International Journal of Industrial Electronics, Control and Optimization © 2021 IECO
Vol. 4, No. 3, pp.313-320, July (2021)

Methods and Criteria for Evaluating Controllability of Video Bit Rate in HEVC-SCC

Hadi Esmaeeli[1], Mehdi Rezaei[2,†]

[1,2] Department of Electrical and Computer Engineering, University of Sistan and Baluchestan, Zahedan, Iran

ABSTRACT

Videos directly captured from a computer or smartphone screen have certain characteristics that differentiate them from camera-captured (CC) ones. These videos are called screen content (SC) videos whose specific encoder has been introduced as a new extension of the HEVC standard called screen content coding (SCC). Most screen content applications are real-time with low delay requiring an accurate rate control. The difference in the characteristics and use of special coding tools such as palette mode, intra block copy, and adaptive color transform in this standard, have affected the mechanism of bit rate generation and control. This paper presents methods and criteria to evaluate the controllability of the bit rate of SC videos and compare it with that of CC counterparts. Furthermore, the requirements of SC video rate control are studied. The experimental results indicate that the bit rate of SC videos is much less controllable than the conventional ones so that the conventional rate-distortion models and bit rate control algorithms are not effective in coding the SC videos.

Article Info

Keywords: Bit rate, Control, HEVC standard, Screen content, Video coding

Article History:
Received 2021-03-06
Accepted 2021-06-04

I. INTRODUCTION

The focus of all video coding standards up to the first version of the HEVC standard has been on the camera-captured (CC) videos. However, in recent years, screen content (SC) videos, which are known as the content type due to a computer or mobile screen, have become a popular video type. This is driven partly by recent advances in mobile, cloud, and display technologies, such as wireless displays, screen sharing and remote collaboration, cloud computing, and gaming [1]. However, unlike CC videos, the SC is a set of images with a large number of uniformly flat areas, repeated patterns, a limited number of colors, and numerically identical blocks without sensor noise [2]. Given these characteristics, the SC has been considered during the development of the HEVC standard, and SC coding tools were gradually expanded. The first draft of SCC was published in July 2014 and was officially introduced as one of the HEVC extensions called HEVC-SCC.

The most important techniques and tools used in the HEVC SCC extension, which have originated from the SC characteristics, include the palette mode, intra block copy, adaptive color-space transform, and adaptive motion vector resolution [3]. These techniques are briefly introduced below:

- The palette mode is characterized by the use of a limited number of colors of the SC. All pixels in a block are classified into a list of major colors. For each coding unit, a color index table is created and all pixels in that unit are converted into the indices corresponding to each color, except for some rarely used ones that can not be quantized to any of the major colors and are called escape pixels [4]. The palette mode is a new coding path in the encoder block diagram [1].
- Intra block copy is a very effective technique in terms of improving the coding performance, which takes advantage of the repeated patterns in the SC. It is a block matching technique in which the current predictor block is predicted from a reference block located in the previously reconstructed regions of the same image [5].
- Adaptive color-space transform is used to identify the redundancy between color components, i.e., statistical redundancy between the different color components [6].
- Adaptive motion vector resolution is inferred from the

[†]**Corresponding Author**: mehdi.rezaei@ece.usb.ac.ir,
Tel: +98-5431132628, Fax: +98-5433447908, Faculty of Electrical and Computer Engineering, University of Sistan and Baluchestan, Zahedan, Iran

fact that in the SC, unlike the continuous CC content, the amount of motion from one image to another is often an integer value. If this mode is enabled, all motion vectors are expressed in integer-pixel resolutions and the additional overhead is avoided [7].

Most of the SC applications require a low delay and constant bit rate. For this purpose, more accurate rate controls (RCs) are needed whose design requires accurate evaluation of their rate controllability. There is no algorithm for controlling the rate in the video coding standard.

So far, several RC algorithms have been proposed for different applications of different standards [8]. For example, an RC algorithm is proposed in [9] for the HEVC standard to keep the consistent objective quality. In the presented algorithm, the probability density function of transformed coefficients is modeled based on a Laplacian function that considers the quad-tree coding unit structure. A frame-level rate control scheme based on a new ρ-domain Rate-GOP[1] based rate-distortion (RD) model is proposed in [10]. Another frame-level RC scheme is proposed in [11] based on texture and non-textured rate models, which is capable of maintaining stable buffer status levels. Authors in [12] found that there existed a more robust correspondence between rate and the Lagrange multiplier λ and proposed a novel λ-domain RC algorithm. An efficient distortion-based Lagrange multiplier approach in low-latency video communications is introduced in [13]. Based on the proposed distortion model, a computationally feasible λ is obtained in the minimization of the total distortion subject to a given bit rate. A proportional, integral, and derivative (PID)-fuzzy RC algorithm is proposed in [14] to reach a higher visual quality in high-delay applications with the buffering constraint. A new RC scheme is proposed in [15] for a region of interest mode coding based on the DCT coefficient model. A joint framework of machine learning and game theory modeling is presented in [16] for inter frame coding tree unit (CTU) level bit allocation and RC optimization.

All of the above-mentioned algorithms well control the bit rate of CC videos and their various applications such as low or high delay. However, they are ineffective for SC videos due to their specific features and new coding tools proposed, which affect the generating mechanism of bit rate in the encoder and its control as a consequence.

Some RC schemes for SC videos have recently been put forward [17-24]. Guo et al. [17] proposed an RC algorithm based on the R-λ model in which the complexity of every picture in the sliding window was estimated and bits were allocated according to the estimated prediction errors. The model parameter λ was dynamically adjusted according to the real consumed bits to achieve the goal of bitrate control. In other work [18], they proposed another RC scheme based on picture classification. The pictures were classified based on their complexity. Meanwhile, the proper bit allocation and parameter updating strategies were selected to control buffer occupancy. Xiao et al. [19] designed a pre-analyzer to collect coding information of the next few frames before encoding the current frame. After acquiring this information, a bit allocation strategy was adopted to prevent buffer overflow and underflow. The proposed RC model was based on the R-λ model. An RC scheme based on video content was proposed by Yang et al. in [20]. The proposed scheme uses different R-λ models of different video contents to characterize the relationships between R and D and update their parameters. Also, a scene change is checked out to accomplish bit allocation for regions with different contents. Wang et al. [21] proposed a frame-level RC scheme for SC in which inter frame correlation was used to classify the frames into key-frames and non-key frames. Then, an efficient bit rate allocation scheme was proposed based on the frame type and Hypothetical Reference Decoder (HRD) to ensure RD performance. Finally, based on the characteristics of the two types of frames, two rate quantization (R-Q) models were established. Tang and Li [22] proposed a low delay RC method for SC coding. In the proposed method, the picture type and buffer status are considered in the bit allocation scheme. A linear R−MAD (Rate-Mean Absolute Difference) model is utilized to estimate frame QP (Quantization Parameter) in the RC scheme. A down-sampling-based RC algorithm aimed at the mobile screen video was presented by Tang et al. [23]. In this RC, the source video is down-sampled and is then encoded twice and the coding information is stored. The real encoding process is optimized at bit allocation and bit control based on the stored coding information. Yang et al. in [24] proposed a very similar content-based RC as in [20] based on the R-λ model.

The whole articles reviewed above are based on the inter frames and do not provide any real solution for intra frames which is required for low-delay applications of SC videos. In this paper, we do not intend to propose an RC algorithm for SC videos. The main contribution of this paper is to compare the controllability of the bit rate of SC videos with that of CC videos from different aspects and then to study the requirements of SC video RC algorithms, especially for low-delay applications.

The rest of this paper is organized as follows. Section II proposes methods to evaluate the controllability of SC videos. Section III presents the experimental results of the methods proposed in Section II, and Section IV gives the conclusions.

II. METHODS AND CRITERIA FOR EVALUATING THE CONTROLLABILITY OF SC VIDEOS

To distinguish the difference between SC and CC videos,

[1] Group of pictures

several methods and criteria have been employed. The corresponding experiments are illustrated in the results section. These methods and criteria are examined in more detail in the following subsections.

A. Consecutive Frame Changes

In CC videos, all consecutive frames have gradual changes, so RD models used for RC are well suited for them, and the model parameters can be updated based on the results of previously encoded frames [25, 26]. As a result, the RC algorithm can provide accurate control over bit rate. On the other hand, in SC videos, abrupt changes in consecutive frames prevent effective control. MAD and SAD (Sum Absolute Difference) can be used as criteria to compare the SC and CC videos in terms of changes in consecutive frames. The results provided are relevant to the rate controllability.

B. Peak-to-Average Bit Ratio

In low delay applications, all frames should be encoded with approximately equal bits, and the video for which the peak-to-average bit ratio tends to one meets the best controllability. Thus, controlling the bit rate of a video for this purpose means reducing the number of bits for the frames having a large number of bits without control and vice versa to push the bit rate peak close to the average bit rate. The higher the value of the peak-to-average ratio in a video is, the harder its RC will be. Therefore, this metric is proposed for comparing the rate controllability of SC and CC videos.

C. Multi-Pass Rate Control Performance

To further compare the rate controllability of SC videos with CC ones in practice, a multi-pass RC algorithm is proposed. It has been attempted to convert the bit rate of several videos to a fixed bit rate by multi-pass encoding. In other words, their peak-to-average bit ratios should approach one. This algorithm is designed in such a way that at each pass, the QP of the frames whose bit rate in the previous pass is far from the average bit with a threshold is modified. The pseudocode of this algorithm can be observed as below. The performance of the proposed multi-pass RC algorithm over the SC and CC videos can be used to compare their controllability.

MULTI-PASS RC ALGORITHM PSEUDO CODE

Step 1: Encode all video frames with a constant *QP*.
Step 2: Calculate the mean of the frame bits.
Step 3: *for* each video frame with index *n*:
Step 4: *If* (frame bits> α*mean of the frame bits)
QPn = QPn + 1
Else If (frame bits < β*mean of the frame bits)
QPn = QPn – 1
Otherwise
QPn = QPn
Step 5: Encode the video frame with the new *QP* value
Step 6: Repeat from Step 2 several times

D. Accuracy of the Standard Model RC Algorithm

In this method, the CC and SC videos have been encoded and compared to control the bit rate with the existing RC of the HM standard model software, which is based on the R-λ model. This RC algorithm has shown good performance for CC videos. Investigation of the performance of this RC algorithm over the SC videos can show the controllability of the SC video bit rate.

E. Content-Based RD Modelling Capability

A content-based RD model is needed for intra-frame RC. However, it can be useful even for inter-frame RC. To compare the RD modeling capability of SC videos with that of CC videos, a set of SC and CC videos are encoded. Then, the fitness of their provided results to a simple content-based RD model is compared. For this purpose, the following simple RD model has been selected from [14].

$$Q = \frac{X_I}{B_I}, \quad (1)$$

where X_I and B_I represent the coding complexity and the consumed bits of intra frame, respectively. Q denotes the quantization step, which is related to the QP as [14]

$$Q = 0.85 \times \left(2^{\frac{QP-12}{6}} \right). \quad (2)$$

It should be noted that several criteria can be used for the coding complexity measurement. The criterion in [27] that has been validated for the AVC/H.264 and previous standards is used here.

$$X = (\bar{V} + \bar{T}_V + \bar{T}_H), \quad (3)$$

in which

$$V = \frac{1}{s^2}\sum_{x=1}^{s}\sum_{y=1}^{s}(P(x,y) - \overline{P(x,y)})^2, \quad (4)$$

$$T_V = \frac{1}{s^2}\sum_{x=1}^{s}\sum_{y=1}^{s}\left|P(x,y) - P(x,y-1)\right|, \quad (5)$$

$$T_H = \frac{1}{s^2}\sum_{x=1}^{s}\sum_{y=1}^{s}\left|P(x,y) - P(x-1,y)\right|, \quad (6)$$

where X denotes the complexity measure, V is the variance of luminance pixels $P(x, y)$ in one CTU of size s, T_V and T_H denote the vertical and the horizontal texture measures on the luminance pixels, respectively, $\bar{V}$, $\bar{T}_V$, and $\bar{T}_H$ are average values of V, T_V, and T_H, on all CTUs in the frame, respectively.

F. Relative Coding Complexity of Intra to Inter Frames

The intra frames usually consume more bits than the inter ones and they thus have a big impact on the video quality and their RC is of high importance [25,28,29,30]. A higher portion of the bit budget consumed by the intra frames means a higher degree of importance for intra frame RC. To compare the SC and CC videos from this point of view, the relative coding complexity of intra to inter frames in the two mentioned video types has been examined. Given a low-delay GOP structure with periodic IDR (Instantaneous Decoder Refresh) pictures, the average relative coding complexity is defined as

$$X_{IP} = \frac{\frac{1}{N}\sum_{i=1}^{N} X_{Ii}}{\frac{1}{M}\sum_{j=1}^{M} X_{Pj}} = \frac{\frac{1}{N}\sum_{i=1}^{N} QP_{Ii} \times B_{Ii}}{\frac{1}{M}\sum_{j=1}^{M} QP_{Pj} \times B_{Pj}}, \quad (7)$$

where i and j denote the index of intra and inter frames, respectively, N and M are the numbers of encoded intra and inter frames, respectively, X_{Ii} and X_{Pj} represent the coding complexity of intra and inter frames, respectively, QP_{Ii} and QP_{Pj} are QP used for encoding intra and inter frames, respectively, and B_{Ii} and B_{Pj} show the consumed bits by the intra and inter frames, receptively. These metrics reveal the importance of intra frames RC in SC videos.

III. EXPERIMENTAL RESULTS

The HEVC-SCC test model in HM-16.16+SCM8.5 software has been used for all experiments. Six experiments corresponding to the proposed methods and criteria in section II are executed, and the results of the experiments are presented in the following subsections. For the first three experiments, the All-INTRA coding structure has been used for encoding, QP offset values have been set to zero, and the intra period has been set to half of GOP.

A. Results of Consecutive Frame Changes

The consecutive frame changes in two test video sequences including Basketball and Web Browsing sequences, as samples of CC and SC videos, are computed in terms of MAD, and the comparison results are displayed in Fig. 1. As can be seen, the MAD of the CC sequence has gradual changes with good continuity and a strong correlation between the sequential frames. On the other hand, in the SC sequence, most frames have a very low MAD over long periods, and very sharp changes are observed in very short periods. Assuming a correlation between the bit rate and MAD, these results show that the rate control task is very difficult in SC videos, especially for low-delay applications.

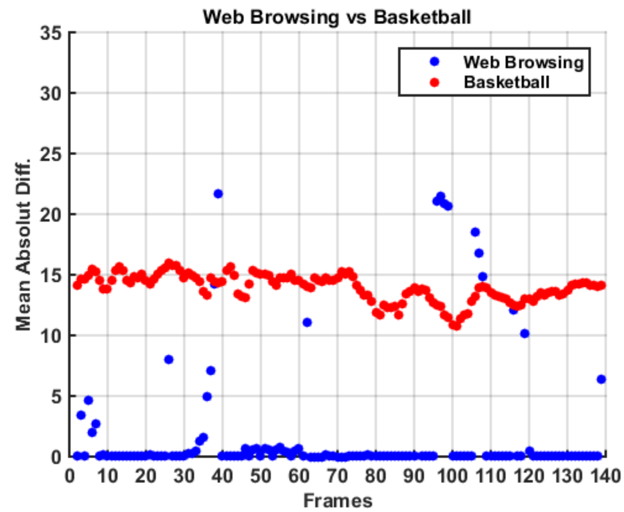

Fig. 1. A comparison of the complexity of consecutive frames in the Web Browsing and Basketball Sequences.

B. Results of Peak-to-Average Bit Ratio Criterion

Four videos of each type have been selected and coded with different QPs and their corresponding peak-to-average (P/A) curves have been plotted in Fig. 2. As shown in this figure, all the CC videos (Park, Kimono, Basket, and 4People) are at the bottom (low P/A), and all SC ones (Map, PCB, Web, and Word) are at the top (high P/A). Table I presents the numerical results and the average values obtained via these experiments. The average values have been obtained as 39.55 and 4.37 for the SC and CC videos, respectively, which indicates a significant difference. So, the controllability of the bit rate of SC videos is more difficult than those of CC videos, especially for high bit rates or low QP values.

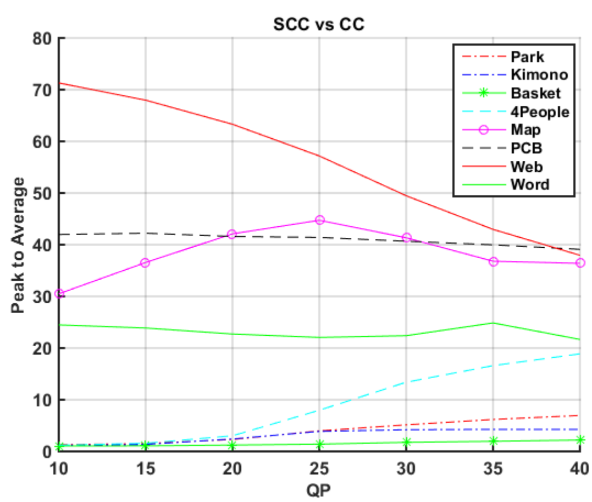

Fig. 2. Variations in the peak-to-average ratios for the CC and SC videos.

Table I

The Numerical Values Of The Peak-To-Average Ratios Associated With The Cc And Sc Videos.

		Peak to Average ratio							
Video type	Sequence name	Qp=10	Qp=15	Qp=20	Qp=25	Qp=30	Qp=35	Qp=40	Average
CC	ParkScene	1.309	1.519	2.304	3.978	5.139	6.181	6.957	3.912
	Kimono	1.187	1.355	2.404	3.880	4.192	4.267	4.262	3.078
	Basketball	1.060	1.082	1.231	1.407	1.753	1.958	2.199	1.527
	4People	1.213	1.570	3.024	7.971	13.390	16.598	18.878	8.949
Total Average									4.367
SC	Map	30.4959	36.5519	42.1037	44.7242	41.3380	36.8037	36.3917	38.344
	PCB	41.9714	42.2193	41.5911	41.4042	40.6735	39.9720	39.1007	40.990
	Web	71.2969	67.9695	63.3051	57.1676	49.471	42.9627	37.9547	55.732
	WordEditing	24.4814	23.8815	22.7150	22.0587	22.3924	24.8658	21.6759	23.153
Total Average									39.55

C. *Results of Proposed Multi-Pass Rate Control*

To check the bit rate controllability with the proposed multi-pass RC algorithm, four CC and four SC videos have been selected and encoded with a fixed QP of 20, as the first step of the algorithm. Then, the next steps of the algorithm were executed and repeated for 20 passes for each test sequence. After each pass, the *Peak-to-Average* criterion is computed for the resulting bitstream. The results of implementing the proposed algorithm for eight videos are shown in Fig. 3. As shown in the figure, all four CC videos at the bottom of the chart approached 1 very quickly, indicating that the bit rate has moved toward a fixed value and has been well controlled. On the other hand, the behavior is different for the four SC videos at the top of the chart. The P/A values of the above three videos approach about 4 or 5 after eleven passes, but in the next passes, they meet an increase in the P/A criterion, and next, they show some fluctuations. In the best cases, their P/A values are about 4 and 5, which are far from 1. Thus, more control over their bit rate is impossible. It can be seen that the fourth SC video from above has a behavior between these two types of videos. The content of

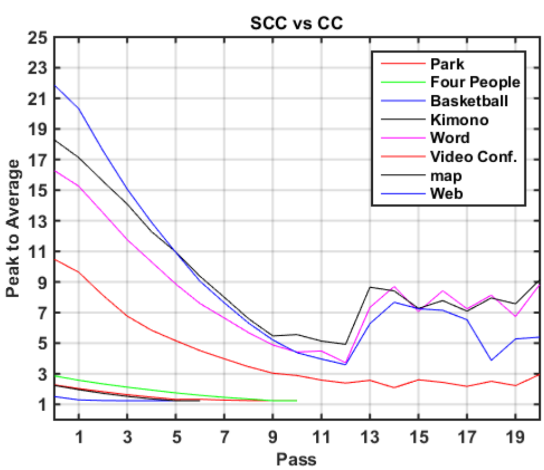

Fig. 3. Video comparison using the proposed multi-pass rate control.

this video (Web Conference) includes a combination of CC and SC videos, so it shows such intermediate behavior.

D. *Results of Standard Model RC Algorithms*

For this purpose, four videos from each type (CC and SC) have been concatenated to make long test sequences with different scenes. The concatenated videos are coded in three different modes: (intra period =32 and GOP = 4),

1) With a constant QP (CQP) of 25
2) RC of HM software for CC and that of HM-SCM for SC videos without any buffer.
3) Similar to mode 2 with enabling HRD (Hypothetical Reference Decoder) constraint.

The variations in the buffer status versus the number of frames are plotted in Figs. 4 and 5 for the CC and SC videos, respectively.

The results indicate that in comparison with the constant QP mode, the bit rate of CC videos is controlled with the RC algorithms to some extent. On the other hand, the RC algorithms fail to control the SC video both with and without buffer. In these scenarios, the RC algorithm should prevent buffer overflow and underflow. The buffer size is shown by the orange color lines in the figures. The graphical results show that the encoded SC videos are far from the buffer constraint and have a low degree of controllability.

E. *Results of Content-Based RD Modelling*

Using the simple RD model in formula (1) and complexity measure in formula (3), the content complexity diagram has been plotted versus the number of coding tree unit (CTU) bits for four CC and SC videos in Figs. 6 and 7, respectively. As can be seen in Fig. 6, the results are very close to each other and almost in the bisector direction, and the relationship is relatively linear. The closer the results are to the straight line, the more accurate the RD model will be. On the other hand, the results are scattered for the SC videos in Fig. 7 and there is no specific correlation between the complexity measure and bits. The results show a low capability of content-based RD modeling for SC videos.

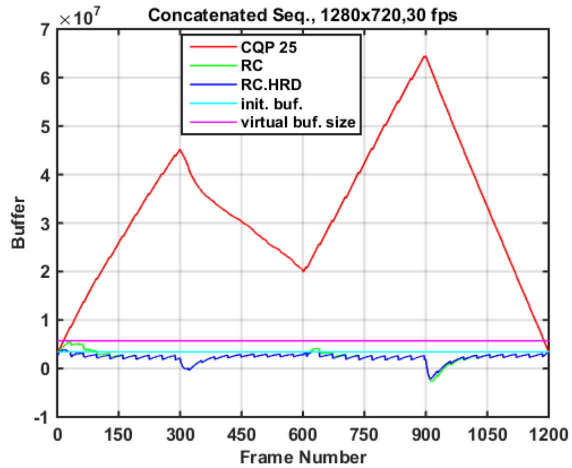

Fig. 4. The buffer status variation with the number of frames in the CC videos.

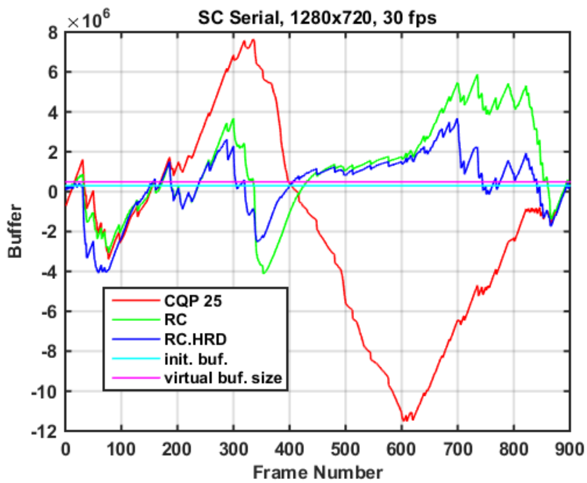

Fig. 5. The buffer status variation with the number of frames in the SC videos.

F. Results of Relative Coding Complexity of Intra to Inter Frames

Three CC (4People, Kristen, and Vidyo) and three SC (Map, Web, and Video Conference) test video sequences with the size of 1280×720 and the chroma format 4:2:0 have been used for this experiment. The test sequences are encoded with low-delay coding structure, IntraPeriod = 8, GOP = 4, QP = 10, 15, …, 40, and default QP offset values. The average relative coding complexity values for all sequences are presented in Table II for different QPs. An average on all QPs is also presented for each sequence. According to this table, the relative coding complexity in SC videos is much higher than that in the CC ones, especially for the QPs smaller than

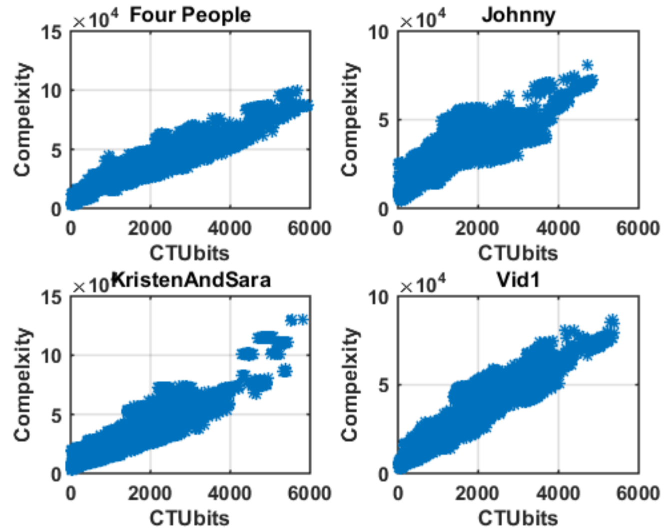

Fig. 6. Content complexity to CTU bits for CC videos.

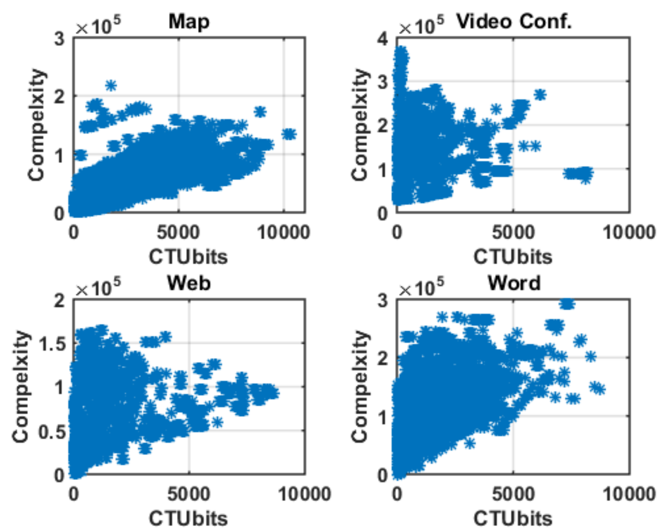

Fig. 7. Content complexity to CTU bits for SC videos.

25. A value larger than 100 for the Video Conference sequence demonstrates that, on average, an intra frame consumes a hundred times more bits than an inter frame. Therefore, a larger portion of the bit budget is consumed by the intra frames in SC than in CC videos. As a result, the intra frame rate control in SC videos is more important than in CC videos. Therefore, the bit rate of intra frames in SC must be controlled with a high degree of accuracy, and a proper accurate intra RD model is required.

Table II
Average relative coding complexity of the intra to inter frames.

QP	SC Video Sequences			CC Video Sequences		
	Map	Web	Video Conf.	4People	Kirsten	Vidyo
10	15.27	63.81	24.67	3.17	3.17	3.19
20	20.23	64.62	49.31	11.47	9.42	9.30
30	27.21	62.43	107.95	26.29	25.03	21.21
40	33.61	59.44	107.55	35.81	34.08	27.25
Average	**24.08**	**62.57**	**72.37**	**19.18**	**17.92**	**15.24**

IV. Conclusions

In this paper, methods and criteria are proposed to examine the controllability of the bit rate of SC videos for the low delay applications and to study the requirements of SC video RC algorithms. The results of experiments showed that the bit rate controllability of this type of video is low and it is very difficult to achieve a fixed bit rate, especially for low-delay applications in which all video frames should consume a near fixed bit budget. It was also found that the used RD model and the RC algorithm in the standard model software are not suitable for this type of video and a more appropriate RD model should be found and a proper RC algorithm should be designed. This model must support new SC coding tools. On the other hand, since the relative coding complexity of intra to inter frames in this type of content is too high, the accuracy of intra RD modeling and RC is very important while the intra RD model must be content-based.

References

[1].W. Peng, F. Walls, R. Cohen, J Xu, J. Ostermann, A. MacInnis, and T. Lin, “Overview of Screen Content Video Coding: Technologies, Standards, and Beyond,” IEEE Journal on Emerging and Selected Topics in Circuits and Systems, vol. 6, No.4, pp. 393 – 408, 2016.

[2]J. Xu, R. Joshi and R. A. Cohen, "Overview of the Emerging HEVC Screen Content Coding Extension," in IEEE Transactions on Circuits and Systems for Video Technology, vol. 26, no. 1, pp. 50-62, Jan. 2016, doi: 10.1109/TCSVT.2015.2478706.

[3].S. Liu, X. Xu, S. Lei, & K. Jou, (2015). Overview of HEVC extensions on screen content coding. APSIPA Transactions on Signal and Information Processing, 4, E10. doi:10.1017/ATSIP.2015.11.

[4].Y. Sun et al., "Improvements of HEVC SCC Palette Mode and Intra Block Copy," in IEEE Journal on Emerging and Selected Topics in Circuits and Systems, vol. 6, no. 4, pp. 433-445, Dec. 2016, doi: 10.1109/JETCAS.2016.2598193.

[5].X. Xu et al., "Intra Block Copy in HEVC Screen Content Coding Extensions," in IEEE Journal on Emerging and Selected Topics in Circuits and Systems, vol. 6, no. 4, pp. 409-419, Dec. 2016, doi: 10.1109/JETCAS.2016.2597645.

[6].L. Zhang et al., "Adaptive Color-Space Transform in HEVC Screen Content Coding," in IEEE Journal on Emerging and Selected Topics in Circuits and Systems, vol. 6, no. 4, pp. 446-459, Dec. 2016, doi: 10.1109/JETCAS.2016.2599860.

[7].B. Li et al, "Adaptive Motion Vector Resolution for Screen Content, document", JCTVC-S0085, Joint Collaborative Team Video Coding, Strasbourg, France, Oct. 2014.

[8] H. Guo, C. Zhu, S. Li and Y. Gao, "Optimal Bit Allocation at Frame Level for Rate Control in HEVC," in IEEE Transactions on Broadcasting, vol. 65, no. 2, pp. 270-281, June 2019.

[9].Ch. W. Seo, J. H. Moon, J. K. Han, “Rate control for consistent objective quality in high efficiency video coding,” IEEE Trans. Image Process. vol. 22, no. 6, pp. 2442–2454, 2013.

[10].Sh. Wang, S. Ma, Sh. Wang, D. Zhao and W. Gao,” Rate-GOP Based Rate Control for High Efficiency Video Coding,” IEEE Journal of Selected Topics in Signal Processing. vol. 7, No. 6, pp. 1101-1111, 2013.

[11].B. Lee, M. Kim, and T. Q. Nguyen,” A Frame-Level Rate Control Scheme Based on Texture and Nontexture Rate Models for High Efficiency Video Coding,” IEEE Transactions on Circuits and Systems for Video Technology, vol. 24, No. 3, pp. 465 – 479, 2014.

[12].B. Li, H. Li, L. Li, and J. Zhang,” λ Domain Rate Control Algorithm for High Efficiency Video Coding,” IEEE Transactions on Image Processing, vol. 23, No. 9, pp. 3841-3854, 2014.

[13].M. Wang, K. N. Ngan and H. Li,” Low-Delay Rate Control for Consistent Quality Using Distortion-Based Lagrange Multiplier,” IEEE Transactions on Image Processing, vol. 25, No. 7, pp. 2943-2955, 2016.

[14].D. Fani and M. Rezaei,” A Novel PID-Fuzzy Video Rate Controller for High-Delay Applications of HEVC Standard,” IEEE Transactions on Circuits and Systems for Video Technology, vol. PP, No. 99, p. 1, 2017.

[15].Z. Zhang, T. Jing, J. Han, Y. Xu, and F. Zhang,” A New Rate Control Scheme for Video Coding Based On Region of Interest,” IEEE Access, vol. 5, pp. 13677-13688, 2017.

[16].W. Gao, S. Kwong, and Y. Jia,” Joint Machine Learning and Game Theory for Rate Control in High Efficiency Video Coding,” IEEE Transactions on Image Processing, vol. 26, No.12, pp. 6074-6089, 2017.

[17] Y. Guo, B. Li, S. Sun, and J. Xu, “Rate control for screen content coding in HEVC,” Circuits and Systems (ISCAS), 2015 IEEE International Symposium on, Lisbon, 2015.

[18] Y. Guo, B. Li, S. Sun, and J. Xu, “Rate control for screen content coding based on picture classification,” Visual Communications and Image Processing (VCIP), Singapore,

2015.
[19].J. Xiao, B. Li, S. Sun and J. Xu, "Rate control with delay constraint for screen content coding," 2017 IEEE Visual Communications and Image Processing (VCIP), St. Petersburg, FL, 2017, pp. 1-4, doi: 10.1109/VCIP.2017.8305100.
[20].Y. Yang, L. Shen, H. Yang, & P. An (2019). "A content-based rate control algorithm for screen content video coding". Journal of Visual Communication and Image Representation, 60, 328–338.
[21].S. Wang, J. Li, S. Wang, S. Ma and W. Gao, "A Frame Level Rate Control Algorithm for Screen Content Coding," 2018 IEEE International Symposium on Circuits and Systems (ISCAS), Florence, 2018, pp. 1-4, doi: 10.1109/ISCAS.2018.8351596.
[22].T. Tang, & L. Li (2019). "A low delay rate control method for screen content coding". Multimedia Tools and Applications, 78(19), 28231–28256.
[23].T. Tang, J. Yang, B. Du and L. Tang, "Down-Sampling Based Rate Control for Mobile Screen Video Coding," in IEEE Access, vol. 7, pp. 139560-139570, 2019, doi: 10.1109/ACCESS.2019.2943887.
[24].H. Yang, L. Shen, Y. Yang and W. Lin, "A Novel Rate Control Scheme for Video Coding in HEVC-SCC," in IEEE Transactions on Broadcasting, vol. 66, no. 2, pp. 333-345, June 2020, doi: 10.1109/TBC.2019.2954062.
[25].Y. Li, B. Li, D. Liu and Z. Chen, "A convolutional neural network-based approach to rate control in HEVC intra coding," 2017 IEEE Visual Communications and Image Processing (VCIP), St. Petersburg, FL, 2017, pp. 1-4, doi: 10.1109/VCIP.2017.8305050.
[26].X. Lu, B. Zhou, X. Jin and G. Martin, "A Rate Control Scheme for HEVC Intra Coding Using Convolution Neural Network (CNN)," 2020 Data Compression Conference (DCC), Snowbird, UT, USA, 2020, pp. 382-382, doi: 10.1109/DCC47342.2020.00055.
[27].M. Rezaei et al., “Analyzed Rate Distortion Model in Standard Video Codecs for Rate Control”, IEEE Workshop on Signal Processing Systems Design and Implementation, Athens, Greece, Nov. 2005.
[28].M. Wang, K. N. Ngan and H. Li, "An Efficient Frame-Content Based Intra Frame Rate Control for High Efficiency Video Coding," in IEEE Signal Processing Letters, vol. 22, no. 7, pp. 896-900, July 2015, doi: 10.1109/LSP.2014.2377032.
[29].L. Sun, O. C. Au, W. Dai, Y. Guo and R. Zou, "An adaptive frame complexity based rate quantization model for intra-frame rate control of High Efficiency Video Coding (HEVC)," Proceedings of The 2012 Asia Pacific Signal and Information Processing Association Annual Summit and Conference, Hollywood, CA, 2012, pp. 1-6.
[30].W. Li, P. Ren, E. Zhang, and F. Zhao, "Rate control for HEVC intra-coding with a CTU-dependent distorti jfv,mhngn xyon model,". SIViP 13, 17–25 (2019). https://doi.org/10.1007/s11760-018-1323-8.

Hadi Esmaeeli received the B.S. degree in electronics engineering from the University of Sistan and Baluchestan (USB), Iran in 1997 and M.Sc. degree in information technology engineering from the Amir Kabir University of Technology (Polytechnic of Tehran), Tehran, Iran in 2007. He was the head of the E-learning Center at the USB from 2011 to 2016. He is currently pursuing the Ph.D. degree in communications systems engineering and is a lecturer in the Department of Information Technology Engineering, USB, Iran. His research interests include multimedia signal processing and communications.

Mehdi Rezaei (M’04) received the B.S. and M.Sc. degrees in electronics engineering from the Amir Kabir University of Technology (Polytechnic of Tehran) and Tarbiat Modares University, Tehran, Iran in 1992 and 1996, respectively, and also Ph.D. degree in Signal Processing from the Tampere University of Technology (TUT), Finland in 2008. His research interests include multimedia signal processing and communications. He has published several papers in these fields. During his Ph.D. program, he had a close collaboration with the Nokia Research Center and he filled several patents. He also received the Nokia Foundation Award in 2005 and 2006. Between 2015, he worked as Deputy Dean for Education and Postgraduate Studies and as Deputy Dean for Research in Faculty of Electrical and Computer Engineering, and also Dean of Education at the University of Sistan and Baluchestan, Iran. Now, he is an Associate Professor of Communications Engineering Department, University of Sistan and Baluchestan, Iran.