Video Compression Optimization for Telemetry Applications

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Abstract: Video compression and transport methods are critical components of a video telemetry system. Meeting video quality, resolution, frame rate, latency, and interoperability requirements can be a challenge when up against datalink bandwidth and platform SWaP-C constraints. A range of video compression and transport options is presented, from highly compressed (H.265), to medium (JPEG 2000), light (JPEG XS), and lossless compression, as well as uncompressed (SMPTE 2110-20) networked architectures. The benefits and disadvantages of the different options are described, along with real-time datalink, ground network video distribution, and video recording use cases.

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Keywords: Video Compression, H.265, HEVC, JPEG XS, JPEG 2000, SMPTE 2110

1. Introduction

Video telemetry requirements can vary significantly as applications range from real-time display of video telemetry over radio data links to ground video distribution and high-quality recording applications. Depending on acceptable limits of the key metrics of video quality, latency, and bandwidth, the type of video processing technology selected for an application can range from highly compressed video, to lightly compressed, to uncompressed transport.

An overview of a range of video telemetry options is presented, from highly compressed H.265 encoding, medium and light compression with JPEG XS, JPEG 2000, and H.265 intra-frame encoding, to lossless and uncompressed video transport and recording options. Video telemetry use cases are presented for the various compression modes. In addition to video quality, latency, and bandwidth considerations, impacts of the compression and transport selection on error resilience, SWaP-C, and future proofing for video resolution growth to 4K and higher are discussed.

2. Highly Compressed Video

The video compression algorithm H.265, first published in 2013 [1] as High Efficiency Video Coding (HEVC) produces high quality video at compression ratios on the order of 100:1, corresponding to a 720p60 4:2:2 encoded bitrate of roughly 10 Mbps. The widely used H.265 and H.264 algorithms are recent generations of the discrete cosine transform (DCT) block-based intra- and inter-frame coded video compression method originally developed in the 1970's, with the first practical video standard H.261 published in 1984. The most recent version, H.266 Versatile Video Coding (VVC), was ratified in 2020. Each succeeding generation of video encoding typically improves compression efficiencies by 25-50% (50% indicating the same video quality at half the bandwidth) along with an increase in processing requirements by a factor of 5 to 10. Apart from the currently sparse VVC decoding infrastructure that creates interoperability issues, the increase in processing power that VVS encoding requires can present challenges for Size, Weight, Power, and Cost (SWaP-C) constrained vehicles or platforms used in telemetry applications.

Most video compression methods first perform a block- or wavelet-based transform to reduce redundant pixel-to-pixel information, followed by a lossy quantization of transform indices, then perform entropy encoding to minimize the number of data bits needed to carry the most frequently transmitted values. In addition to DCT-based transforms, HEVC includes transforms based on the discrete sine transform (DST). To achieve a high level of compression the algorithm relies on the similarity of neighboring pixels within a video frame (intra-frame compression), but most of the efficiency comes from the small and predictable pixel value differences between consecutive frames (inter-frame compression). The encoding sequence normally first creates an intra-coded video frame followed by inter-coded frames which base prediction on surrounding pictures in the sequence of images.

2.1 Latency Considerations

Video telemetry applications which are low and constant video latency should take into account two characteristics of inter-frame encoded H.265 video that can potentially cause latency. The first characteristic is the larger size of intra-coded frames in comparison to inter-coded frames which can cause latency for constant bit rate data links. Since inter-frame compression is more efficient than intra-frame compression, intra-coded frames of similar quality to inter-coded frames typically use significantly more data bits to encode. The size of the intra-coded frames can be limited at the cost of causing a lower quality pixelated "beat" at the intra-coded frame rate. Another solution is to partially intra-code all video frames rather than occasionally intra-coding an entire frame, such that over the course of a number of video frames all pixels are intra-coded. This method keeps the size of compressed video streams more uniform and provides intra-coding refresh to allow recovering from errors in the data stream described below.

The other characteristic of inter-frame encoded video streams that can cause latency is the inclusion of bi-directionally encoded video frames (B frames). The B frames reference the previous frame as well as the next frame and is more efficient than the encoding of frames that only reference the previous frame (P frames). Due to their dependence on future video frames, when a decoder receives a stream with B frames the decoder needs to buffer one or more video frames, causing one or more frames of latency. Video streams without B frames do not incur this latency.

2.2 Error Resilience

Another aspect of video streams with inter-frame compression to consider for telemetry applications is that errors in the data stream can cause video errors in the decoded output video that persist until an intra-coded frame or block arrives and corrects the errors. Conversely, a benefit of intra-frame only encoding, as described in the next section, is that any errors in the data stream will only impact the video frame(s) which include the errors and typically last for only one video frame time. One way to alleviate this error persistence at the expense of lower video quality is to send intra-coded frames more frequently. Other options for error correction methods include (1) Reed-Solomon encoding which adds 9% bandwidth to transport stream packets, and (2) the use of UDP streaming protocols such as Secure Reliable Transport (SRT) [2] and Reliable Internet Streaming Transport (RIST) [3].

3. Medium and Lightly Compressed Video

Medium and lightly compressed video streams typically have compression ratios of 20:1 to 4:1 and use intra-frame only compression. For system infrastructures that can manage the higher bandwidth, benefits can include lower latency associated with intra-frame encoding and quick recovery from any errors introduced in the data link. The latency benefit for intra-frame only coding is due to both the absence of B frames and the streamlined delivery and processing of the video stream, similar to that associated with uncompressed video transport.

Two options for medium compression encoding are H.265 intra-frame only compression and JPEG 2000. JPEG 2000 [4], originally published in 2001, provides a 20% improvement in efficiency compared to the original JPEG standard. JPEG 2000 uses a wavelet-based transform rather than the DCT-based transform of JPEG and employs a significantly more complex entropy coding method than the original JPEG entropy coding. The Motion JPEG 2000 extension [5] defines the streaming protocol and .mj2 file format for JPEG 2000 streams. The H.265 intra-frame encoder has been shown to provide a 16% improvement in compression compared to JPEG 2000 [6].

JPEG XS is an example of a light compression encoder, producing excellent quality video with compression ratios from 4:1 to 12:1. The JPEG XS algorithm was built as a viable alternative to uncompressed video, with key features (1) visually lossless imagery [7], (2) low codec complexity, allowing 4Kp60 encoding on a standard i7 x86 processor, or low-cost FPGA without requiring external memory, (3) precise constant bitrate control, and (4) ultra-low latency with a maximum of 32 video lines of end-to-end algorithmic latency [8]. Transport protocols supporting JPEG XS include MPEG-2 Transport Stream (TS) [9], as well as SMPTE 2110-22 [10] for constant bitrate encoded video transport over Internet Protocol (IP) networks.

The SMPTE 2110 suite of standards specifies the transport of compressed or uncompressed video and associated audio and metadata as a system of RTP-based essence streams with a common reference clock. The Video Services Forum (VSF) technical recommendation TR-10, the Internet Protocol Media Experience (IPMX) set of technical recommendations, is based on the SMPTE 2110 standards and the AMWA Networked Media Open Specifications (NMOS) [11] which support network management, discovery, and registration for compressed and uncompressed video streams. VSF TR-10-11 [12] is the technical recommendation that describes the transport of constant bitrate compressed video in the IPMX protocol suite.

JPEG XS video streams and single images can be stored using file formats described in the table below.

File Format	Imagery Content	Specification
Material Format MXF (.mxf)	Video	SMPTE ST 2124 [13]
ISO Base Media File Format (.mp4)	Video	ISO/IEC 21122-3 [14], and references therein
MPEG-2 Transport Stream (.ts)	Video, single images	ISO/IEC 13818-1 Ed. 8 Annex W [15]
High Efficiency Image Format (.heif)	Video, single images	ISO/IEC 21122-3 [14], and references therein
JPEG XS (.jxs)	Single images	ISO/IEC 21122-3 [14]

Note that the MPEG-2 TS specification includes the transport of JPEG XS still images which could be used for the real-time object detection use case discussed below.

4. Uncompressed Video and Lossless Compression

The advantages of using uncompressed rather than compressed video include preserving the original quality of the imagery, low latency, and low processing requirements. The disadvantage is the high bandwidth required, and for recording applications the required large-capacity storage and high data rate recording capability. Two options for the transmission of

uncompressed video are baseband point-to-point infrastructure, such as SDI or HDMI, or Ethernet.
For baseband video, the hardware infrastructure is constrained to a fixed number of inputs and outputs, limited distance for the video transmission, and currently has bandwidth limitations for growth to higher resolutions and frame rates. SDI cables are rated to 12Gbps, whereas Ethernet infrastructure can scale with growing video resolutions, currently with 100GbE support and specifications up to 400GbE [16].

The SMPTE 2110-20 standard [17] is designed to migrate the video, audio, and metadata SDI infrastructure to IP with PTP network timing. SPMTE 2110 supports up to 4:4:4 chroma sampling, 32K resolution, and bit depths up to 16. The VSF TR-10-2 [18] is the IPMX technical recommendation that describes the transport of uncompressed video.

Lossless video compression is a format that reduces the video bitstream data rate but preserves the original video content. Lossless compression for imagery is mostly used for storing video or still pictures to save memory storage space while not sacrificing the video quality. As described below, video telemetry applications for which lossless compression could be beneficial would be recording and playback use cases. For these cases the compression should support real time compression at the incoming video rate. The algorithm HuffYUV [19] is a fast lossless encoder that uses prediction and Huffman entropy coding, originally released in 2000 and supported by FFmpeg [20].

5. Video Telemetry Use Cases

5.1 **Ground Network Video Distribution**

The first use case for medium and lightly compressed video, as well as uncompressed video over IP, addresses ground video distribution requirements for ultra-low latency visually lossless video, historically fulfilled by the transmission of uncompressed video over SDI. SMPTE 2110-20 and 2110-22 present options to replace SDI video with new and existing GbE, 10GbE, or 25GbE networked distribution of multi-channel high definition (HD) and ultra-high definition (UHD) video. As an example, JPEG XS 10:1 compression of 4Kp60 8 bps 4:2:2 video has a bitrate less than 800Mbps. Low-power JPEG XS video encoders co-located with HD and UHD sensors would enable video transmission over GbE links and networked switching to multiple range real-time monitoring and recording stations.

5.2 **Video Recording, Post-Mission Transmission**

This use case concerns missions that employ video recording followed by post-mission transmission. All video compression modes presented, from high, medium, light, and lossless compression, to uncompressed video, are relevant to this use case. H.265 video streams allow long-term mission high quality video recording due to the high compression ratio and lack of errors in the data stream on the vehicle or platform. This recording use case also presents a good fit for lossless compression with the capability to capture the original video and provide significant savings in the data storage required and post-mission transmission time. The benefits of a visually lossless lightweight 10:1 compression technology like JPEG XS for this case compared to the recording of uncompressed video or highly compressed video are described in the RCC SR-22-002 Image Compression report [21]. The report details significant savings in time and resources for Kineto Tracking Mount-based workflows compared to recording and downloading uncompressed video, as well as diminishing returns for further compression and complexity from H.264 or H.265 compression.

For video recording and playback applications, vehicles or platforms with SWaP-C constraints can benefit from JPEG XS compared to uncompressed or more complex compression technologies in several ways:

- The low complexity of JPEG XS compression reduces the power consumed and cost compared to more complex compression technologies
- Compression ratios up to 10:1 permit longer recording times, shorter download times compared to uncompressed video, as well as the advantage of lower speed interfaces with recording media

5.3 **Real-Time Video Telemetry**

Video telemetry uses cases for H.265 highly compressed video streams include real-time low latency transmission of single-channel and multi-channel video streams over telemetry data links with bit rates from 250kbps to 15Mbps. There has been a rapid growth in the use of unmanned vehicles and object detection for safety, security, and surveillance. With the advent of fast object detection algorithms such as You Only Look Once (YOLO), object detection is increasingly performed on remote vehicles and platforms. Combining object detection with higher quality Region-of-Interest encoding is a potentially powerful tool for relaying in real time high quality detailed imagery.

For low-power vehicles or scenarios where the accuracy and determination of objects are critical there can be an advantage to offloading processing to the ground station and connected servers. An area of study has developed for best methods and architectures for edge-assisted video processing and object detection with respect to power consumption of the vehicle and the latency and reliability of detection results [22].

The visually lossless, low complexity, and low latency attributes of JPEG XS compression make it a good fit for these use cases. The limited datalink bandwidth prevents the transmission of full frame rate high-definition video at a compression ratio of 10:1. By narrowing the pixel range or decimating the frame rate, JPEG XS can be used for encoding and transmission of high-quality imagery from remote sensors to the receiving system.

The table below lists sample bitrates, ranging from 20.7Mbps for 1080p video at 5fps to 2.3Mbps for 320x240 region-of-interest video at 15fps at a compression ratio of 10:1, a component bit depth of 10 bits, and 4:2:2 chroma sampling.

Video Resolution	Frame Rate (fps)	JPEG XS Bitrate (kbps) at 10:1 Compression
1920x1080	5	20,736
1280x720	5	9,216
640x480	10	6,114
320x240	15	2,304

Real-time transmission of high-quality video imagery permits receiving systems to perform high-power video processing object detection, geolocation, and unique object identification with access to large databases. Significant uncertainties in object classification or identification could elicit snapshot requests from the ground station for particular regions of interest. Regions of interest can be carried as timestamped still images within a transport stream encoded as H.265 still image, JPEG 2000, JPEG XS, in parallel with highly compressed video streams.

6. Conclusion

An overview of a range of video telemetry options is presented, from high to lossless compression and uncompressed streaming. The options are discussed with respect to key characteristics of quality, latency, and bandwidth, as well as error resilience and SWAP-C perspectives. The widely used H.265 algorithm offers high quality and low bandwidth for high and medium compression applications along with error correction coding or reliable UDP transport methods. JPEG XS presents a visually lossless alternative with light compression for applications with higher bandwidth such as ground network video distribution or video recording and post-mission transmission workflows. The benefits of IPMX video streaming networks compared to baseband SDI video are discussed. A real-time video over telemetry link use case is explored with respect to object detection and H.265 as well as JPEG XS region of interest streaming.

7. References

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