IMPACT OF COMPRESSION ON THE VIDEO QUALITY

Miroslav UHRINA[1], *Jan HLUBIK*[1], *Martin VACULIK*[1]

[1]Department Department of Telecommunications and Multimedia, Faculty of Electrical Engineering, University of Zilina, Univerzitna 8215/1, 010 26 Zilina, Slovak

miroslav.uhrina@fel.uniza.sk, jan.hlubik@fel.uniza.sk, martin.vaculik@fel.uniza.sk

Abstract. *This article deals with the impact of compression on the video quality. In the first part, a short characteristic of the most used MPEG compression standards is written. In the second part, the parameter Group of Picture (GOP) with particular I, P, B frames is explained. The third part focuses on the objective metrics which were used for evaluating the video quality. In the fourth part, the measurements and the experimental results are described.*

Keywords

MPEG, SSIM, Video quality, VQM.

1. Introduction

In recent 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 and most of them are based on the MPEG technology.

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. MPEG-2

MPEG-2 is still one of the most used compression standards. It was approved in 1994. MPEG-2 is the extension of MPEG-1 and the video coding scheme is a refinement of MPEG-1 standard. The advantage of the MPEG-2 standard is that it is suitable for coding both progressive and interlaced video. Furthermore, a lot of new functionalities such as scalability were established. MPEG-2 also introduces the profiles and levels.

Profiles and levels specify conformance points that provide interoperability between encoder and decoder implementations within applications of the standard and between various applications that have similar functional requirements. A profile is defined as a specific subset of the entire bitstream syntax and functionality that supports a class of applications (e.g., low delay video conferencing applications, or storage media applications). Within each profile, several levels are defined to support applications which have different quality requirements (e.g., different resolutions). Levels are specified as a set of restrictions on some of the parameters (or their combination) such as the sampling rates, picture sizes, resolutions and bitrates in a profile. Both profiles and levels have a hierarchical relationship, and the syntax supported by a higher profile or level must also support all the syntactical elements of the lower profiles or levels.

The most important application of the MPEG-2 standard is TV broadcasting (DVB-T, DVB-S, DVB-C), but it is used also for storage of the movies on DVD and other similar disks [2], [3], [4], [5], [6], [7], [8].

2.2. MPEG-4 Part 2 (Visual)

MPEG-4 Part 2 (Visual) is the combination of standard coding and object coding. It was approved in 1998 and improves on the popular MPEG-2 standard both in terms of compression efficiency and flexibility. It achieves this in two main ways, by making use of more advanced compression algorithms and by providing an extensive set of "tools" for coding digital media. Some of the key features that distinguish MPEG-4 Visual from previous coding standards include:

- efficient compression of progressive and interlaced video sequences,
- coding of video objects (irregular-shaped regions of a video scene),
- support for effective transmission over networks,
- coding of still "texture" (image data),
- coding of animated visual objects such as 2D and 3D polygonal meshes, animated faces and animated human bodies,
- coding for specialized applications such as "studio" quality video.

This standard defines many profiles and levels, but the vast majority of them are not used by commercial applications [3], [9].

2.3. MPEG-4 Part 10 (H.264/AVC)

The latest and currently most used compression standard designed for a wide range of applications, ranging from video for mobile phones through web applications to TV broadcasting (HDTV) is MPEG Part 10 (H.264/AVC). Some of the feature enhancements in MPEG-4 Part 10 (H.264/AVC) standard over the earlier codecs are:

- DCT algorithm works at 4x4 pixels instead of 8x8 but also supports 8x8,
- DCT is layered using Hadamard transforms,
- colour sampling 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.

MPEG-4 Part 10 (H.264/AVC) also defines the profiles and levels but its organization is much simpler than in MPEG-4 Part 2. There are only three profiles currently defined (Baseline, Main, Extended), [2], [5], [10], [11].

3. Group of Pictures (GOP)

Very important factor that also influences the video quality is the frame type. There are three defined types of frames – I, P, B.

I (intra) frames are coded without reference to other frames (without any motion-compensated prediction), in a very similar manner to JPEG, which means that they contain all the information necessary for their reconstruction by the decoder. For this reason, they are the essential entry point for access to a video sequence. An I frame is used as a reference for further predicted frames (P and B). The compression rate of I frames is relatively low.

P (predicted) frames are inter-coded using motion-compensated prediction from a reference frame (the P frame or I frame preceding the current P frame). Hence a P frame is predicted using forward prediction and a P frame may itself be used as a reference for further predicted frames (P and B frames). The compression rate of P frames is significantly higher than of I frames.

B frames are inter-coded using motion-compensated prediction from two reference frames, the P and/or I frames before and after the current B frame. Two motion vectors are generated for each macroblock in a B frame – one pointing to a matching area in the previous reference picture (a forward vector) and one pointing to a matching area in the future reference picture (a backward vector). A motion-compensated prediction macroblock can be formed in three ways – forward prediction using forward vector, backwards prediction using backward vector or bidirectional prediction (where the prediction reference is formed by averaging forward and backward prediction references). Typically, an encoder chooses the prediction mode (forward, backward or bidirectional) that gives the lowest energy into the difference macroblock. B frames offer the highest compression rate.

All these different frame types (I, P, B) are then grouped together to a sequence (specific repeating order) – called the Group of Pictures (GOP). A GOP must always start with an I frame and can contain only I or combination of I and P or I, P, B frames. The use and also number of B or P frames within a GOP can be increased or decreased depending on image content, compression rate or application that the compressed video is intended for. Two parameters – M and N describe the succession of I, P and B frames. M is the distance (in number of frames) between two successive P frames and N is the distance between two successive I frames, which means GOP. Various GOP lengths and combinations of P and B frames can be encoded, but mostly a typical GOP pattern is used – IBBPBBPBBPBBI – where each letter represents viewing order and type of the frame. This pattern can be expressed with N and M parameters as N = 12 and M = 3, [9], [10], [12], [13].

4. Objective Assessment

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" which 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).

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

The PSNR in decibels is defined as:

$$PSNR = 10\log\frac{m^2}{MSE}[dB], \quad (1)$$

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 $\tilde{I}$:

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

for pictures of size X, Y and T frames. Technically, MSE measures image difference, whereas PSNR measures image fidelity. The biggest advantage of the PSNR metric is that can be computed easily and fast [2].

4.2. 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).

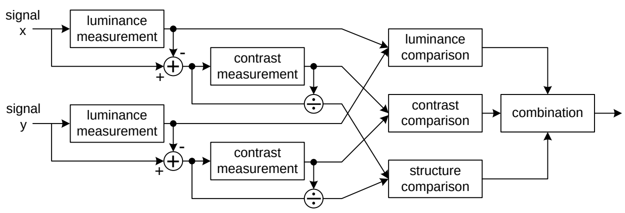

Fig. 1: The block diagram of SSIM metric.

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

4.3. 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.

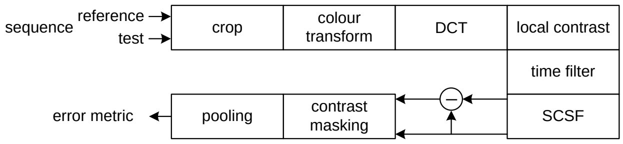

Fig. 2: The block diagram of VQM metric.

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 by 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 [15]. 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.

5. Measurements

The measurements can be divided into two sections:

- the measurements of the impact of bitrate on the video quality,
- the measurements of the impact of GOP parameter on the video quality.

5.1. The Impact of Bitrate on the Video Quality

In these experiments, two test sequences were used – one with dynamic scene (the "Football" sequence – Fig. 3) and one with slow motion (called the "Train" sequence – Fig. 4). Both sequences were in the resolution of 720×576 px with 25 fps (frames per second). The length of these sequences was 220 frames, i.e. 8,8 seconds. The measurement procedure consists of four steps:

- first, both sequences were downloaded from [16] in the uncompressed format (*.yuv) and used as the reference sequences,
- afterwards, they were encoded to different MPEG compression standards (MPEG-2, MPEG-4 AVS, MPEG-4 H.264/AVC) using the tools FFmpeg [17] or x264 [18]. The target bitrates were in the range from 2 Mbps to 10 Mbps, changed in 1 Mbps step. The parameters of the encoded sequences were set to Main Profile, Level 3. 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,
- then, the sequences were decoded using the same tool FFmpeg [17] or x264 [18] 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 version 2.7.3 [19]. SSIM and VQM objective metrics were used.

Fig. 3: The "Football" sequence.

Fig. 4: The "Train" sequence.

The whole process of measuring of both sequences is shown in the Fig. 5.

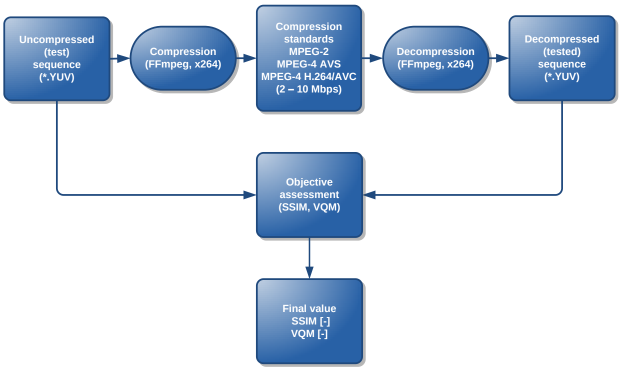

Fig. 5: The process of measuring of the impact of the bitrate on the video quality.

The figures from 6 to 13 show the measurements results of the impact of bitrate on the video quality.

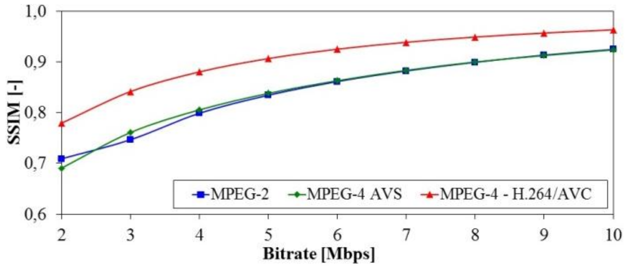

Fig. 6: The relationship between the video quality measured with SSIM metric and bitrate for MPEG-2, MPEG-4 AVS, MPEG-4 H.264/AVC compression standards ("GOP 12 – BF 2") for "Football" test sequence.

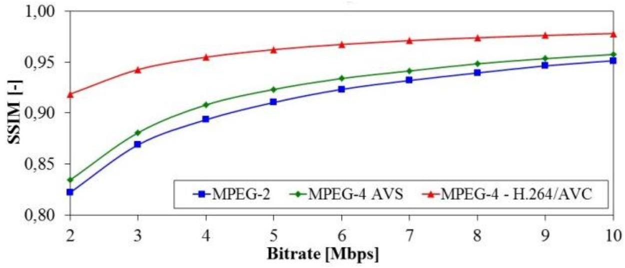

Fig. 7: The relationship between the video quality measured with SSIM metric and bitrate for MPEG-2, MPEG-4 AVS, MPEG-4 H.264/AVC compression standards ("GOP 12 – BF 2") for "Train" test sequence.

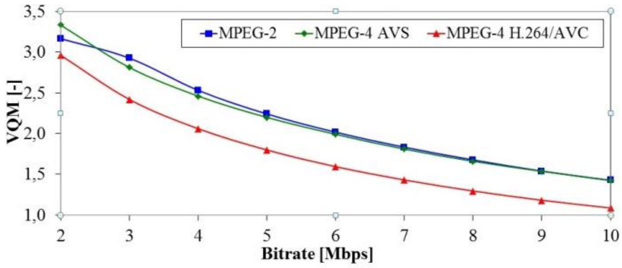

Fig. 8: The relationship between the video quality measured with VQM metric and bitrate for MPEG-2, MPEG-4 AVS, MPEG-4 H.264/AVC compression standards ("GOP 12 – BF 2") for "Football" test sequence.

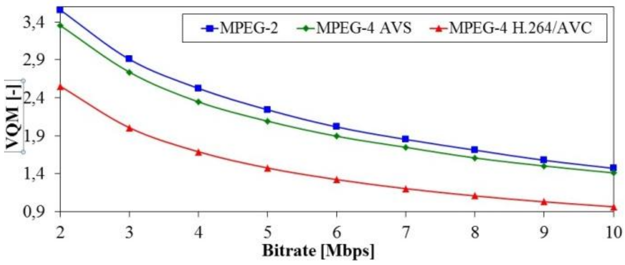

Fig. 9: The relationship between the video quality measured with VQM metric and bitrate for MPEG-2, MPEG-4 AVS, MPEG-4 H.264/AVC compression standards ("GOP 12 – BF 2") for "Train" test sequence.

As it can be seen from the graphs, in both test sequences measured with both metrics the MPEG-4 H.264/MPEG-4 compression standard can be considered as the best one. This confirms the fact that H.264/AVC uses the best compression algorithms. The quality of the MPEG-2 compression standard is similar to MPEG-4 AVS compression standard. From previous measurements the graphs that show the impact of the content on the video quality could be plotted.

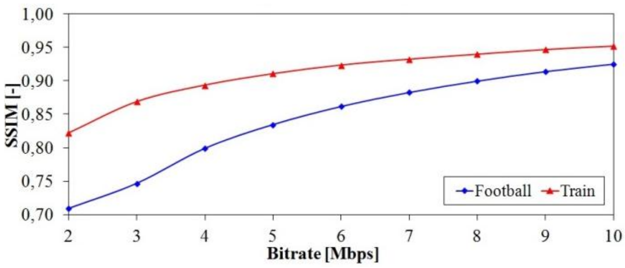

Fig. 10: The relationship between the video quality measured with SSIM metric and bitrate for both test sequences for MPEG-2 compression standard ("GOP 12 – BF 2").

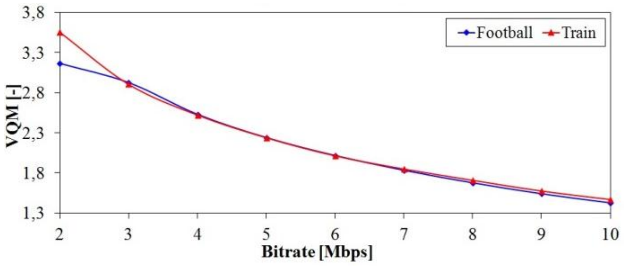

Fig. 11: The relationship between the video quality measured with VQM metric and bitrate for both test sequences for MPEG-2 compression standard ("GOP 12 – BF 2").

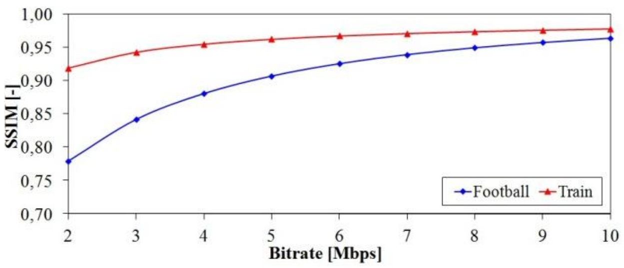

Fig. 12: The relationship between the video quality measured with SSIM metric and bitrate for both test sequences for MPEG-4 H.264/AVC compression standard ("GOP 12 – BF 2").

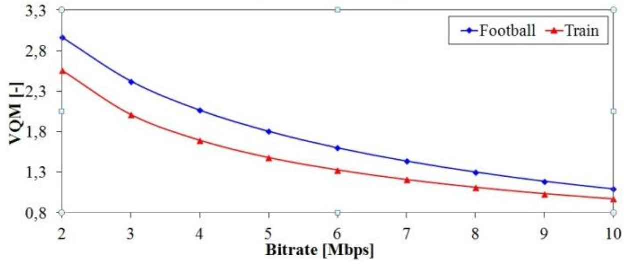

Fig. 13: The relationship between the video quality measured with VQM metric and bitrate for both test sequences for MPEG-4 H.264/AVC compression standard ("GOP 12 – BF 2").

According to the graphs the slow "Train" sequence reached after compression better quality as the dynamic "Football" sequence. This difference is bigger in sequences with lower bitrate.

Since P and B frames carry information about motion-compensated prediction in a sequence, for dynamic sequence it is necessary to encode more information (data) in these frames than in P and B frames for sequences with a slow motion. Thus after bitrate constraint (e.g. 3 Mbps) in I frames (which carry necessary information about picture) for dynamic sequence is encoded less information (data) than in I frames for sequences with slow motion. That results in lower video quality. These arguments confirm the pictures 14 and 15 that show the frames succession of both types sequences of MPEG-4 H.264/AVC ("GOP 12 – BF 2") compression standard encoded to 3 Mbps. The height of the columns show the picture size, the colours show the types of frames (red – I; blue – P; green - B).

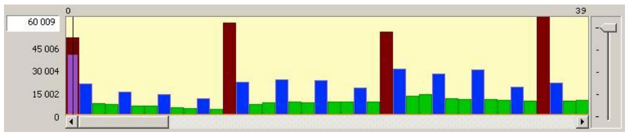

Fig. 14: The frames succession of MPEG-4 H.264/AVC ("GOP 12 – BF 2") compression standard encoded to 3 Mbps by "Football" sequence.

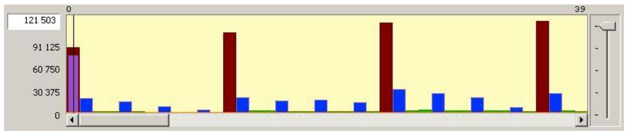

Fig. 15: The frames succession of MPEG-4 H.264/AVC ("GOP 12 – BF 2") compression standard encoded to 3 Mbps by "Train" sequence.

5.2. The Impact of GOP Parameter on the Video Quality

The testing procedure was the same as in the previous chapter, only the second step was changed: the uncompressed sequences were encoded to MPEG-4 H.264/AVC compression standard using the tool x264 [18]. The parameters of the encoded sequences were set to Main Profile, Level 3. The target bitrates were in the range from 2 Mbps to 10 Mbps, changed in 1 Mbps step.

Five different GOP sizes and two different B frames numbers were encoded and tested:

- all frames within the sequence were encoded as the I frames (called “only I”); N = 220, M = 0,
- the size of the GOP was set to 6 and two B frames between each P or I frame within a GOP were stored – called “GOP 06 – BF 2”; N = 6, M = 3,
- the size of the GOP was set to 12 and two B frames between each P or I frame within a GOP were stored – called “GOP 12 – BF 2”; N = 12, M = 3,
- the size of the GOP was set to 24 and two B frames between each P or I frame within a GOP were stored – called “GOP 24 – BF 2”; N = 24, M = 3,
- the size of the GOP was set to 48 and two B frames between each P or I frame within a GOP were stored – called “GOP 48 – BF 2” N = 48, M = 3,
- the size of the GOP was set to 12 and 6 B frames between each P or I frame within a GOP were stored – called “GOP 12 – BF 6”; N = 12, M = 7,
- the size of the GOP was set to 12 and 10 B frames between each P or I frame within a GOP were stored – called “GOP 12 – BF 10”; N = 12, M = 11.

The whole process of the video quality measuring of both sequences is shown in the Fig. 16.

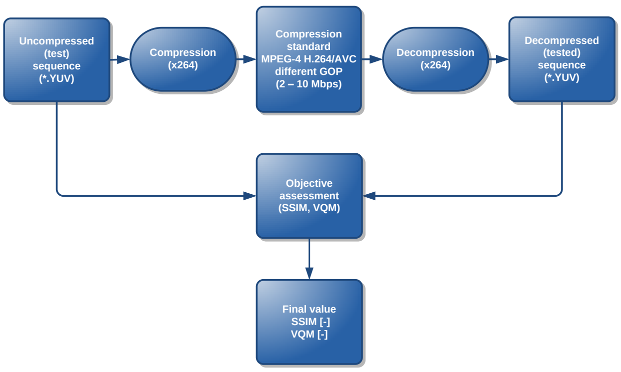

Fig. 16: The process of measuring of the impact of the GOP parameter on the video quality.

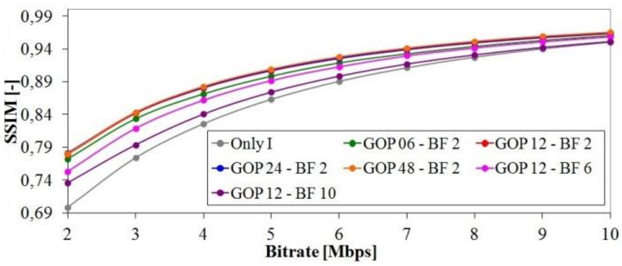

Fig. 17: The relationship between the video quality measured with SSIM metric and bitrate for MPEG-4 H.264/AVC compression standard with different GOP parameter for “Football” test sequence.

The figures from 17 to 20 show the measurements´ results of the impact of GOP parameter on the video quality.

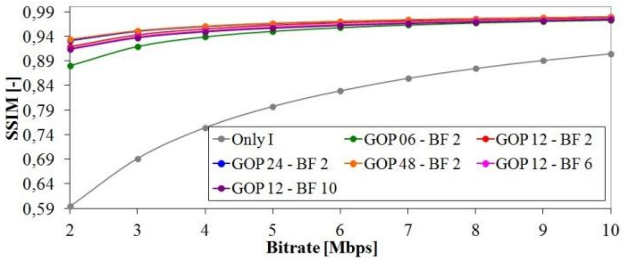

Fig. 18: The relationship between the video quality measured with SSIM metric and bitrate for MPEG-4 H.264/AVC compression standard with different GOP parameter for “Train” test sequence.

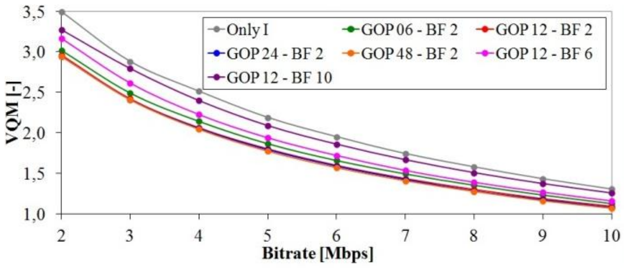

Fig. 19: The relationship between the video quality measured with VQM metric and bitrate for MPEG-4 H.264/AVC compression standard with different GOP parameter for “Football” test sequence.

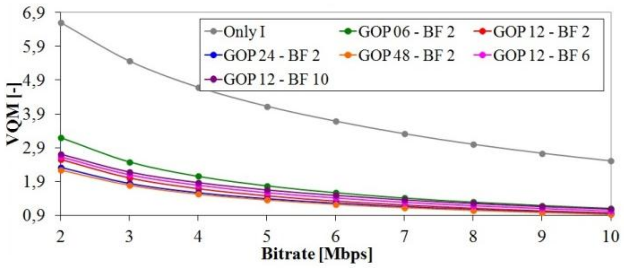

Fig. 20: The relationship between the video quality measured with VQM metric and bitrate for MPEG-4 H.264/AVC compression standard with different GOP parameter for “Train” test sequence.

According to the graphs it can be seen that the “Only I” sequence - where all frames within a GOP were encoded as the I frames – reached worse quality than other sequences. This difference is bigger in the sequence with slow motion – the “Train” sequence and also in the sequence with lower bitrate.

Since the “Only I” sequence is encoded as a succession of only I frames (that carry necessary information about the picture), the whole bitrate is almost evenly divided into all I frames. For encoding other sequences which contain also P, respectively B frames (that carry information about motion-compensated prediction) is necessary to use less information. Thus after bitrate restriction (e.g. 3 Mbps) in the sequences with P and B frames is the ability to encode more information into I frames than in sequence which contain only I frames. That results to higher video quality. These arguments confirm the pictures 21 and 22 that show the frames succession of “Football” sequence of MPEG-4 H.264/AVC compression standard encoded to 3 Mbps with different GOP parameters. The height of the columns show the picture size, the colours show the types of frames (red – I; blue – P; green - B).

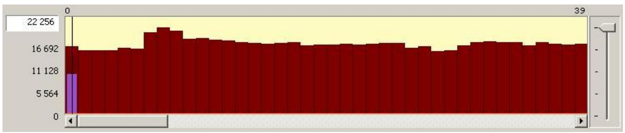

Fig. 21: The frames succession of MPEG-4 H.264/AVC compression standard with only I frames encoded to 3 Mbps by “Football” sequence.

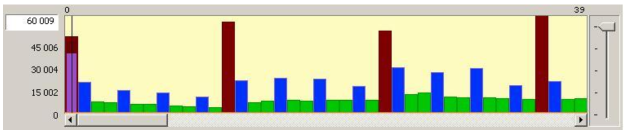

Fig. 22: The frames succession of MPEG-4 H.264/AVC compression standard with GOP parameter “GOP 12 – BF 2” encoded to 3 Mbps by “Football” sequence.

6. Conclusion

This article dealt with the impact of compression on the video quality. First a short characteristic of the most used MPEG compression standards was written. Then the parameter Group of Picture (GOP) with particular I, P, B frames was explained. Next chapter focused on the objective metrics which were used for evaluating the video quality. Finally, the measurements and the experimental results were described. The measurements were divided into two sections - first the impact of bitrate and then the impact of GOP parameter on the video quality were tested.

From the first measurements, the MPEG-4 H.264/MPEG-4 compression standard could be considered as the best one. This confirms the fact that H.264/AVC uses the best compression algorithms. The quality of the MPEG-2 compression standard was similar to MPEG-4 AVS compression standard. From these measurements the impact of the content on the video quality was plotted. The graphs showed that the slow “Train” sequence reached after compression better quality as the dynamic “Football” sequence. This difference was bigger in sequences with lower bitrate. From the second measurements could be seen that the “Only I” sequence - where all frames within a GOP were encoded as the I frames – reached worse quality than other sequences. This difference was bigger in the sequence with slow motion – the “Train” sequence and also in the sequence with lower bitrate.

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About Authors

Miroslav UHRINA was born in 1984 in Zilina, Slovakia. He received his M.Sc. and Ph.D. degrees in Telecommunications at the Department of Telecommunications and Multimedia, Faculty of Electrical Engineering at the University of Zilina in 2008 and 2012, respectively. Nowadays, he is an assistant lecturer at the Department of Telecommunications and Multimedia, at the University of Zilina His research interests include audio and video compression, TV broadcasting (IPTV, DVB-T, DVB-H) and IP networks.

Jan HLUBIK was born in 1982 in Humenne, Slovakia. He received his M.Sc. and Ph.D. degrees at the University of Zilina, Faculty of Electrical Engineering, Slovakia, in 2000 and 2008, respectively. Nowadays, he is an assistant lecturer at the Department of Telecommunications and Multimedia, University of Zilina. Areas of his research include video and audio compression, video streaming, 3D modeling and animation, augmented reality and multimedia technologies. From 2008 his research interests cover system, services, terminals of DVB-H technology and systems and services of intelligent transport.

Martin VACULIK was born in 1951. He received his MSc. and Ph.D. in Telecommunications at the University of Zilina, Slovakia in 1976 and 1987 respectively. In 2001 he was habilitated as associate professor of the Faculty of Electrical Engineering at the University of Zilina in the field of Telecommunications. Currently he works as a head of Department of Telecommunications and Multimedia University of Zilina. His interests cover switching and access networks, communication network architecture, audio and video applications.