoder input image and part of expanded intra prediction image generated from the input image of AVC-Intra. You can see the high accuracy of the prediction.

Figure 3. Original input image and Intra prediction image

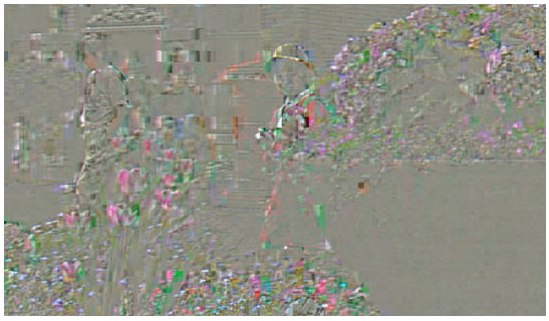
(a) Original input image

(b) Intra prediction image

Compressed Recording of Residual image and Prediction mode

The Intra Frame Predicted image is subtracted from original input image, the result, a “difference” or residual image is seen in Figure 4. AVC-Intra performs a DCT of this residual image and then compresses the DCT data. Both the prediction mapping data and compressed residual image are “recorded” together. Because the amount of data required for the residual image can be reduced by highly accurate intra prediction, high efficiency compression can be achieved even with Intra (I-only) compression. Different from INTER frame prediction employed in long GOP encoding, Intra Prediction is performed within the confines of a single frame, as such the prediction accuracy and subsequent compression efficiency does not deteriorate with motion as it would with long GOP.

Figure 4. Residual Image



CABAC, the next Generation Encoding Feature that will be widely used in the future.

The Entropy encoding choices for H.264 High Profile can be selected from either Context Adaptive Binary Arithmetic Coding (CABAC) or Context Adaptive Variable Length Coding (CAVLC). Context means "Surrounding circumstances", and it is a method used to achieve high compression efficiency by adjusting the entropy encoding parameters to best match the content of the image. Table 3 shows the comparison of the methods of entropy encoding. MPEG-2 that does not support this context adaption function and

performs entropy encoding as simple VLC, i.e. by means of a fixed code table is compared to newer methods. Simple VLC is not optimal and so compression efficiency may decrease with increasing image structure. Conversely, CAVLC and CABAC can compress images in high efficiency by adjusting the operation precisely to each image. Significantly, CABAC is able to perform “text-book” entropy encoding almost to the limit of the theory due to the combination of the arithmetic coding and context adjustment. CABAC is a very significant contribution to the efficiency of modern HD encoding algorithms. It can be found in Blu-Ray, HD-DVD, the AVC-HD consumer format, as well as newer H.264 based devices. The efficiency increases that CABAC brings will ensure even wider utilization in the future.

Table 3: Comparison of Entropy Encoding Methods.

	MPEG-2 VLC	MPEG-4 AVC/H.264	
		CAVLC	CABAC
Encoding method	Variable Length Coding		Arithmetic Coding
Context Adjustment process	No	DCT coefficient unit	1bit unit
Encoding efficiency	Moderate	Very good	Excellent
Major application	DVD DTV	Cell Phone Video-casting	Next generation Blu-ray, HD-DVD, AVC-HD

AVC-I 50Mb/s and 100Mb/s, the application of CABAC vs. CAVLC.

The AVC-I CODEC utilizes CABAC for increased efficiency at the 50 Mb/s bit rate. At lower bit rates, hence higher compression, CABAC provides significantly better compression efficiency than would CAVLC. Indeed as a result of data from numerous test sequences, CABAC has been shown to reduce the bit rate 20～30% more than CAVLC for the 50Mbps of AVC-I compression. For less compressed, higher bit rate images, CABAC’s efficiency benefit lessens, hence at the AVC-I 100Mb/s level we chose to use CAVLC. This results in less processing complexity, another benefit that is useful. CABAC is very useful for highly compressed HD material to be found in AVC-HD and Blu-ray formats, here the bit rates may be as low as 6Mb/s, CABAC at such bit rates is a very powerful encoding tool and makes such low data rates possible.

Lineup of equipment for AVC-Intra.

Full Sized, P-2 Memory card camera recorder, the AJ-HPX2000・HPX2100

DV to DVCPRO HD multi codec, HD/SD multi format and support both 59.97Hz/50Hz recording.

The AJ-HPX2000・2100 will support AVC-I compression via a simple board option. The AJ-HPX2000・2100 are full sized ENG/ Production camcorder capable of fulfilling the roles of SD and HD News, through high-end production. With 5 P2 card slots and AVC-I compression, the camera could record for literally hours! The HPX2000 is also able to record proxy video (MP4) onto the P2 cards along with the regular P2 file contents. The AJ-HPX2000・2100 use 3 x 2/3" 1 million progressive HD pixel imagers, it features high sensitivity F10 (2000lux), and an amazing +74dB gain. (Digital gain + cumulative + Line mix). The camera's CCDs and DSP processing are based upon that of the renowned Varicam. An interesting adaptive gamma technique known as DRS (Dynamic Range Stretching) automatically provides a wider dynamic range with minimal blown highlights and blocked shadows in scenes with mixed dark and light areas.

Memory card portable recorder "P2 Mobile" the AJ-HPM100

A portable SD / HD P-2 field recorder designed for field recording in rugged environments, it features multiple CODEC support, from DV to DVCPRO HD and optional AVC-I CODEC. Able to preview, playlist edit P2 files without a computer, it provides a more traditional workflow. With its 6 P-2 card slots and ability to interface with external IEEE1394 and USB drives, the P-2 mobile offers markedly superior HD performance to existing HD field recorders.

Alliances and Future developments.

Similar to the widely used DVCPRO series, we have formed an alliance of AVC-Intra Partners with nonlinear editing/server manufacturers. Apple and Avid have declared support of AVC-Intra, with others to follow. Those interested in utilizing AVC-Intra would be welcome to join this growing community.

In due course, new products will be introduced to support the AVC-I CODEC. The ability to record very high quality HD with much reduced storage / networking requirements and work in an IT infrastructure will benefit HD users greatly.