Executive Summary

Digital video compression involves sacrificing some degree of picture quality for a lower bit rate that facilitates transmission and storage. Compression not only requires a high level of performance from the processor but also some versatility in design, since different types of video applications have different sets of requirements for resolution, bandwidth and resiliency. The extended flexibility provided by Texas Instruments’ video encoders address these differences and take full advantage of the options offered by advanced video compression standards to help system developers optimize their products. Operating on TMS320C64x+™ digital signal processors (DSPs), DaVinci™ technology video processors and OMAP™ mobile media processors, TI's encoders offer easy-to-use application programming interfaces (APIs) in a standard system interface that help simplify video integration and optimization in a variety of applications.

The Need for Flexible Optimization

Digital video continues to extend visual communication to an ever-larger range of applications, and an increasing number of developers are becoming involved in creating new video systems or enlarging the capabilities of existing designs. Video not only demands very high performance but the wide variety of video applications requires the performance to be optimized depending on the particular system. Programmable, high-performance DSPs and platforms from TI allow developers to adapt their software readily to application requirements that can vary widely in terms of transmission bandwidth, storage, image specifications and quality requirements.

The inherent structure and complexity of video encoding and decoding (codec) algorithms drives the optimization approach. Encoders are particularly important because they must adapt to the application and they represent a major portion of the heavy processing load of video applications. The goal for video compression is to encode digital video using as few bits as possible while maintaining acceptable visual quality. While encoders are based on the mathematical principles of information theory, they may still require implementation trade-offs, which can be quite complex. TI encoders are highly configurable, providing an easy-to-use system interface and performance optimization for a wide range of video applications. Even if the developer is new to DSPs or video algorithms, TI video encoders offer a number of techniques that can make the optimization process easier and more effective in terms of compression and picture quality.

Options in Compression Standards

Raw digital video requires a lot of data to be transmitted or stored. For example, in the absence of any compression, standard-definition (SD) digital TV in North America typically requires a data rate of over 165 Mbps or more than 100 GB required to store a standard movie. Even lower-resolution CIF video, which is often used in...
streaming, requires over 36.5 Mbps, which is much more than can be sustained on most of
today’s broadband networks. An advanced video codec such as H.264/MPEG-4 AVC can
achieve compression ratios of between 60:1 and 100:1 with sustained throughput. This
makes it possible to squeeze video with a high data rate through a narrow transmission
channel and store it in a limited space.

Like JPEG for still images, the widely used ITU and MPEG video encoders employ a
combination of discrete transform coding (DCT) or something similar, quantization and
variable-length coding to compress macro-blocks in key frames also referred to as intra-
frames. Once the algorithm has established a baseline intra-coded (I) frame, a number of
subsequent predicted (P) frames are created by only coding the difference in visual content
or residual between each of them. This inter-frame compression is achieved using a tech-
nique called motion compensation. First the algorithm estimates where the macro-blocks
of the current frame were in the previous frame. Then it subtracts and compresses the
residual.

Improved motion compensation techniques, along with other techniques, have doubled
the compression ratio from MPEG-2 to MPEG-4, but the performance requirements have
also increased. The motion estimation (ME) stage, which creates the motion vectors that
describe where each of the blocks has moved, is usually the most computation-intensive
stage of the algorithm. Figure 1 shows the flow of a generic motion compensation-based
video codec. Typically, the macro-blocks contain four 8×8-pixel luminance blocks and two
8×8-pixel chrominance blocks (YCbCr 4:2:0), though other video formats are specified.

Figure 2 on page 3 shows a P frame (right) and its reference (left). Below the P frame,
the residual (black) shows how little remains to be encoded once the motion vectors (blue)
have been calculated.
Video compression standards specify only the bit-stream syntax and the decoding process, leaving a large scope for innovation within the video encoders. For example, in the ME stage, the ways that the motion vectors describe block movement are standardized, but there are no constraints on what techniques the encoder can use to determine the vectors. Rate control is another area with significant latitude for innovation, allowing the encoder to assign the quantization parameters and thus “shape” the noise in the video signal in appropriate ways. In addition, the advanced H.264/MPEG-4 AVC algorithm adds flexibility and functionality to earlier standards with multiple options for macro-block size, quarter-pel (pixel) resolution for motion compensation, multiple-reference frames, bi-directional prediction (B frames) and adaptive loop de-blocking. Important additions in the new standard are shown in Figure 3 on the following page.

Video application requirements can vary enormously. The range of features in advanced compression standards offer a large potential for trading off the options in order to balance complexity, delay and other real-time constraints. Consider, for instance, the different requirements for video surveillance, video conferencing and video phones, video mobile phones and digital video recorders (DVRs).

Video surveillance can require compression within digital cameras for DVRs, network transmission (IP netcams) or concentration units taking feed from analog cameras. Even with a high level of compression, storing the vast amount of visual information generated is often the key problem. One solution is to keep only the frames containing pertinent activity, such as someone entering or leaving through a secure door. The software used to ensure this may access the frame motion information to determine if any activity is occurring. A high magnitude in motion vectors signifies suspicious activity is occurring and the frame...
is immediately stored. All TI encoders available on TI devices based on DaVinci™ technology (TMS320DM644x, TMS320DM643x, TMS320DM647 and TMS320DM648 processors) provide access to motion vectors, a feature that not all competitors possess.

Surveillance software may also need to access the encoder parameters to compensate for dawn, dusk or other condition changes. In addition, having the ability to simultaneously encode two different rates can be an advantage with surveillance, since it allows the system to display video at one rate on a monitor while storing it on a disk at another rate. The ability to dynamically trade-off a single high-quality channel with two low-quality channels allows the amount of information stored to be greater when something happens in front of one of the cameras. These changes, like compression itself, must occur in real time in order to capture events as they occur.

Video conferencing and video phones. The most important issue with video-phone and video-conferencing applications is typically the transmission bandwidth, which can range from tens of kilobits per second up to multi-megabits per second depending on the link. In some cases, the bit rate is guaranteed but with the Internet and many intranets, bit rates are highly variable. As a result, encoders used in video conferencing frequently have to address the delivery requirements of different types of links and adapt in real time to changing bandwidth availability. The transmitting system, when it is advised of reception conditions via a reverse channel or RTCP acknowledgement, should adjust its encoded output continually so that the best possible video is delivered with minimal interruption. When delivery is poor, the encoder may respond by reducing its average bit rate, skipping frames or changing the group of pictures (GoP) structure which represents the mix of I

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*Figure 3. H.264/MPEG-4 AVC key features.*
and P frames. Since I frames are not as heavily compressed as P frames, sending fewer I frames requires less bandwidth overall. Since the visual content of a video conference does not change frequently, it is usually acceptable to send fewer I frames than it would be to send with, say, TV or a movie.

H.264 uses an adaptive in-loop de-blocking filter that operates on the block edges to smooth the video for current and future frames. The de-blocking filter significantly improves the subjective quality of video encoded by H.264, especially at low bit rates. On the other hand, turning off the filter can reduce the computational complexity but increase the amount of visual data at a given bit rate, as can changing the ME resolution from quarter-pel to half-pel or more. In some cases, it may be necessary to sacrifice the higher quality of de-blocking and fine ME resolution in order to reduce the computational complexity of encoding.

Since packet delivery via the Internet is not guaranteed, video conferencing often benefits from encoding mechanisms that increase error resilience. For instance, progressive strips of P frames can be intra-coded (I strips), as shown in Figure 4. This technique eliminates the need for complete I frames (after the initial frame), reducing the risk that an entire I frame will be dropped and the picture broken up. Also, without the bursts created by I frames, the data flow is steadier. There is a trade-off in compression, though, since the presence of narrow I strips reduces the encoder’s ability to exploit spatial redundancy. An estimated two to five percent is lost in bit rate, so it is useful if the encoder can switch this capability on or off as needed for coping with network delivery conditions.

Video mobile phones. In wireless phones with video capabilities, bandwidth is at a premium, even with 3G channels. Processing may also be more limited in these systems since handsets are designed to trade-off low power consumption for performance. The encoder

![Figure 4. Intra-coded strips in P frames.](image-url)
at the transmitting end has to take the receiving limitations into account by adjusting the resolution to the small display. For video streaming, a lower frame rate with fewer I frames or I strips is likely, since the picture degradation is not as apparent as it would be on a larger display, while the bandwidth savings are considerable. Video conferencing is an extreme case since the handset needs to encode as well as decode. Due to background that is usually static and little motion in the foreground, traffic may be limited to a single I frame at the beginning of the call, followed only by P frames.

**Video recording.** Digital video recorders (DVRs) for home entertainment are perhaps the most widely used application for real-time video encoders. For these systems, achieving the best trade-off of storage with picture quality is a significant problem. Unlike video conferencing, which is not delay tolerant, compression for video recording can take place with some real-time delay if sufficient memory is available in the system for buffering. Realistic design considerations mean the output buffer is designed for handling several frames, which is sufficient to keep a steady flow of data to the disk. Under certain conditions, however, the buffer may become congested because the visual information is changing quickly, thus creating a large amount of P frame data. In this case, the encoder should be able to trade-off quality for a lower bit rate. When the congestion has been taken care of, then the quality can be increased again.

A mechanism for performing this trade-off effectively is by changing the quantization parameter, Qp, on the fly. Quantization, as shown in Figure 1, is one of the last steps in the algorithm for compressing data. As quantization introduces noise, it creates picture distortion in direct proportion to the square of Qp. Increasing Qp reduces the bit rate output of the algorithm but sacrifices picture quality. However, since the change occurs in real-time, it reduces the likelihood of frame skips or picture break-up. When the visual content is changing rapidly, as it is when the buffer is congested, lower image quality is likely to be less noticeable than it is when the content changes slowly. Once the visual content returns to a lower bit rate and the buffer clears, Qp can be reset to a normal value.

As we have seen, video compression standards give encoding programmers wide latitude in implementing the algorithms. H.264/MPEG-4 AVC provides a number of options that can be used by encoders in adapting to specific application requirements. TI processors are used in a wide range of systems and TI encoders are designed with flexibility to support these options through easy-to-use application APIs. Encoder versions are available that operate on any TMS320C64x+™ DSP or DaVinci™ technology video processor, with or without acceleration from the video and imaging coprocessor (VICP). Non-VICP versions are also available for OMAP™ media processors.
A basic set of APIs with default parameters is used in all the encoders, so that the system interface remains the same, regardless of the type of system. Extended API parameters adapt an encoder to the requirements of specific applications. By default, parameters are preset to high-quality settings; a high-speed preset is also available. All preset parameters can be overridden by the program using extended parameters.

Features of the encoders include support for both YUV 4:2:2 and YUV 4:2:0 input formats, motion resolution down to a quarter-pel, GoP sizes with I frame intervals ranging from every frame to none after the first frame, bit-rate control via Qp, access to motion vectors, de-blocking filter, simultaneous encoding of two channels, I strips in P frames for resiliency, and many other options for a wide range of applications. In motion estimation, TI’s encoders allow the search range to be restricted for compliance with some standards, such as H.263. By default, the encoder dynamically and unrestrictedly determines the search range.

TI’s encoders allow a wide range of encoding bit rates. However, there are generally “sweet spots” of operation, where output bit rates operate optimally for a given input resolution and frames per second (fps). Developers should be aware of the sweet spots with TI encoders in order to design their systems for the best trade-offs of transmission and picture quality. For DVD-type content using H.264, the main sweet spot correspondences are as follows:

- Below 128 kbps: QCIF at 15 fps
- Between 128 and 256 kbps: QCIF/QQVGA at 30 fps
- Between 256 kbps and 1 Mbps: CIF/QVGA at 30 fps
- Above 1 Mbps: VGA/D1 30 fps

For the same content with MPEG-4 compression, bit rates should increase by 30 percent to allow for the reduced compression efficiency of the MPEG-4 standard. Since video conferencing and surveillance have relatively static visual content, they have a 30 percent lower bit rate need compared to DVD-type content.

Development of the encoders is ongoing, and TI works closely with its customers to make available the features that are needed for their products. Planned enhancements include auto-detection of scene changes in order to place I frames for better picture quality and support for additional intra prediction modes that improve compression. Regardless of what changes are introduced, the encoder APIs will remain simple and straightforward in order to keep video system integration uncomplicated.
Digital video continues to spread to new types of systems, and developers need to be aware of the many differences that exist among entertainment, video conferencing, surveillance, mobile and other video applications. In general, compression requirements trade-off bit rate and picture quality, though the many different ways of achieving these trade-offs can be complicated. Since H.264/MPEG-4 AVC provides a number of options that can affect these trade-offs, and since the standard does not specify how the encoder determines data such as motion vectors, there is a great deal of latitude in encoder design for optimization. TI encoders use this specification latitude to provide a straightforward interface that provides the flexibility to adapt video compression to the requirements of a wide range of applications. As the world of digital video continues to expand, TI processors and codecs provide high performance, ease of use and versatility that enable developers to optimize their products effectively for a wide variety of application requirements.
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