Impact of H.264/AVC and H.265/HEVC Compression Standards on the Video Quality for 4K resolution

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Abstract. *This article deals with the impact of H.264/AVC and H.265/HEVC compression standards on the video quality for 4K resolution. In the first part a short characteristic of both compression standards is written. The second part focuses on the well-known objective metrics which were used for evaluating the video quality. In the third part the measurements and the experimental results are described.*

Keywords

H.264/AVC, H.265/HEVC, PSNR, SSIM, VQM.

1. Introduction

In the last years the demand of the multimedia services that means the broadcasting, transmission and receiving the video, audio and other data in one stream, the multimedia stream has increased. Because of this progress, the video quality measuring as one part of the multimedia technology has become an important role. The video quality is affected by:

- the resolution of the scanning part of the camera,
- the processing of the television signal in the studio,
- the compression technology,
- the transmission link imperfection.

The compression technology can be considered as one of the main factors that influence the video quality. Nowadays many new compression standards are being developed, e.g. H.265/HEVC or VP9. Because of that video quality assessment plays still a big role in research area. Today some institutes and research teams deal with video quality evaluation but most of them focuse on the FullHD resolutions [20], [21] and [22]. While in this paper the impact of H.264/AVC and H.265/HEVC compression standards on the video quality for 4K resolution is measured and evaluated.

2. MPEG Compression Standards

MPEG, which stands for Moving Picture Experts Group, is the name of a family of standards used for coding audio-visual information (e.g. movies, video, music) in a digital compressed format [1].

2.1. H.264/AVC

H.264/AVC is currently the most used compression standard. It has been designed for a wide range of applications, ranging from video for mobile phones through web applications to TV broadcasting (HDTV). Some of the feature enhancements in H.264/AVC standard over the earlier codecs are:

- DCT algorithm works at 4×4 pixels instead of 8×8, but also supports 8×8,
- DCT is layered using Hadamard transforms,
- colour sampling is supported at 4:2:2 and 4:4:4,
- up to 12 bits per pixel are possible,
- motion compensation blocks are variable sizes,
- arithmetic variable-length coding,
- built-in de-blocking filter and hinting mechanism,

- rate-distortion optimizer,
- weighted bi-directional prediction,
- redundant pictures,
- flexible macroblock ordering,
- direct mode for B-frames,
- multiple reference frames,
- sub-pixel motion compensation.

H.264/AVC also defines profiles and levels. There are only three profiles currently defined: Baseline, Main and Extended [2], [3], [4], [5] and [6].

2.2. H.265/HEVC

The High Efficiency Video Coding (HEVC) standard is the most recent joint video project of the ITU-T video Coding Experts Group (VCEG) and the ISO/IEC Moving Picture Experts Group (MPEG) standardization organizations, working together in a partnership known as the Joint CollaborativeTeam on Video Coding (JCT-VC).

H.265/HEVC has the same basic structure as previous standards such as MPEG-2 Video and H.264/AVC. However, H.265/HEVC contains many incremental improvements such as:

- More flexible partitioning, from large to small partition sizes.
- Greater flexibility in prediction modes and transform block sizes.
- More sophisticated interpolation and deblocking filters.
- More sophisticated prediction and signalling of modes and motion vectors.
- Features to support efficient parallel processing.

The result is a video coding standard that can enable better compression, at the cost of potentially increased processing power. With H.265/HEVC, it should be possible to store or transmit video more efficiently than with earlier technologies such as H.264/AVC. This means:

- At the same picture size and quality, an HEVC video sequence should occupy less storage or transmission capacity than the equivalent H.264 video sequence.
- At the same storage or transmission bandwidth, the quality and/or resolution of an HEVC video sequence should be higher than the corresponding H.264 video sequence.

The H.265/HEVC standard is designed to achieve multiple goals, including coding efficiency, ease of transport system integration and data loss resilience, as well as implementability using parallel processing architectures. The video coding layer of H.265/HEVC employs the same hybrid approach (inter/intrapicture prediction and 2-D transform coding) used in all video compression standards since H.261. In the following, the various features involved in hybrid video coding using H.265/HEVC are highlighted as follows:

- coding tree units and coding tree block (CTB) structure,
- coding units (CUs) and coding blocks (CBs),
- prediction units and prediction blocks (PBs),
- TUs and transform blocks,
- motion vector signaling,
- motion compensation,
- intrapicture prediction,
- quantization control,
- entropy coding,
- in-loop deblocking filtering,
- sample adaptive offset (SAO) [7], [8] and [9].

3. Objective Video Quality Assessment Methods

The video quality evaluation can be differentiated into objective and subjective assessment. The subjective assessment consists of the use of human observers (people) who score the video quality. It is the most reliable way how to determine the video quality. The disadvantage of these methods is that they are time consuming and human resources are needed. Because of this fact, the objective methods are mostly used. They consist of the use of computational methods called "metrics" that produce values that score the video quality. They measure the physical characteristics of a video signal such as the signal amplitude, timing, signal-to-noise ratio. The big advantage of them is their repeatability. The well-known and mostly used objective metrics are peak signal-to-noise ratio (PSNR), video quality metric (VQM) and structural similarity index (SSIM).

3.1. PSNR (Peak Signal-to-Noise Ratio)

The PSNR in decibels is defined as:

$$\mathrm{PSNR} = 10 log \frac{m^2}{\mathrm{MSE}} \, [\mathrm{dB}] \, , \tag{1}$$

where m is the maximum value that pixel can take (e.g. 255 for 8-bit image) and MSE (Mean Squared Error) is the mean of the squared differences between the gray-level values of pixels in two pictures or sequences I and $\tilde{I}$:

$$\mathrm{MSE} = \frac{1}{TXY} \sum_t \sum_x \sum_y \left[I\left(t,x,y\right) - \tilde{I}\left(t,x,y\right) \right]^2 \tag{2}$$

for pictures of size $X \times Y$ and T frames.

Technically, MSE measures image difference, whereas PSNR measures image fidelity. The biggest advantage of the PSNR metric is that it can be computed easily and fast [2].

3.2. SSIM (Structural Similarity Index)

The SSIM metric measures three components, the luminance similarity, the contrast similarity and the structural similarity and combines them into one final value, which determines the quality of the test sequence (Fig. 1). This method differs from the methods described before, from which all are error based, using the structural distortion measurement instead of the error one. It is due to the human vision system that is highly specialized in extracting structural information from the viewing field and it is not specialized in extracting the errors. Owing to this factor, SSIM metric achieves good correlation with subjective impression [10].

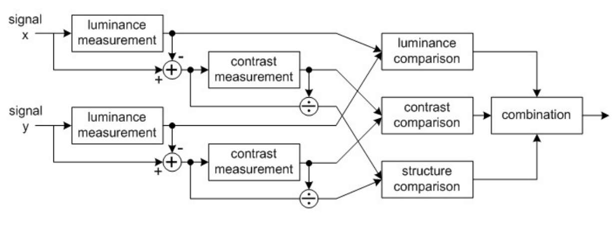

Fig. 1: The block diagram of SSIM metric.

The results are in interval [0,1], where 0 is for the worst and 1 for the best quality.

3.3. VQM (Video Quality Metric)

The VQM metric computes the visibility of artefacts expressed in the DCT domain. Figure 2 shows the block diagram of this metric, which can be divided into 9 steps.

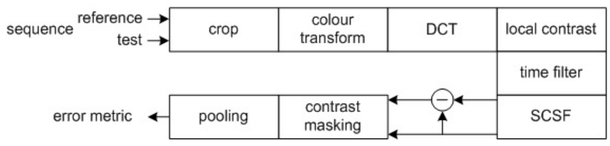

Fig. 2: The block diagram of VQM metric.

The input of the metric is a pair of colour image sequences, the reference one and the test one. Both sequences are cropped, then converted from the input colour space to the YOZ colour space, then transformed to blocked DCT and afterwards converted to units of local contrast. In the next step the input sequences are subjected to temporal filtering, which implements the temporal part of the contrast sensitivity function. The DCT coefficients, expressed in a local contrast form, are then converted to just-noticeable-differences (jnds) by dividing their respective spatial thresholds. This implements the spatial part of the contrast sensitivity function. In the next step, after the conversion to jnds, the two sequences are subtracted to produce a difference sequence. In the following step the contrast masking operation to the difference sequence is performed. Finally the masked differences are weighted and pooled over all dimensions to yield summary measures of visual error [11]. The output value of the VQM metric indicates the amount of distortion of the sequence, for no impairment the value is equal to zero and for rising level of impairment the output value rises.

4. Measurements

Nowadays some free databases containing video sequences used for video quality evaluation are available. Many of them include video sequences in FullHD or 4K resolution in uncompressed form (yuv) or compressed by H.264/AVC or H.265/HEVC standards [12], [13], [14], [15] and [16]. In our experiments four types of test sequences were used:

- “Beauty”: Closeup on female face, hair waving around. Black background (Fig. 4).
- “Bosphorus”: Zoomed in luxury yacht, huge bridge on background. Panning right (Fig. 5).
- “Jockey”: Horse racing with camera panning to the left to follow (Fig. 6).
- “ReadySteadyGo”: Horse racing track, riders getting ready for launch. The gates open and horses are running to the left (Fig. 7).

All sequences were in the 4K resolution (3840×2160 px) and 16:9 aspect ratio with 30 fps (frames per second). The length of these sequences was 600 frames, i.e. 20 seconds. The measurement procedure consists of four steps:

- First, both sequences were downloaded from [12] in the uncompressed format (*.yuv) and used as the reference sequences.
- Afterwards, they were encoded to both MPEG compression standards, H.264/AVC and H.265/HEVC, using the x264 [17], x265 tool respectively [18]. The target bitrates were in range from 2 Mbps to 30 Mbps, changed in 2 Mbps steps. The parameters of the encoded sequences were set to High Profile, Level 5.2 for H.264/AVC compression standard and Main Profile, Level 5.2 for H.265/HEVC compression standard. The GOP parameter was set to $N = 12$ and $M = 3$ which means that GOP length was 12 and two B frames between two successive P frames were stored. The command line settings of both x264 and x265 tools are shown in Tab. 1.
- Then, the sequences using the same tools (x264, x265) were decoded back to the format *.yuv.
- Finally, the quality between these sequences and the reference (uncompressed) sequence was compared and evaluated. This was done using the MSU Measuring Tool Pro version 3.0 [19]. PSNR, SSIM and VQM objective metrics for the measurements were used.

Tab. 1: Command line settings of x264 and x265 tools.

Command line options	x265, x264, command line settings
Input options	– input Beauty_3840×2160 _30fps_420_8bit.yuv – input-res 3840×2160 – input-csp i420 – input-depth 8 – fps 30
Slice decision	– no-open-gop
Options	– keyint 12 – min-keyint 12 – no-scenecut – bframes 2 – b-adapt 0
Quality, rate control and rate distortion options	– bitrate 4000 – vbv-maxrate 4000 – vbv-bufsize 4000
Debugging options	– recon Beauty_3840×2160 _30fps_420_8bit_GOP12-BF2_4M_x256.yuv Beauty_3840×2160_30fps _420_8bit_GOP12-BF2 _2M_x256.mp4

The whole process of measuring of both sequences is shown in Fig. 3. Figure 8, Fig. 9, Fig. 10, Fig. 11, Fig. 12, Fig. 13, Fig. 14, Fig. 15, Fig. 16, Fig. 17, Fig. 18 and Fig. 19 show the measurements results of the H.264/AVC and H.265/HEVC compression standards impact on the video quality for various test sequences.

According to the graphs the H.265/HEVC compression standard yields better compression efficiency than H.264/AVC compression standard, at the same resolution and bitrate the compression quality of H.265/HEVC standard is better than H.264/AVC. Bigger difference in quality between these two compression standards is in lower bitrates, with increasing bitrate the quality of H.264/AVC standard approach

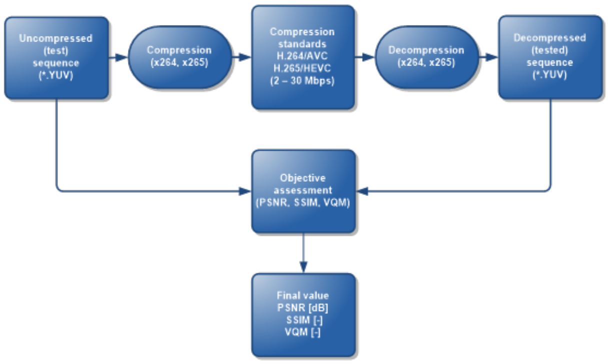

Fig. 3: The process of measuring the impact of H.264/AVC and H.265/HEVC compression standards on the video quality.

Fig. 4: The “Beauty” test sequence.

Fig. 5: The “Bosphorus” test sequence.

Fig. 6: The “Jockey” test sequence.

Fig. 7: The “ReadySetGo“ test sequence.

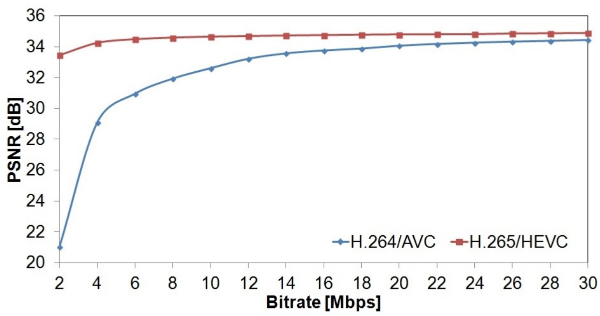

Fig. 8: The relationship between video quality (PSNR) and bitrate of both compression standards for "Beauty" test sequence.

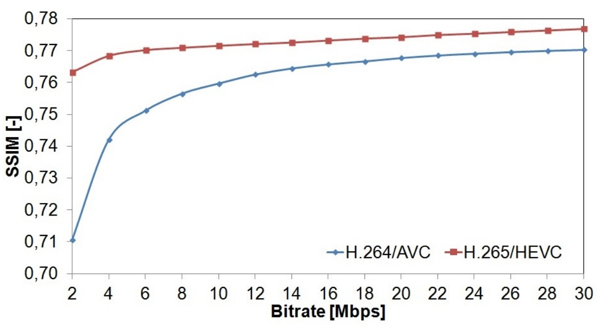

Fig. 9: The relationship between video quality (SSIM) and bitrate of both compression standards for "Beauty" test sequence.

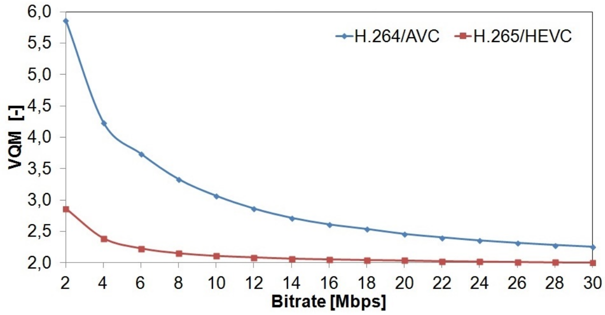

Fig. 10: The relationship between video quality (VQM) and bitrate of both compression standards for "Beauty" test sequence.

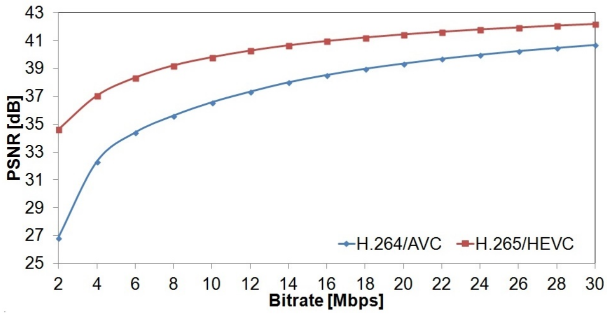

Fig. 11: The relationship between video quality (PSNR) and bitrate of both compression standards for "Bosphorus" test sequence.

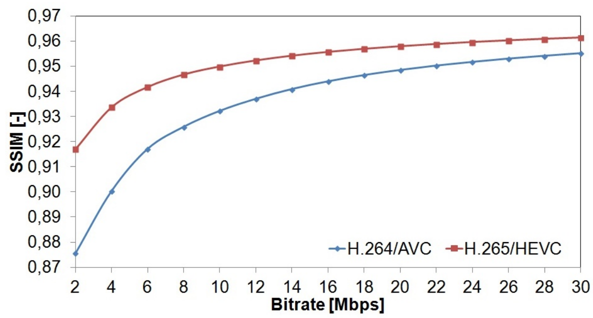

Fig. 12: The relationship between video quality (SSIM) and bitrate of both compression standards for "Bosphorus" test sequence.

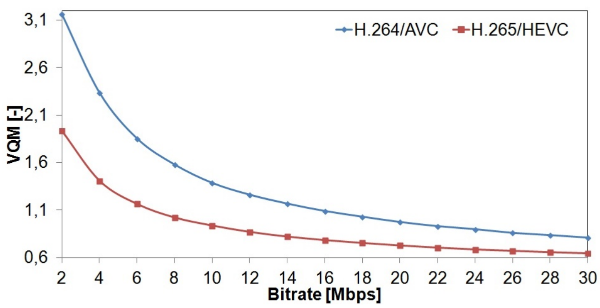

Fig. 13: The relationship between video quality (VQM) and bitrate of both compression standards for "Bosphorus" test sequence.

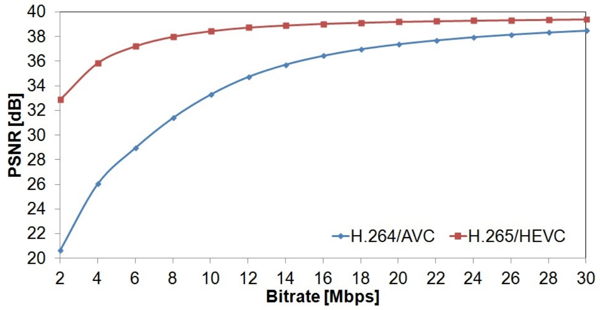

Fig. 14: The relationship between video quality (PSNR) and bitrate of both compression standards for "Jockey" test sequence.

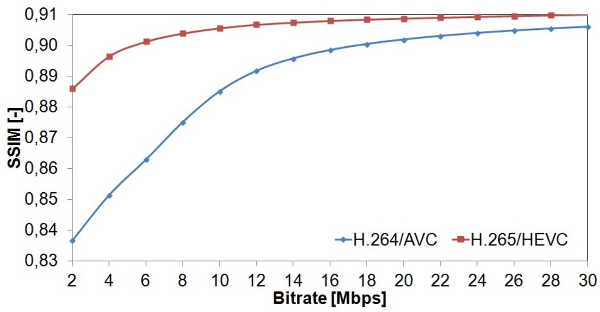

Fig. 15: The relationship between video quality (SSIM) and bitrate of both compression standards for "Jockey" test sequence.

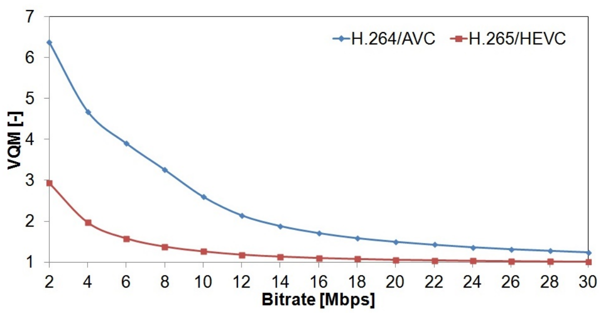

Fig. 16: The relationship between video quality (VQM) and bitrate of both compression standards for "Jockey" test sequence.

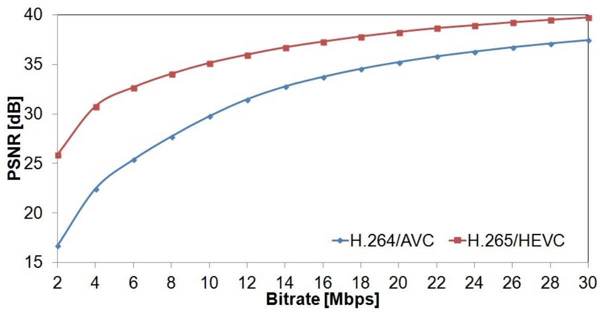

Fig. 17: The relationship between video quality (PSNR) and bitrate of both compression standards for "ReadySteadyGo" test sequence.

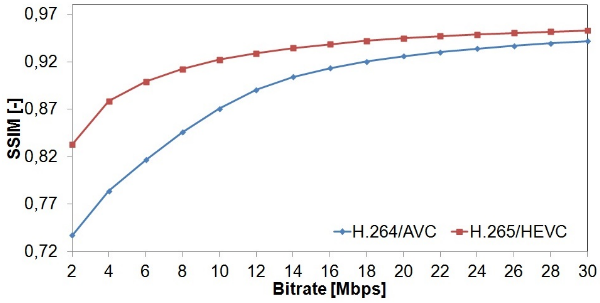

Fig. 18: The relationship between video quality (SSIM) and bitrate of both compression standards for "ReadySteadyGo" test sequence

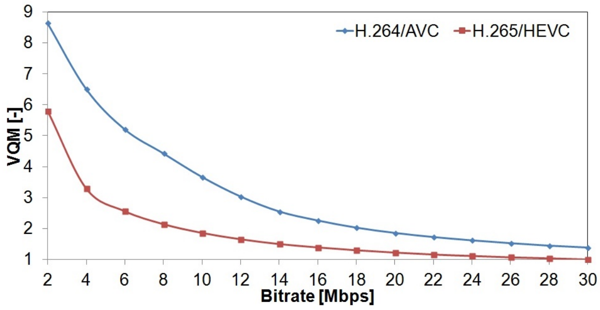

Fig. 19: The relationship between video quality (VQM) and bitrate of both compression standards for "ReadySteadyGo" test sequence

the H.265/HEVC standard. The effectiveness of compression depends on the type of sequence. Figure 20, Fig. 21, Fig. 22 and Fig. 23 show compression efficiency of both compression standards for various test sequences.

As it can be seen from the graphs, the compression efficiency depends on the types of test sequences. In consideration of measurements results we can say that:

- in sequences where is a slightly movement of one object on a static background as by "Bosphorus" sequence (Zoomed in luxury yacht, huge bridge on background. Panning right), not only best quality is achieved but also settled, there is no big difference between quality by low and high bitrates,
- in sequences where is a quick movement of more objects on a static background as by "ReadySteadyGo" sequence (Horse racing track, riders getting ready for launch. The gates open and horses are running to the left), only in higher bitrates very good quality is reached (not settled), there is a difference between quality by low and high bitrates,
- in sequences where is a quick movement of one object on a static background as by "Jockey" sequence (Horse racing with camera panning to the left to follow), very good quality is achieved and

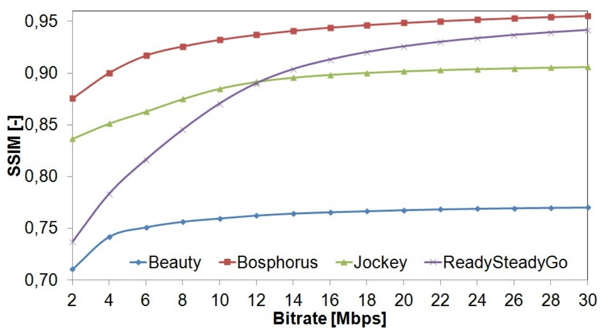

Fig. 20: The relationship between video quality (SSIM) and bitrate of all test sequences for H.264/HEVC compression standard.

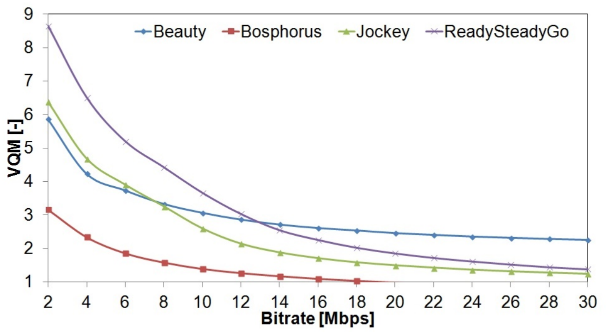

Fig. 21: The relationship between video quality (VQM) and bitrate of all test sequences for H.264/HEVC compression standard.

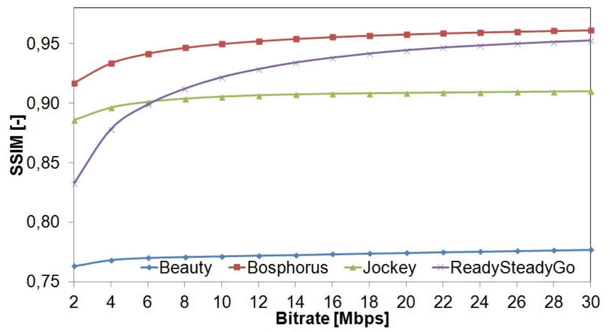

Fig. 22: The relationship between video quality (SSIM) and bitrate of all test sequences for H.265/HEVC compression standard.

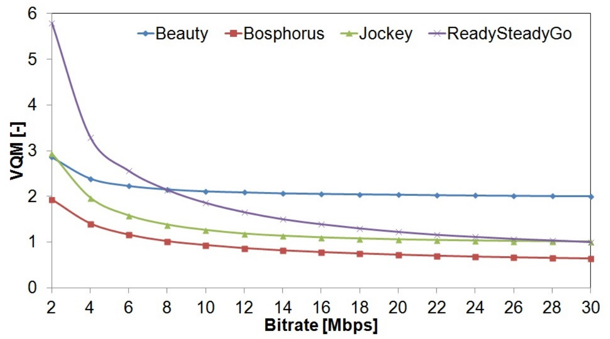

Fig. 23: The relationship between video quality (VQM) and bitrate of all test sequences for H.265/HEVC compression standard.

also settled, there is no big difference between quality by low and high bitrates,

- in sequences which are almost static as by "Beauty" sequence, where are only a few movements of female face (Closeup on female face, hair waving around. Black background), not so good quality is reached but settled, there is no big difference between quality by low and high bitrates.

5. Conclusion

In this article the impact of H.264/AVC and H.265/HEVC compression standards on the video quality for 4K resolution was tested. First a short characteristic of both compression standards was written, then the well-known objective metrics for evaluation of video quality were described and finally the measurements with experimental results were done and evaluated. Two types of experiments were done, the compression efficiency of both standards and the impact of the type of sequence on the video quality. According to the results, the H.265/HEVC compression standard yield better compression efficiency than H.264/AVC compression standard. The bigger difference in quality between these two compression standards is in lower bitrates with increasing bitrate the quality of H.264/AVC standard approaches the H.265/HEVC standard. It can be also stated that the effectiveness of compression depends on the type of sequence.

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