HDR Video Compression Using High Efficiency Video Coding (HEVC)

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***Abstract*—It is only a matter of time before High Dynamic Range (HDR) video content becomes commercially available. It is necessary, therefore, to develop proper video compression standards that address the peculiarities of this content and enable the introduction of this technology to the consumer market. So far there is no dedicated standard for HDR content. This paper investigates the performance of the emerging High Efficient Video Coding (HEVC) standard on HDR content and compares it with that of the H.264/AVC standard. Performance evaluations show that HEVC outperforms the H.264/AVC standard by 22.47% to 58.61% in terms of bitrate or 1.02 dB to 4.88 dB in terms of PSNR in the case of HDR content.**

Keywords-HEVC; H.264/AVC; HDR compression

I. INTRODUCTION

The human visual system is able to adapt to light conditions at approximately 10,000,000,000:1 contrast or dynamic range, and at a single time instant, human eyes can perceive a dynamic range at the order of 100,000:1 [1]. Contrary to the wide range of light intensity allowed by the human vision system, only a range between the order of 100:1 to 1000:1 – known for this reason as "Low Dynamic Range (LDR)" - is supported by the majority of existing capturing and display devices. A new-generation of imaging systems promises to overcome this restriction by capturing and displaying high dynamic range (HDR) images and videos which contain information that covers the full visible luminance range and the entire color gamut [2].

In order to fully capture and represent the color space and dynamic range visible to human eyes, many solutions have been proposed in recent years. One solution is to combine multiple LDR videos captured at different exposure levels. Recently capturing HDR videos has become even more feasible, due to the availability of novel sensors that allow capturing multiple exposures.

The display industry has also started to take note of the potential of HDR technology. In recent years important developments in HDR display and projection technology have been made. Prototypes of HDR display are built with dynamic ranges of well beyond 50,000:1 according to [3]. Moreover to ensure smooth transition from LDR to HDR service, the backward compatibility with current low dynamic range display systems has been investigated. At the introductory phase of HDR systems, HDR displays (that accept 10-bit or 12-bit signals) and LDR systems (that accept only 8-bit data) will coexist. Thus, the broadcasters should provide both LDR and HDR signals for consumers. To efficiently allow for this overlap, a number of tone-mapping operators have been developed which converts 10-bit or 12-bit high dynamic range content to the 8-bit low dynamic range signal. Simple tone-mapping methods utilize the tone-mapping curve for all the pixels in an image [4] [5]. More sophisticated tone-mapping algorithms consider the local features of each pixel and use local operators to perform tone reproduction [6] [7].

As with all HDR technologies for capture and display, HDR compression is a topic worth more research attention as it is going to enable efficient transmission of HDR video. The transmission of HDR content requires provisions beyond those used in transmission of conventional LDR content. So far there is no dedicated video coding standard for HDR content. Some of the existing video coding standards allow coding of LDR video content with more than 8-bits per pixel. These encoders are optimized to compress video content with the statistical distributions of LDR video with more detail than the traditional LDR video (the same dynamic range though). However, HDR content differs from LDR content as it uniquely has higher color bit-depth with more details in high intensity (brightness) as well as low intensity regions. Overall, this introduces more texture and information, which result in large amounts of data.

To this day, the majority of compression efforts related to HDR have focused on separating HDR to a LDR stream and an enhancement layer both coded with existing 8-bit based standards [8]. This approach comes at a cost of low compression efficiency, but it ensures backward compatibility with the existing LDR displays, and allows reconstruction of the HDR content for HDR displays [6]. Only some very preliminary studies have been done on direct compression of HDR content. The method proposed in [9] adapts HDR signals to the JPEG-2000 coding requirements while the one described in [10] is developed around MPEG.

Among the existing video coding standards the H.264/AVC is the most advanced and efficient video compression standard (developed by the Joint Video Team (JVT) of the ITU-T Video Coding Experts Group (VCEG) and the ISO/IEC Moving Picture Experts Group (MPEG)). Recently, the international community for standardization has considered a new generation of video compression technology, known as High Efficient Video Coding (HEVC).

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This standard is offering substantially higher compression capability than the existing H.264/AVC standard. Current comparison results show that HEVC offer superior compression performance compared with H.264/AVC.

The performance of the HEVC standard on HDR content has not been taken into account at the time of developing this standard and all the tests were conducted using LDR content. Given the difference in properties and characteristics between LDR and HDR content, it is important to consider how HEVC will perform on HDR video and from these tests try to identify challenges and additions or changes to the new standard.

In this paper we investigate the compression performance of HEVC on HDR video content, to examine if HEVC has the potential to be used as a platform for a devoted HDR compression scheme. We conduct experimental tests on HDR content and compare the performance of HEVC with that of H.264/AVC standard. Comparable experiment settings of two codecs are introduced which could also be used in other similar tests.

The remainder of the paper is structured as follows. Section II provides a brief background on the formats of HDR content and the specifications of high efficiency video coding technology, Section III presents the details of our experiment, Section IV discusses the results and future work and Section V includes conclusions.

II. BACKGROUND

This section provides a brief background on the HDR content and the emerging high efficiency video coding technology.

A. *High Dynamic Range (HDR) Format*

HDR imaging offers the opportunity of capturing, storing, manipulating, and displaying dynamic real-world lighting. HDR signals preserve colorimetric or photometric pixel values (such as CIE XYZ) within the visible color gamut and allow for intra-frame contrast to reach the magnitude of 10^6:1, without introducing contouring, banding or posterization artifacts caused by excessive quantization. The photometric or colorimetric values, such as luminance ($cd{\cdot}m^{-2}$) or spectral radiance ($W{\cdot}sr^{-1}{\cdot}m^{-3}$), span to a much larger range of values than the luma and chroma values (gamma corrected) used in typical video encoding (JPEG, MPEG, etc.). In order to represent the dynamic range of intensities found in a real life scene, we need to use more than the typical 8-bits for each color. An intuitive solution is to represent the pixel value with floating point numbers to cover the larger dynamic range. One shortcoming of using floating-point numbers is that compression of HDR content becomes challenging since floating-point numbers are not optimal for compression compared to integer values. The other issue is that the precision error of floating point numbers varies across the full range of possible values. For these reasons, several file formats have originally been proposed for storing HDR data, including the Radiance RGBE (.hdr) [13], OpenEXR (.exr) [14], and LogLuv TIFF (.tiff) [15]. The RGBE format assigns four bytes to represent each pixel: one byte used for the mantissa of each of the RGB channels and the remaining one byte is used as a shared exponent. The exponent byte together with the mantissa part is able to represent a value of a very large range. On the other hand, OpenEXR spends 16 bits for each of the RGB channels: a sign bit, five bits for exponent and ten bits for mantissa. The LogLuv TIFF format represents the data in the logarithmic domain and supports 32 bits per pixel using one sign bit, 15 bits to encode the log scale of the luminance, and 8 bits for each of the two chrominance channels. These three formats are considered nearly lossless and require high data rate.

B. *High Efficiancy Video Coding (HEVC)*

The recent advances in technology have made it possible to capture and display video material with ultra-high definition (UHD) resolution. To enable transmission of large amounts of data the ISO/IEC Moving Picture Experts Group (MPEG) and ITU-T Video Coding Experts Group (VCEG) established a Joint Collaborative Team on Video Coding (JCT-VC) with the objective to develop a new high-performance video coding standard. A formal Call for Proposals (CfP) on video compression technology was issued in January 2010, and 27 proposals were received in response to that call [16]. The evaluations that followed showed that some proposals could reach the same visual quality as H.264/MPEG-4 AVC High profile at only half of the bitrate and at the cost of two to ten times increase in computational complexity. Since then, JCT-VC has put a considerable effort towards standardization of a new compression technology known as the High Efficiency Video Coding (HEVC), with the aim to significantly improve the compression efficiency compared to the existing H.264/AVC high profile. Generally speaking, HEVC is a block-based compression scheme, similar to H.264/AVC, with some new features. Some of the key elements of HEVC compared to H.264/AVC are: flexible block structure (recursive quad-tree partitioning and block sizes up to 64x64 pixels), more intra prediction modes (35 in total), improved motion vector estimation, and different integer transforms allowing non-square transforms. HEVC also includes two new filters (Sample Adaptive Offset (SAO) and Adaptive Loop Filter (ALF)) to undo the distortion introduced in the main steps of the encoding process (prediction, transform and quantization) [11]. The effort for standardization of HEVC is still ongoing, and it is expected to be finalized by July 2012. So far, the objective comparison results reported in [11] show that the current HEVC design outperforms H.264/AVC by 29.14% to 45.54% in terms of bitrate or 1.4dB to 1.87dB in terms of PSNR. Subjective comparison of the quality of compressed videos – for the same (linearly interpolated) Mean Opinion Score (MOS) points - shows that HEVC outperforms H.264/AVC, yielding average bitrate savings of 58% [12]. Note that all the reported performance evaluations are based on LDR content.

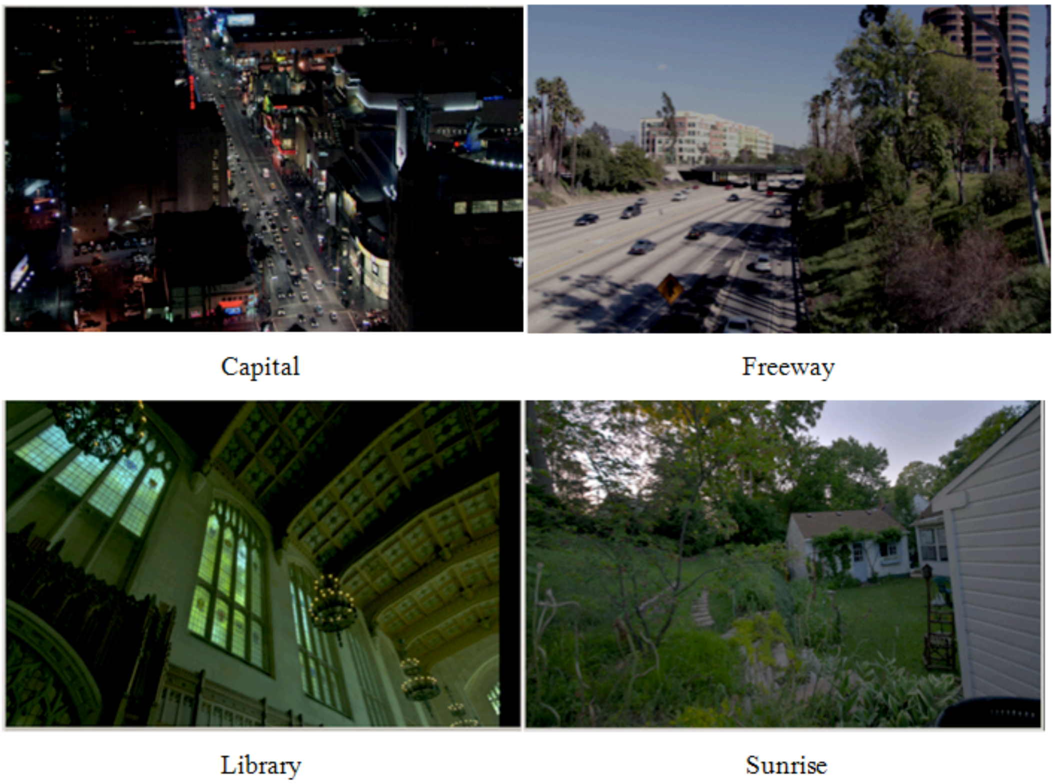

Figure 1. Snap shot of the test sequences.

Conventionally, video compression techniques have considered only 8 bits-per-pixel (bpp) input videos, yet HDR videos require 10-14 bpp. The current design of HEVC provides the necessary capabilities to handle LDR videos of up to 14 bpp without clipping the bit depth during the encoding process. This allows us to encode HDR content using HEVC. However, the compression performance might not be optimal, since HEVC is optimized to compress video content with the statistical distributions of LDR video but not HDR video.

III. EXPERIMENT

In this paper, our objective is to test the performance of HEVC for compressing HDR content, and compare it with that of H.264/AVC. The following subsections elaborate on the details of our experiment.

A. *Test sequences*

For our experiment, four test sequences are selected from the database provided by JVT of ISO/IEC MPEG & ITU-T VCEG [17] [18]. These test videos are in YUV 4:2:0 format, with a resolution of 1080p and a frame rate of 50 fps. The dynamic range of two of the videos is 10 bits and that of the other two is 12 bits. Fig. 1 shows a snap shot of the four test sequences. The specifications of the test sequences are summarized in Table I.

TABLE I HDR TEST SEQUENCES

Name	Bit Depth	Resolution	Frame Rate
Capital	10	1920x1080	50 fps
Freeway	10	1920x1080	50 fps
Library	12	1920x1080	50 fps
Sunrise	12	1920x1080	50 fps

These test sequences have been generated form high dynamic range video content that was originally stored in floating point format and in a linear RGB space. The representation of the sequence was created by first normalizing the RGB values to the set [0, 1]. Then these normalized values were converted to the YCbCr format using the ITU-R BT.709 reference primaries. Chroma planes were subsampled by a factor of two in each dimension using the given separable filter (refer to [17] for more details). Finally, the resulting 4:2:0 YUV file was quantized linearly with a rounding operation to create the test sequences [18].

B. *HEVC configuration*

To evaluate the performance of HEVC on HDR content we used the High Efficiency Video Coding Test Model 5 (HM 5.0) [19]. Note that HM 5.0 was the latest available

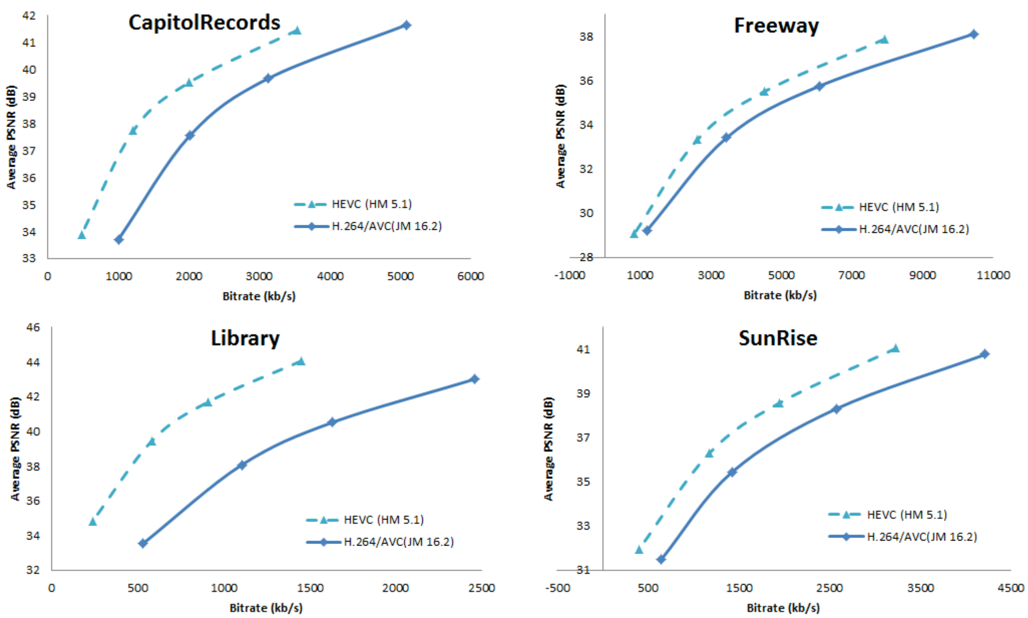

Figure 2. RD curves for HDR content.

HEVC Test model at the time of conducting this experiment. To enable the highest possible compression performance, the Random Access High Efficiency (RA-HE) configuration is used in our experiment: Hierarchical B pictures, Group of Picture (GOP) length of 8, ALF (Adaptive Loop Filter), SAO (Sample Adaptive Offset) and Rate Distortion Optimized Quantization (RDOQ) were enabled. In order to obtain a reasonable span of Rate-Distortion (RD) curves, the following Quantization Parameters (QPs) were used: 28, 32, 36, and 44. QP is the parameter, which controls the quantization step size, and in turn decides the level of quantization error involved during compression. A higher QP value leads to a larger quantization step size and worse video quality.

C. *H.264/AVC configuration*

In our experiment, the performance of HEVC is compared with the state-of-the-art video compression standard H.264/AVC (JM 16.2). To accommodate HDR content, the configuration of H.264/AVC was set to High 4:4:4 Profile, which accepts up to 14 bits. In our experiment we used hierarchical B pictures, GOP length of 8, CABAC entropy coding and RDOQ enabled. These settings were recommended for comparing H.264/AVC to HEVC by MPEG/VCEG in the Joint Call for Proposals (for more details check the Alpha anchor in [20]). The same QP settings as those in the HEVC case are used for H.264/AVC.

All the above-mentioned configuration settings were chosen to ensure a fair comparison between HEVC and H.264/AVC. However, these codecs are so different and have different tools and configuration options. As a result, aside from the necessary changes and above-mentioned settings, the default settings are used for the rest of available options.

IV. RESULTS AND DISCUSSION

To evaluate the performance of HEVC versus H.264/AVC for coding HDR content, we conducted our experiment using the infrastructure provided in the previous section. Fig. 2 shows the RD curves for all the test sequences and Table II lists the average PSNR improvement and average PSNR savings achieved by HEVC over the H.264/AVC standard.

As it can be observed, HEVC outperforms H.264/AVC by 22.47% to 58.61% in terms of bitrate (with same PSNR) or 1.02 dB to 4.88 dB in terms of PSNR (with same bitrate). Our results show that the compression efficiency of HEVC when applied to HDR content is dramatically higher than H.264/AVC and seems to follow the performance already witnessed for LDR content. In future work, we will include a new rate-distortion optimization process with HEVC that features an updated signal model and coding parameters derived specifically for HDR content. Moreover, subjective tests using an HDR display will be conducted to evaluate the performance of the two standards and the proposed schemes.

TABLE II AVERAGE COMPRESSION IMPROVEMENT

Name	Average PSNR Improvement	Average Bitrate Saving
Capital	1.26 dB	42.12 %
Freeway	1.02 dB	22.74 %
Library	4.88 dB	58.61 %
Sunrise	1.79 dB	32.60 %

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V. CONCULUSION

This paper compared the performance of the current HEVC test model with the state of the art compression standard, H.264/AVC, for compressing HDR content. Configuration settings used for this study were chosen carefully to represent similar scenarios and ensure a fair comparison. Our experiment results show that HEVC outperforms H.264/AVC by 22.47% to 58.61% in terms of bitrate (with same PSNR) or 1.02 dB to 4.88 dB in terms of PSNR (for the same bitrate).

The current progress of HEVC is proved to be promising and HEVC has the potential to replace H.264/AVC as the next state-of-the-art compression standard. Our study confirms that HEVC does not only offer superior compression performance for LDR content but also HDR videos. The compression improvement in the HDR case is in line with that of LDR. However the overall saving differs among different sequences (content dependent). Service providers could greatly benefit from HEVC due to more efficient use of bandwidth. It is worth mentioning that HEVC's high compression performance comes at the price of increased coding complexity compared to H.264/AVC.

With the rapid growth in the multimedia industry, it is only a matter of time before HDR videos become widespread. HEVC and future compression standards should be optimized accordingly to fully capitalize on this upcoming trend.

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