

# New Network Bandwidth-limited Multi-view Video plus Depth Coding Method for 3D Video

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**Abstract**—Prospective 3D video transmission systems that would use compression of both multiview video and depth maps was dealt with in this paper. To get the optimal synthesized view quality with the transmission bit rate being constant, it firstly analyzed the overall behavior of combined coding and view synthesis, color and depth data with different coding qualities were combined for intermediate view synthesis. Then, individual coding results for color and depth data were evaluated in order to investigate, how well the synthesized view quality was at certain compression. Finally, a new joint coding method for multi-view video plus depth (MVD) was proposed by utilizing the optimal combinations of the quantization parameters of color videos and the corresponding depth maps. Simulation results demonstrated that the proposed method decreased the bit-rate by 12.72%~24.02% in comparison with JMVC and can be used to guide sequence-level texture/depth coding for 3D video compression. The proposed method has better performance in optimizing the tradeoff between bit-rate and visual quality.

**Index Terms**—3D Video, Multi-view video plus depth, Network bandwidth, Quantization parameters

## I. INTRODUCTION

Multi-view video plus depth (MVD) is efficient three dimensional (3D) representation of scene, it can be used to reduce the complexity of virtual view generation at the user end in 3D video (3DV) systems [1] [2]. The initial problem in such 3DV applications is the interdependency among view capturing, coding and synthesis [3]. For support of a large range of high-quality displays, there should not be an increase in the rate simply because the display requires a higher number of views to cover a larger viewing angle [4]. In order to transmit and store these signals for practical use, it is necessary to investigate efficient coding scheme of MVD for high quality of intermediate view synthesis with the given transmission bandwidth [5].

The compression of MVD data has recently received a lot of attention. Lai et al. derived a new distortion metric

that takes into consideration camera parameters and global video characteristics in order to quantify the effect of depth map coding on synthesized view quality [6, 7, and 8]. Klimaszewski et al. observed that the quality of video is much more important than the quality of the depth maps for good view synthesis, and defined the critical value of depth quantization parameter (QP) as a function of the video QP [9]. Muller et al. investigated the interdependency between compression and view synthesis, and obtained bit-rate ratios for video and depth maps for the best intermediate view synthesis [10]. Zhang et al. evaluated the typical prediction structures of multi-view video coding using hierarchical B picture (HBP) for the integrative [11]. Wang et al. assessed the quality of videos in agreement with human quality judgments and optimized the stereoscopic video systems [12]. Among these, the HBP prediction structure was selected as a reference prediction structure in Joint Multiview Video Model (JMVM) [13] and Joint Multiview Video Coding (JMVC) standard [14]. Besides coding efficiency of MVD, the MVD coding artifacts can also affect the quality of virtual views when network bandwidth is restricted. The fixed texture and depth bits ratio (5:1) bit allocation was used in traditional MVD coding within the limited bandwidth, but it cannot guarantee that it is optimal for 3D rendering [15]. Although the algorithms of Morvan [16] can find the optimal quantization parameter (QP) pair for texture videos and depth maps, but in Morvan's algorithms, it is assumed that a real view exists at the synthesis position, and the distortion of the synthesized virtual view is evaluated by mean squared error (MSE) between the synthesized virtual view and its corresponding real view. The applications of those algorithms are restricted by the high complexity.

Generally, 3DV technology is in its infancy, there are still lots of key aspects should be researched deeply. In this paper, we propose a novel bandwidth-limited MVD coding method that incorporates a rendering technique, into the MVD process. The remainder of this paper is organized as follows. Section 2 depicts problem in MVD coding within limited bandwidth in 3DV applications. Different combinations of QP are tested separately in Sections 3. In Section 4, experimental results and analyses are given in detail. The work is concluded in Section 5.

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## II. PROBLEM DESCRIPTION IN MVD CODING WITHIN LIMITED BANDWIDTH

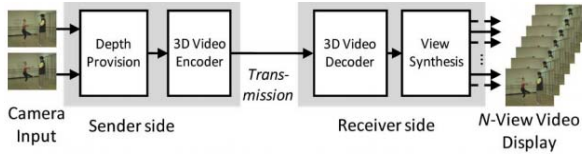


Figure 1. 3DV system based on MVD.

3DV systems based on stereo video signals are currently being commercialized for 3-D cinema, 3-D home entertainment, and mobile applications [17]. The provision of a large number of views for multi-view displays is not efficient with video data only. The efficiency can be drastically increased using scene geometry information like a depth map. Such a transmission system for 3DV using depth maps is shown in Fig. 1. These systems are based on stereo technology from capturing via coding and transmission to 3D displays.

Among view capturing, coding and synthesis, the amount of MVD data is usually huge, hence the data compressing and streaming with less degradation and delay over limited bandwidth are challenging tasks. For representing a large number of videos, a multi-view extension of stereo video coding is used, typically requiring a bit rate that is proportional to the number of views [18] [19]. However, 3DV systems encounter bottlenecks in coding performance improvement especially with the limited network bandwidth. For example, in order to drive a 45-view display, typically five videos and their associated depth maps should be streamed using about 30 Mb/s, and the remaining views are rendered at the receiver side. The coding rate of videos and corresponding depth maps should be modified during streaming to adapt to the dynamic network conditions [20]. When network conditions are restricted, the distortion of texture videos and depth maps can be propagated to the synthesized virtual views.

This paper is to achieve the best picture quality at a given network bandwidth through a proper QP combination process. In this paper, the effects of coding artifacts in MVD data on synthesized view are firstly analyzed and reasonable QP combinations in video and depth are tested through many experiments. In addition, it was found that areas with depth edges are especially vulnerable to coding errors, which cause visible artifacts in the synthesized view [21]. This paper preserves the edge areas in compression.

## III. MVD CODING METHOD WITHIN LIMITED BANDWIDTH

In order to evaluate how the compression of MVD influences the synthesized view quality, we propose a new bandwidth-limited MVD coding method by adopting the idea illustrated in fig. 2. For the intermediate views, no original reference is available for objective PSNR measures. Hence a reference signal is synthesized from uncompressed color and depth data. According to the assumption that texture acquisition, depth generation,

view synthesis, and 3D display modules in Fig. 1 are fixed, the distortion of virtual views can only be affected by three factors, i.e. texture compression, depth compression and the inherent depth inaccuracy induced by depth estimation. This paper firstly generates results from the compression, where video and depth coding is carried out all together. In the next step, we generate results from the coding stage only, where color and depth coding is carried out separately. Furthermore, we derive the edges to find how the areas with concurrent depth edges are especially vulnerable to coding errors. Finally, the robustness of the network bandwidth-limited MVD coding is presented.

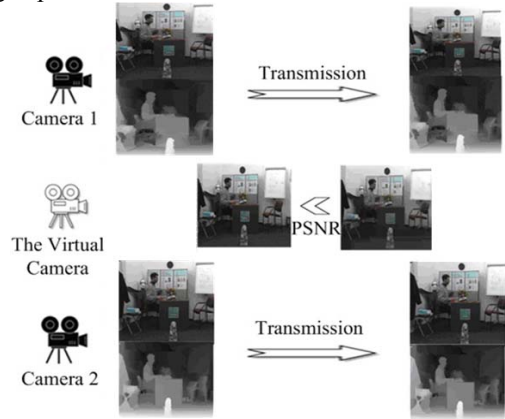


Figure 2. Evaluation of synthesized view quality with compressed video and depth maps.

### A. The Distortion of Synthesized View

In case of an MVD representation, artifacts in synthesized views are introduced directly because of coding of color data as well as indirectly through coding of depth data. For the influence of coding artifacts, we look into the view synthesis, derived in [22]. Consider an arbitrary sample  $s_k$  in an intermediate view at position  $(u_k, v_k)$ , which is interpolated from appropriate original samples  $s_0$  and  $s_l$  at associated positions.

$$s_k[x_k, y_k] = (1-k) \cdot s_0[x_0, y_0] + k \cdot s_l[x_l, y_l] \quad (1)$$

Here,  $k \in [0 \dots 1]$  represents the intermediate position parameter, which specifies the intermediate position between views  $s_0$  and  $s_l$ . For instance, a value of  $k = 1/2$  specifies the middle view between both original views. For each original sample, depth values  $z_0$  and  $z_l$  exist, but for simplicity, we assume a strictly parallel camera setting, where depth can be converted into horizontal disparity shifts  $d_0$  and  $d_l$  (otherwise, a disparity shift in horizontal and vertical directions occurs). Thus, the above equation can be modified to relate the horizontal sample position in the intermediate view  $u_k$  with the positions in the original views  $u_0$  and  $u_l$ , using the  $k$ -scaled disparity shifts.

$$s_k[x_k, y_k] = (1-k) \cdot s_0[x_k - (1-k) \cdot d_0, y_k] + k \cdot s_l[x_k - k \cdot d_l, y_k] \quad (2)$$

During coding, color and depth values are subject to coding errors, such that their reconstructed values differ from the original. While color errors only change the interpolation value, depth errors cause sample shifts  $\Delta d_0$

and  $\Delta d_i$  such that erroneous neighboring samples from original views are used for the individual color contributions.

$$s_k[x_k, y_k] = (1-k) \cdot \hat{s}_0[x_k - (1-k) \cdot (d_0 + \Delta d_0), y_k] + k \cdot \hat{s}_1[x_k - k \cdot (d_1 + \Delta d_1), y_k] \quad (3)$$

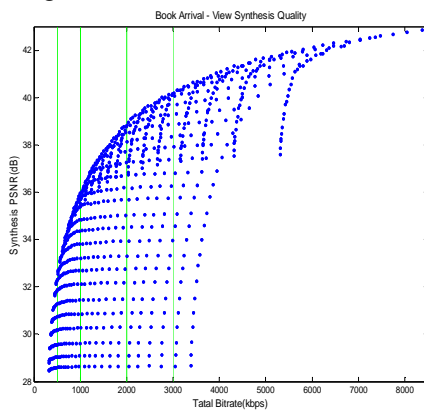
Equation (3) implies that coding errors at depth edges translate into erroneous sample shifts. In combination with color edges, completely different color values could be used for interpolation and strong sample scattering and color bleeding is exhibited in the synthesized view. Therefore, the applied view synthesis algorithm was specifically designed to cope with such data.

In addition to this general approach, our reliability-based synthesis first detects unreliable areas along depth discontinuities. These areas are known to produce visual artifacts in the projection process and are therefore processed separately. A more detailed description can be found in the following sections.

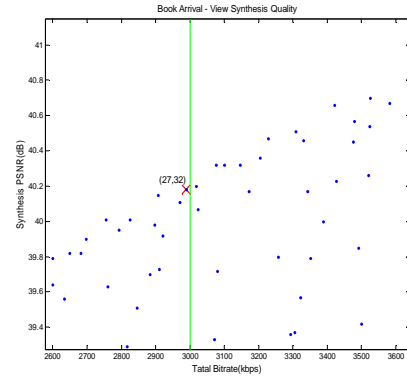
### B. Further Analysis on the Combinations of QP for MVD Coding

First, combined coding results for color and depth data are analyzed in order to obtain initial QP combinations and to investigate, which QP combinations between color and depth data is obtained at the optimal qualities. We used multi-view video coding (MVC extension of H.264/MPEG4-AVC) to separately compress video as well as depth maps [23] [24]. For this, we used the JMVC 8.3 reference software and a GOP-size of 15.

Fig. 3 shows the R-D results of combined color and depth coding, using 3 original views for each sequence. These results show the typical PSNR curves for color and depth data. The important part here is the relation between the total bit-rate and the synthesized PSNR: For sequence, Book Arrival, coded with QP combinations leading to a total bit rate close to the target bit rates of 3000kbit/s, 2000 kbit/s, 1000 kbit/s and 500 kbit/s and highest PSNR of the synthesized views have been chosen for the exploration experiments. The numbers in the brackets show the combinations  $s$  of QP for video and depth in the format: (Video QP, Depth QP). Table I summarizes the selected QP for Video and Depth as well as the resulting bit rate distributions.



(a) PSNR of synthesized views vs. total bit rate for various QP combinations; target bit rates are marked with green lines.



(b) PSNR of synthesized views vs. total bit rate at 3000 kbit/s.

Figure 3. PSNR of synthesized views vs. total bit rate for various QP combinations.

With the constant target rate, the bit rate of the video accounts for more than 70% in the total bit rate. As a consequence, the quality of synthesized view quality is highly dependent from video quality.

Fig. 4 shows the first frame of the view 2 synthesized from coded data as an example. From Fig.4, we can see clearly that at the higher bit-rate, the video quality is perfect and clear. With the decreasing of the bit-rate, the view is blurred.

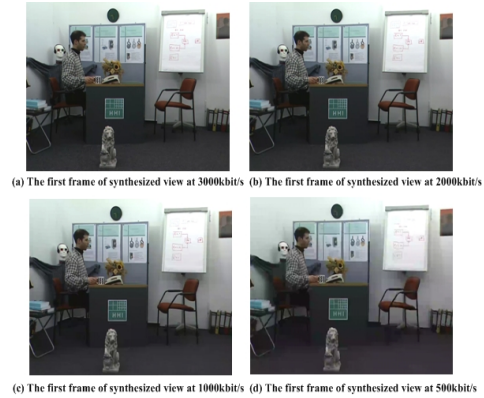


Figure 4. The first frame of synthesized views at each target bit-rate.

TABLE I.  
THE OPTIMAL QP COMBINATIONS  $s$  FOR MVD WITHIN THE TARGET RATE

Target rate (kbps.)	3000	2000	1000	500
QP video	27	30	35	42
QP depth maps	32	35	43	47
Bit-rate video/Total bit-rate	74	70	75	71

### C. Influence of Depth Maps Compression on Synthesized View

In this section, the influence of depth maps compression on the quality of synthesized view was investigated. By adopting the setting of QP illustrated in Table II, videos and depth maps with different coding qualities were combined to synthesize the intermediate view. To analyze the overall behavior of combined compression and view synthesis, a full set of color-depth-pairs were recorded according to the method depicted in Fig.

2. The results for the Book Arrival and Leave Laptop are shown in Fig. 5.

For sequence, Book Arrival, the results are shown in Fig. 5(left). The horizontal abscissa stands for the total bit-rate for encoding the two views and depth maps with different QP setting. The vertical one denotes the finally obtained objective PSNR values of the synthesis views. Here, the grid is shown, which is formed by the 5 curves with constant video fidelity and varying depth fidelity. A low QP value results in a higher PSNR value at the expense of a higher bit rate. Following the solid curves with constant video fidelity, a decrease in depth fidelity only moderately decreases the intermediate view quality. The QP setting of the depth maps has negligible (less than 0.2 dB decrease) impact on synthesized view quality as long as its value is in bounds estimated from the experiments. So the PSNR of the synthesized view decreased by 0.2dB will be corresponded to an allowance-maximum QP setting of the depth maps. Table III tabulates the relationship of the constant QP setting in videos and the allowance-maximum QP setting in depth maps with the decrease of 0.2dB in PSNR of the synthesized views.

TABLE II.  
THE QP SETTING IN VIDEOS AND DEPTH MAPS OF TEST SEQUENCES

QP setting in video	The QP setting in depth maps
21	21, 23, 25, 27, 29, 31, 33, 35, 37, 39
26	21, 23, 25, 26, 27, 29, 31, 33, 35, 37
31	21, 23, 25, 27, 29, 31, 33, 35, 37, 39
36	21, 23, 25, 27, 29, 31, 33, 36, 37, 39, 41
41	21, 23, 25, 27, 29, 31, 33, 35, 37, 39, 41, 43, 45

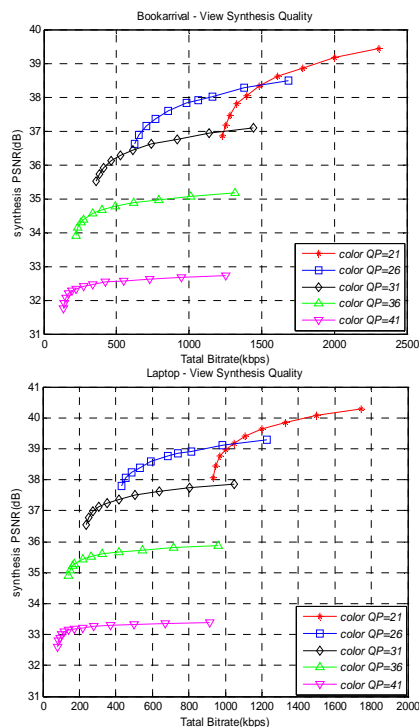


Figure 5. Synthesis quality as a function of total bit-rate of two views and depth maps for Book Arrival and Leave Laptop. Five lines correspond to different QP setting for reference video compression.

TABLE III.  
THE RELATIONSHIP OF QP SETTING IN VIDEO AND DEPTH MAPS

The constant QP setting in video	The allowance-maximum QP setting in depth	
	Book Arrival	Leave Laptop
21	23	23
26	28	28
31	33	33
36	38	38
41	43	43

#### D. The Influence of right view Compression on Synthesized View

In this section, the influence of right view compression on the quality of synthesized view was investigated. In both videos and depth maps, the QP setting for the left and right view are presented in Table IV. A full set of left-right-pairs were recorded according the method depicted in Fig. 2. The results for the Book Arrival and Leave Laptop are illustrated in Fig. 6.

As described in section 3.3, the similar principle is adopted here. Table V tabulates the relationship of the constant QP setting of the left view and the allowance-maximum QP setting in the right view with the decrease of 0.2dB in PSNR of the synthesized views.

TABLE IV.  
THE QP SETTING IN LEFT AND RIGHT VIEW

QP setting in left view	The QP setting in right view
22	22, 25, 28, 31, 34, 37, 40, 43, 45, 48
27	22, 25, 27, 28, 31, 34, 37, 40, 43, 45, 48
32	22, 25, 28, 32, 34, 37, 40, 43, 45, 48
37	22, 25, 28, 31, 34, 37, 40, 43, 45, 48
43	22, 25, 28, 31, 34, 37, 40, 43, 45, 48
48	22, 25, 28, 31, 34, 37, 40, 43, 45, 48

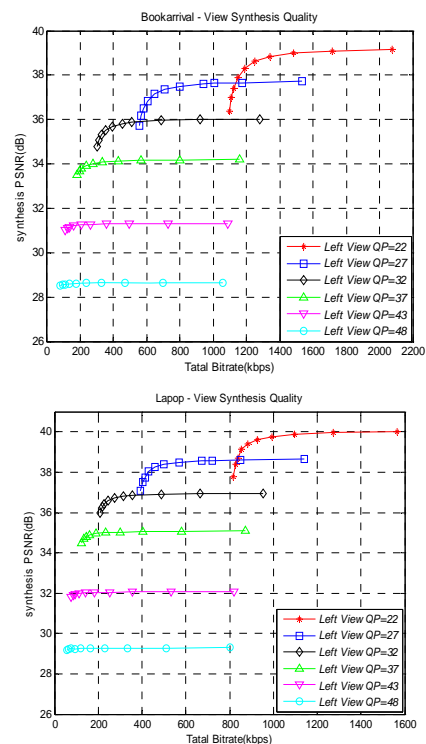




Figure 6. Synthesis quality as a function of total bit-rate of two views and depth maps for Book Arrival and Leave Laptop. Six lines correspond to different QP setting for left view compression.

TABLE V.  
THE RELATIONSHIP OF QP SETTING IN LEFT AND RIGHT VIEW

The constant QP setting in left view	The allowance-maximum QP setting in depth	
	Book Arrival	Leave Laptop
22	28	28
27	33	33
32	37	37
37	42	42
43	48	48

#### E. Influence of Non-edge Compression on Synthesized View

After analyzing the coding behavior for color and depth data, the step of non-edge compression is added. The QP setting for the edge and the non-edge areas in depth maps are presented in Table VI. For sequence, Book Arrival, the particular result with which the QP of the edge areas is 21 is shown in Fig. 7.

As described in section 3.3, the similar principle is adopted, the PSNR of the synthesized view decreased drastically will be corresponded to an allowance-maximum QP setting of the non-edge areas. Table VII tabulates the experiment results.

TABLE VI.  
QP SETTING OF EDGED AND NON-EDGED AREAS IN DEPTH MAPS

QP setting in edged areas	The $\Delta$ QP setting in the non-edged areas
21	4, 8, 12, 16, 20, 24, 28, 32
26	4, 8, 12, 16, 20, 24, 28
31	4, 8, 12, 16, 20
36	4, 8, 12, 16

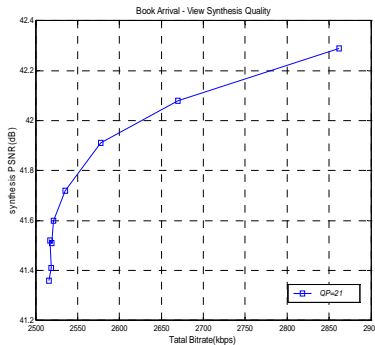


Figure 7. Synthesis quality as a function of total bit-rate of two views and depth map.

TABLE VII.  
THE RELATIONSHIP OF QP SETTING BETWEEN THE EDGE AND THE ALLOWANCE-MAXIMUM QP SETTING IN THE NON-EDGE AREAS

The constant QP setting in left view	The allowance-maximum QP setting in depth	
	Book Arrival	Leave Laptop
21	12	16
26	12	12
31	12	8
36	8	8
Average	11	

## IV. EXPERIMENTAL RESULTS

To evaluate the performance of the proposed MVD coding method utilizing the QP combination, the experiments are performed complying with the section 3.2. The experiments are performed mostly complying with the common test conditions except the following:

(1) Only 49 frames of “Book Arrival” and “Leave Laptop” provided by HHI were tested due to lack of time. The test sequences of the video and the depth maps are illustrated by Fig. 8.

(2) Resolution of Book Arrival and Leave Laptop is 1024x768.

Firstly, the detailed QP settings for MVD are listed in Table I, i. e. the QP settings in video are 27, 30, 35, 42, and the QP settings in the depth maps are quite different which corresponds to 32, 35, 43, 47. All tests in the experiment are run on the Intel Xeon 3.2 GHz with 12 GB RAM and the OS is Microsoft Windows Server 2003.

It defines BS as the average bit-rate saving in coding process by

$$BS = \frac{Bitrate_{JMVC} - Bitrate_{proposed}}{Bitrate_{JMVC}} \times 100\% \quad (4)$$

Table VIII shows the RD performances of the proposed MVD coding method. Every cell shows bit rate of a test sequence with respect to a certain QP. Compared with the JMVC, the bit-rate of the proposed method decreases significantly by average 17.98%, ranging from 16.07% to 24.02%. Figure 9 shows the RD performance comparison of the proposed method and the JMVC for “Book Arrival” and “Leave Laptop”. The vertical axis in each figure is the PSNR of the Y component in the synthesized view, while the horizontal axis corresponds to the sum of the bitrates used for encoding the video and the depth maps. As depicted by the results, the proposed method clearly outperforms JMVC. Here, the same horizontal coordinate on the two curves indicates the same bitrates used for encoding the video and the depth maps, while the red curve which stands for the proposed method reflects a larger PSNR in the synthesized view.

TABLE VIII.  
RD PERFORMANCE COMPARISON BETWEEN THE JMVC AND THE PROPOSED METHOD

Color QP	Book Arrival total bit-rate (kbps)		
	JMVC	Proposed	Saved(%)
27	3650.00	3987.97	18.13
30	2446.83	1988.86	18.31
35	1303.42	990.29	24.02
42	603.66	499.10	17.32
Color QP	Leave Laptop total bit-rate (kbps)		
	JMVC	Proposed	Saved(%)
27	2861.58	2401.70	16.07
30	1902.94	1591.05	16.39
35	1026.02	813.44	20.72
42	467.27	407.12	12.87

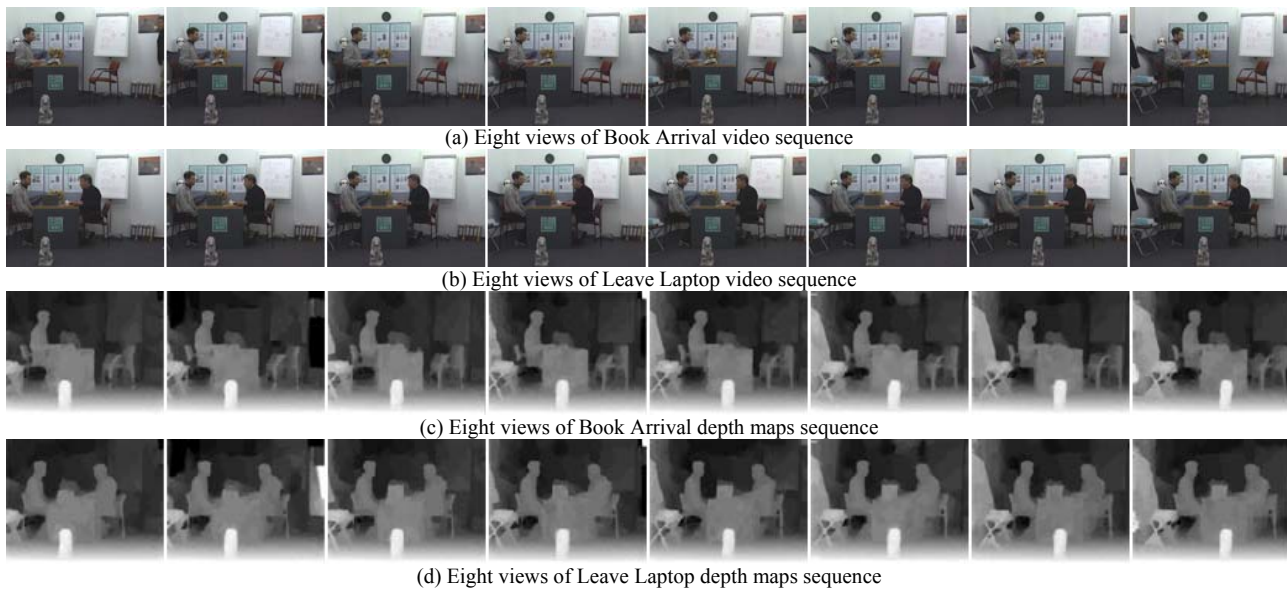


Figure 8. Multiview video and depth maps test sequences.

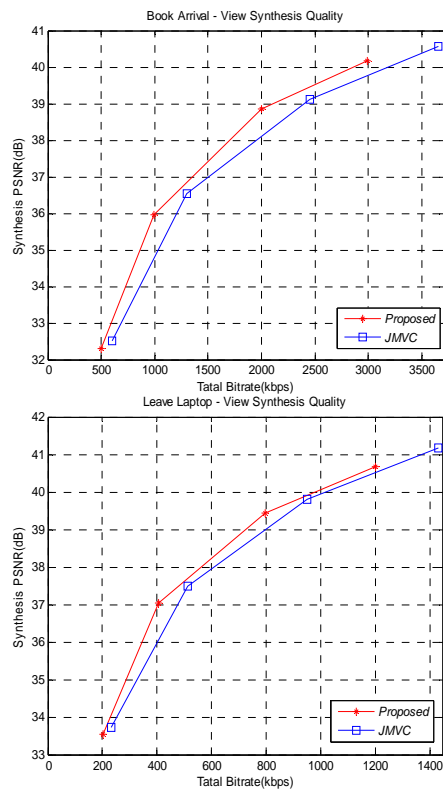


Figure 9. RD performance comparison between JMVC and the proposed method.

As for the second test, for the left view, the QP settings in video are 22, 27, 32, 37, and the QP of the depth are increased by 2 which correspond to 24, 29, 34, and 39. While for the right view in video and depth, the QP setting is increased by 6 as follows, 28, 33, 38, and 43. In addition, the QP setting of the non-edge areas in the depth maps is 33, 38, 43, and 48, respectively.

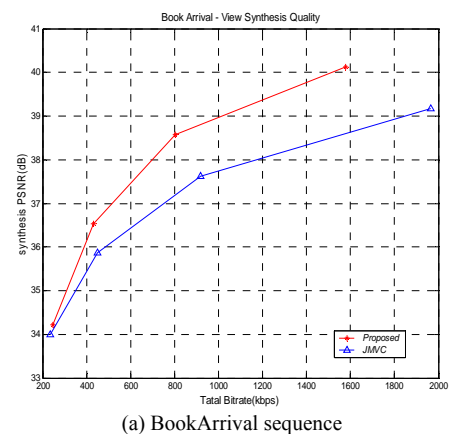
Table IX shows the RD performances of the proposed method and the JMVC. Every cell shows bit-rate of a test sequence with respect to a certain QP. Experimental

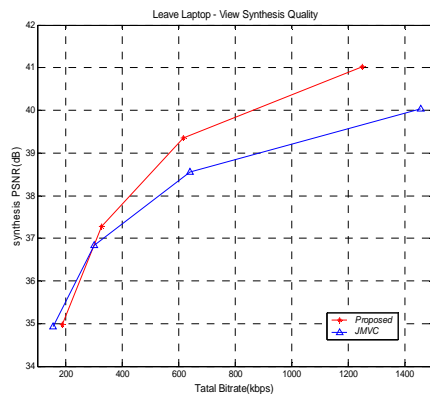
results of encoding bit-rate in which indicates the bit-rate saving in coding process and it is defined by (1).

For the Table IX with inconstant video and depth fidelity, the behavior can be categorized as follows: First, at high color qualities, the bit-rate of the proposed method decreases significantly by average 10.91%, ranging from 3.63% to 19.65%. Then, at low color qualities, the bit-rate rather increases remarkably. So the proposed method works well at high color qualities.

TABLE IX.  
RD PERFORMANCE COMPARISON BETWEEN THE JMVC AND THE PROPOSED METHOD

Color QP	Book Arrival total bit-rate (kbps)		
	JMVC	Proposed	Saved(%)
22	1964.40	1578.48	19.65
37	919.57	802.62	12.72
32	449.41	430.33	4.25
37	235.74	247.28	-4.89
Color QP	Leave Laptop total bit-rate (kbps)		
	JMVC	Proposed	Saved(%)
27	1457.60	1249.01	14.31
30	640.81	617.52	36.3
35	300.88	327.57	-8.87
42	154.86	189.05	-22.08
Average	10.91%		





(b) Leave Laptop sequence

Figure 10. RD performance comparison between JMVC and the proposed method.

Figure 10 shows the RD performance comparison of the proposed method and the JMVC for “Book Arrival” and “Leave Laptop”. The vertical axis in each figure is the PSNR of the Y component in the synthesized view, while the horizontal axis corresponds to the sum of the bitrates used for encoding the video and the depth maps. As depicted by the results, the proposed method clearly outperforms JMVC at higher bit-rate. Here, the same horizontal coordinate on the two curves indicates the same bitrates used for encoding the video and the depth maps, while the red curve which stands for the proposed method reflects a larger PSNR in the synthesized view. As a whole, compared with JMVC, the proposed method leads to significant RD performance optimization in synthesized quality at higher bit-rate.

## V. CONCLUSION

The work presented in this paper combines multi-view video plus depth coding with reliability within fixed bandwidth limitations based on view synthesis. It was found that characteristic of the depth, especially areas with depth edges are especially vulnerable to coding errors, which can be utilized in view synthesis.

In practice, different combinations of quantization parameters for multi-view video plus depth are coded in order to synthesize better quality of the virtual views. First, the joint multi-view video plus depth coding which aims to analyze the overall performance of the coding artifacts is processed. And the experiment results demonstrate the optimal combinations of the quantization parameters which close to the target bit rates. Second, the effects of video and depth maps compression artifacts were analyzed separately, when the quantization parameters of the left and right views in video and depth maps are the same, the quantization parameters value in depth maps can be increased by 2 compared to the corresponding views. On the contrary, the quantization parameters of the right view can be increased by 6 in comparison of the left one. In addition, the quantization parameters of the non-edge ones can be increased by 11 compared with the edge regions without significant influence on the synthesized views. Third, utilizing the chosen combinations of the quantization

parameters, the joint coding for multi-view video plus depth is conducted. The experimental results show the 12.72%~24.02% bit-rate reductions with better subjective quality in comparison with JMVC.

These results have been obtained for the state-of-the-art depth estimation and view synthesis techniques but may be modified when more precise techniques for depth estimation and view synthesis would be available.

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