

Rate Control Algorithm for High Quality Compression of Static Test Pattern Using Target Bit Allocation in Digital TV System

Soo-Wook Jang¹, Gwang-Soon Lee², Sung-Hak Lee¹, In-Ho Song¹, Chan-Ho Han¹, Eun-Su Kim³, and Kyu-Ik Sohng²

¹School of Electrical Engineering and Computer Science, Kyungpook National University,
1370 Sangyuk-Dong, Buk-Gu, Daegu 702-701, Korea.

²Electronics and Telecommunications Research Institute,
161 Gajeong-Dong Yuseong-Gu, Daejeon 305-350, Korea.

³Division of Electronic Engineering, Sunmoon University,
30 Tangjeong-Meun, Asan, Chungcheongnamdo, 336-708, Korea.

Tel. +82-53-940-8633. Fax. +82-53-940-8533

e-mail : jjang@ee.knu.ac.kr

Abstract: In this paper, we propose a new algorithm for generating a high quality test bit-stream to evaluate the static image quality of DTV receiver based on a target bit allocation in the process of rate control. In order to allocate the number of target bits, we consider the normalized complexities, which are updated or maintained according to GOP picture qualities. The proposed rate control method is suitable for compression of static test pattern while MPEG-2 Test Model 5 is suitable for moving picture. To evaluate the performance of proposed algorithm, the test bitstream are generated by an MPEG-2 software en-coder using the proposed algorithm. Experimental results show that average PSNR of the proposed method is higher than those of the conventional case. With experiment in DTV system, we have confirmed that the proposed algorithm has a stable bit rate and good video quality and it is suitable for evaluation of the DTV receiver.

1. Introduction

As the service using the digital TV (DTV) increases, how to measure a picture quality becomes the main issue in digital TV manufacturers. When an original image for a test has been encoded and decoded, there will be differences between the original and decoded images. So, generating the reference test stream to guarantee the high picture quality and stable bit rate is necessary for the test of DTV receiver [1]-[4]. Moreover, the test bitstream must satisfy MPEG-2 [5], DVB [6], and ATSC [7] standards.

The MPEG-2 Test Model 5 (TM5) [8] algorithm is widely used for bit rate control. In TM5, however, the target number of bits and the number of actual coding bits do not match well at static video compression, such as test patterns. To perform the high quality video compression for static test patterns such as color bar, pulse & bar, and multi-burst, we propose a method to generate test pattern in high quality by considering the partition of DCT block. Specially, we propose a new target bit allocation method using normalized complexities in the process of rate control, which are updated or maintained by means of GOP picture qualities. The proposed method is using the fact that the generated bits and average quantization value have almost identical distribution per each GOP, and is suitable for compression

of the static test pattern while the target bit allocation method in MPEG-2 TM5 is suitable for moving picture.

To evaluate the proposed algorithm, we generate the test bitstream about three static test patterns by using the proposed algorithm and TM 5 respectively. Experimental results showed that average PSNR of the proposed method is higher than those of the conventional case. And we have tested the generated test stream in experimental DTV broadcasting system, and confirmed that the proposed algorithm has a stable bit rate and good video quality.

2. Rate Control Algorithm of MPEG-2 TM5

The amount of bits being generated in MPEG-2 can be controlled by complexity of images and by some setting variables of an encoder. Therefore, the encoder can controls the amount of bits after estimating bits generation with a virtual buffer. The MPEG-2 TM5 (test model 5) rate control scheme comprises of three steps, target bits allocation, bit rate control and adaptive quantization [8],[9].

After encoding each picture, a global complexity measure, X_i , X_p , or X_b is updated as follows.

$$X_{[i,p,b]} = S_{[i,p,b]} \times Q_{[i,p,b]} \quad (1)$$

where S_i , S_p , and S_b are the number of bits generated by encoding a picture type I, P, and B respectively, and Q_i , Q_p , and Q_b are their average quantization parameters over all the macroblocks in the picture. A target number of bits, T_i , T_p , or T_b is then assigned for the next picture of the same type in the GOP as follows.

$$T_i = \max \left\{ \frac{R}{1 + \frac{N_p X_p}{X_i K_p} + \frac{N_b X_b}{X_i K_b}}, \frac{bit_rate}{8 \times picture_rate} \right\} \quad (2)$$

$$T_p = \max \left\{ \frac{R}{N_p + \frac{N_b K_p X_b}{K_b X_p} + \frac{N_b X_b}{X_i K_b}}, \frac{bit_rate}{8 \times picture_rate} \right\} \quad (3)$$

$$T_p = \max \left\{ \frac{R}{N_b + \frac{N_p K_p X_p}{K_p X_b} + \frac{N_b X_b}{X_i K_b}}, \frac{bit_rate}{8 \times picture_rate} \right\} \quad (4)$$

where K_p and K_b are constant parameters, R is the remaining number of bits assigned to the current GOP, N_p and N_b are the number of P and B pictures remaining in the current GOP, respectively. bit_rate is the rate at which the coded bitstream is delivered from encoder to decoder, and $picture_rate$ is the frame rate at which pictures are reconstructed from the decoding process.

In the process of the bit rate control, reference quantization variables are computed for each macroblock based on the status of virtual buffer fullness. Finally, the adaptive quantization makes the buffer status be even by controlling the quantization steps of the pictures being encoded, based on both the current buffer status and spatial divergence.

3. Generation of Test Pattern in High Quality

As a quantization process in encoder is lossless transform, the image compression using this technique brings the quantization error inevitably. This quantization error results in degrading image quality, so that a special method to reduce it is necessary to implement video test pattern in high quality for DTV system. In order to reduce the quantization error, the coefficients generated by DCT transform should be minimized and grouped at the low frequency area of DCT block. In case of generating a static test pattern for DTV, what we should consider is that patches on test image are made by 8×8 block which is quantization process unit. It means that patches on the test image are divided at the boundary of blocks as possible as it can. Moreover, one more thing we have to take into account is a block size at color images. Macroblock (MB) in color image can be comprised at the format of 4:4:4, 4:2:2 or 4:2:0 according to the rate of between luminance and chrominance signal, where 4:2:0 format is widely used in case of DTV broadcasting. So, in order to consider 8×8 block size at even chrominance images, Cb, Cr of 4:2:0 format, the patches on the test image should be made by 16×16 MB unit as much as possible.

We performed the computer simulation as shown in Fig. 1 to investigate the amount of bit generation according to patch's position on an image of one MB. Test MBs for this simulation is as shown in Fig. 2, where MB (a) is luminance level 128 and chrominance level 64, MB (b) is composed of a patch that is 8×8 block size and its luminance level 255, (c) and (d) are MB whose patch moves to the right. As a result, in case any border of patch is not included in the MB as shown in (a), quantization coefficients are generated to the least. On the other hand, in case the patch is included in the MB, quantization coefficients are generated more and more. Further, the more quantization coefficients are

generated, the more quantization error which lead to degrade image quality, so that the compression ratio is decreased.

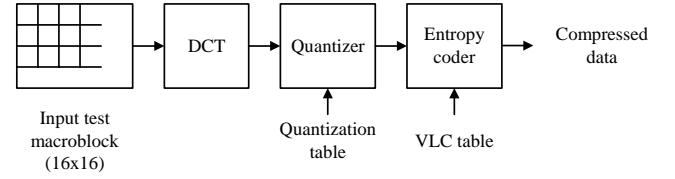


Figure 1. Block diagram for measuring the generated bit at each MB patterns.

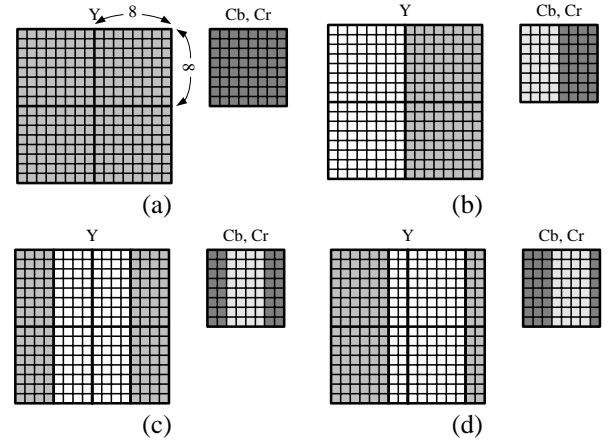


Figure 2. MB patterns with variation of the patch position: (a) Patch 0, (b) Patch 1, (c) Patch 2 and (d) Patch 3.

The amount of bits generated at this simulation is shown in Table 1. From the result of this table, we can see that the amount of bit generation is the smallest in case there are no borders of patches in MB as shown in Fig. 2 (a), being the secondary smallest in case of patches having border of 8×8 blocks as shown in Fig. 2(b).

Table 1. Generated bits of MB patterns with variation of the patch position.

	Patch 0	Patch 1	Patch 2	Patch 3
Generated Bits	34	148	272	453

4. Proposed Rate Control Algorithm for static images

In this paper, we propose new algorithm for target bit allocation during rate control to encode the static test images in high quality at MPEG-2 vide encoder. We could see that target bits in MPEG-2 TM 5 are allocated variably according to each I, P and B pictures in order to be suitable for compression of the moving picture, as shown in equation (2), (3), (4). On the other hand, our method for target bit allocation is suitable for static images like test images that can be used for the DTV receiver.

When the images composed of little moving objects, like static test patterns, are encoded, the generated bits and average quantization variables are almost identical per each GOPs. In this condition, it is reasonable to allocate the target bits by GOP unit because information used at the previous GOP can be reference to the complexity estimation of the current GOP. Therefore, we propose the algorithm to maintain the optimum picture quality by checking the picture quality per GOP, as shown in Fig. 3. The rate control at initial GOP of image sequences is performed by the same way as the TM 5. The proposed algorithm at first calculates an average picture quality per GOP, if it is bigger than the maximum picture quality that is also updated per each GOP, then distribution of bit allocation in GOP are updated, or it is maintained as previous one.

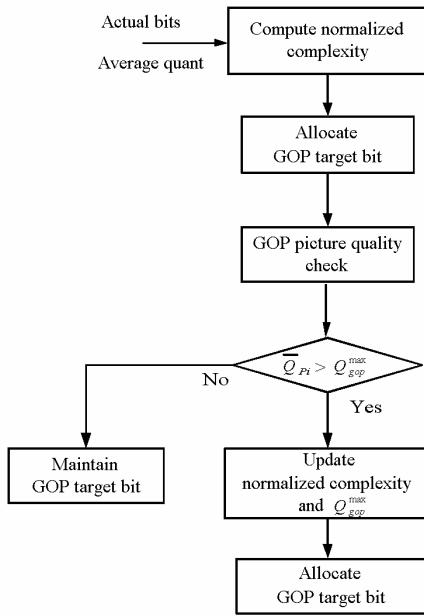


Figure 3. The proposed algorithm for allocating the target bits suitable for encoding of static image.

4.1 Target bit allocation by GOP unit

In our algorithm, the initial values for bit allocation are same with TM 5. From the second GOP, in order to use the normalized complexity of previous GOP and to estimate that of current GOP, we define the normalized complexity of i -th GOP, $X_i^{norm}(k)$, as

$$X_i^{norm}(k) = \frac{\alpha(k) \cdot X_i(k)}{X_{total}} \quad \text{for } k = 0, 1, 2, \dots, N-1 \quad (5)$$

where $X_{total} = \sum_{k=0}^{N-1} \alpha(k) X_i(k)$, and $X_i(k) = S_i(k) \times Q_i(k)$.

$X_i(k)$ is k -th picture complexity of i -th GOP, and $\alpha(k)$ is the ratio coefficient of picture type, I, P, and B.

Therefore, the ratio of target number of bits, T_I , T_P , and T_B can be expressed as

$$T_I : T_P : T_B = X_I^{norm} : X_P^{norm} : X_B^{norm} \quad (6)$$

Finally, the number target of bits k -th picture of i -th GOP $T_i(k)$ is decided as

$$T_i(k) = X_i^{norm}(k) \times B_i^{total} \quad \text{for } k = 0, 1, 2, \dots, N-1 \quad (7)$$

where $B_i^{total} = R_{i-1} + N \times B_{pic}$, and $B_{pic} = \frac{R_{bit}}{R_{pic}}$. R_{i-1} is remaining bits of previous GOP, and B_{pic} is uniformly allocated bits per each picture. Consequently, the number of target bits, $T_i(k)$, is rationally allocated by means of normalized complexities, $X_i^{norm}(k)$. Besides the number of target bits, $T_i(k)$, is updated or maintained by means of GOP picture qualities.

4.2 Update of target bits by GOP unit

In the proposed algorithm, in order to obtain the maximum image quality, we update or maintain the normalized complexities and the number of target bits for each GOP. The relationship between the GOP and proposed normalized complexity is shown in Fig. 4. In this paper, the target bits being calculated by equation (7) is updated or maintained according to average picture quality of GOP. At first, average picture quality of the present GOP, \bar{Q}_{Pi} , is calculated as

$$\bar{Q}_{Pi} = \frac{1}{N} \sum_{k=0}^{N-1} Q_{Pi}(k) \quad (8)$$

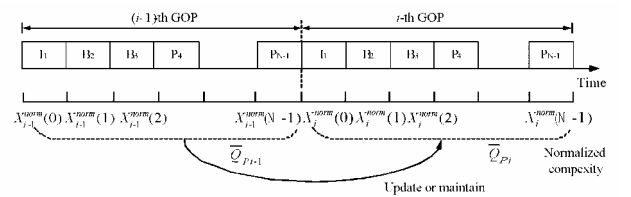


Figure 4. Relationship between the GOP and proposed normalized complexity.

where $Q_{Pi}(k)$ is picture quality of k -th picture in i -th GOP. Then, \bar{Q}_{Pi} is compared with Q_{GOP}^{max} which is maximum average picture quality up to the previous GOP.

If \bar{Q}_{Pi} is larger than Q_{GOP}^{max} , then normalized complexity at the present GOP and the target bits using this are updated, or else the target bits at each picture inside GOP are maintained. As a result, the proposed algorithm makes sure the best picture quality by continuously updating the normalized complexity and target bits so that the average picture quality per GOP, \bar{Q}_{Pi} , can be the maximum.

5. Experiments and Results

To evaluate the performance of proposed algorithm, the test bitstream are generated by an MPEG-2 software encoder using either the proposed algorithm or MPEG-2 TM5 with three test patterns, multiburst, crosshatch, and KNU composite test pattern which is modified TCM test image [11], as shown in Fig. 5.

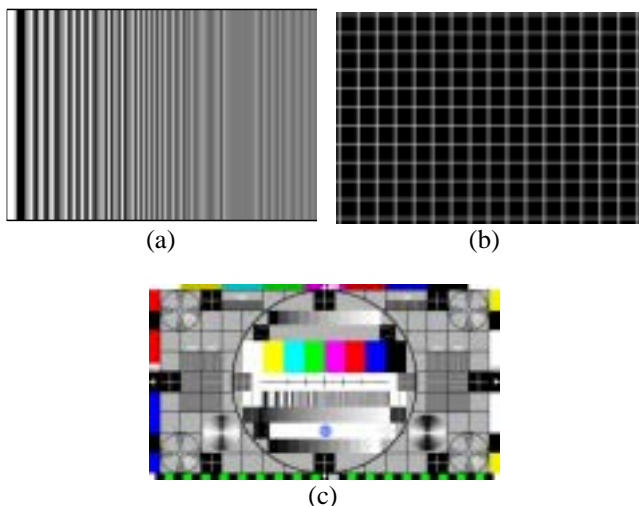


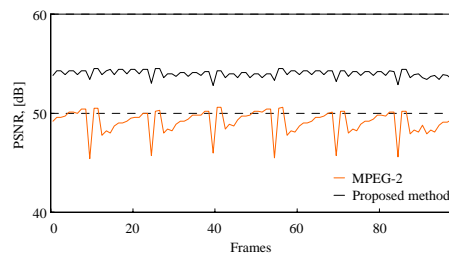
Figure 5. (a) Multiburst (1280x720), (b) crosshatch (1920x1080), and (c) KNU composite test pattern (1920x1080).

The KNU composite test pattern is designed to be suitable by us for evaluating the static picture quality in DTV. The borders of patterns on these test images are aligned by 16 pixel macroblock or 8 pixel units to be encoded effectively. Further, the overflow problem at VBV buffer, which may cause in encoding process of the static images, was resolved by using a zero stuffing method [6]. In order to use the proposed method, we set $\alpha(k)$ in equation (5) as 1, 0.4 and 0.4 for I, P and B pictures respectively. In case $\alpha(k)$ becomes lower, the quantization scale factor become the minimum value, so that picture quality was no longer enhanced.

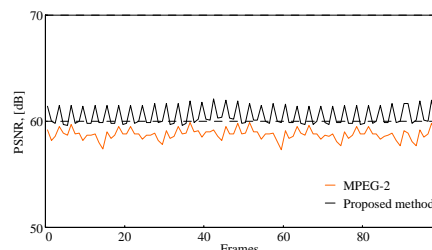
Table 2 shows their corresponding PSNR values of the three test streams. From this table, the PSNR of the proposed algorithm is about 3 to 5dB more efficient than that of MPEG-2 TM5 for luminance signal and about 1 to 2dB for chrominance signal. Fig. 6 shows variation of PSNR values at the luminance signal and chrominance signal when KNU composite video test pattern is encoded by 12 Mbps. From these figures, we can see the variation of picture quality become stable less than 1dB in case of luminance signal. Fig. 7 compares a part of the decoded KNU test images and we can confirm image enhancement at the proposed method as well.

Table 2. The average PSNR of conventional and proposed method for static test patterns.

Test images	Video rate [Mbps]	PSNR [dB]					
		Conventional			Proposed		
		Y	Cb	Cr	Y	Cb	Cr
Multiburst	4	49.9	INF	INF	52.2	INF	INF
Crosshatch	6	44.4	INF	INF	59.6	INF	INF
KNU Composite	8	37.7	52.0	52.3	40.1	54.3	54.4
KNU Composite	12	49.2	58.8	59.1	54.0	59.1	59.3

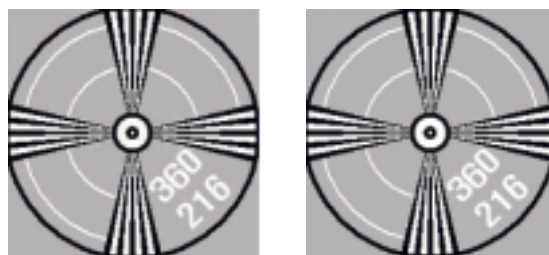


(a)



(b)

Figure 6. PSNR values of KNU composite video test pattern encoded by 12 Mbps: (a) Luminance signal and (b) chrominance signal.



(a)

(b)

Figure 7. Picture quality comparison of KNU composite video test pattern encoded by 12 Mbps; (a) MPEG-2 and (b) proposed method.

6. Conclusions

This paper proposed a new algorithm for generating a high quality test bitstream to evaluate the static image quality of DTV receiver based on the rate control improvement. To evaluate the performance of proposed algorithm, the test bitstreams were generated by the MPEG-2 software encoder using the proposed algorithm. We can see that the proposed algorithm is about 2 to 5dB more efficient than that of MPEG-2 TM5. The result showed that the proposed bitstream has a good picture quality and stable bit rate, making it suitable to evaluate the picture quality of DTV. The proposed test bitstreams are currently being used in LG Electronics DTV production without any problems.

References

- [1] A. N. Raul, "Automated Test System for Digital TV Receivers," *IEEE International Conference on Consumer Electronics*, Los Angeles, USA, pp. 13-15, June 2000.
- [2] C.-M. Kim, B.-U. Lee, and R.-H. Park "Design of MPEG-2 Video Test Bitstreams," *Consumer Electronics, IEEE Transactions on*, vol. 45, pp.1213-1220, Nov. 1999.
- [3] K. D. McCann, "Testing and Conformance Checking in the Digital Television Environment," *IEE International Broadcasting Convention*, vol. 428, pp. 331-336, Sep. 1996.
- [4] P. Kavanagh, "Patterns for all Format," *IEE International Broadcasting Convention*, no. 414, pp. 63-69, Sep. 1995.
- [5] ISO/IEC JTC1, *Information technology - Generic coding of moving pictures and associated audio information, Part 2: Video International Standard (IS)*, ISO/IEC 13818-2, March 1996.
- [6] DVB, *Digital Broadcasting Systems for Television, Sound and Data Service; Specification for Service Information in Digital Video Broadcasting (DVB) systems*, ETSI 300 468, 1996.
- [7] ATSC, *ATSC Digital Television Standard, Rev. B*, ATSC Standard A/53B with Amendment 1, Aug. 2001.
- [8] ISO/IEC JTC1/SC29/WG11, *Test Model 5*, Draft, April 1993.
- [9] J. W. Lee and Y. S. Ho, "Target bit matching for MPEG-2 video rate control," *IEEE Region 10 International Conference on Global Connectivity in Energy, Computer, Communication and Control*, vol. 1, pp. 66-69, Sep. 1998.
- [10] Snell & Wilcox Internet Site: <http://www.snellwilcox.com>
- [11] S.-W. Jang and G.-S. Lee, "MPEG-2 Test Stream with Static Test Patterns in DTV System," *Lecture Notes in Computer Science* vol. 3656, pp. 375-382, Sep. 2005.