A Just Noticeable Distortion Based Rate Control Algorithm for Multiview Video Coding

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Abstract—**To quantify human visual system characteristics to carry out rate controlling efficiently, this paper presents a new macroblock (MB) layer rate control algorithm for multi-view video coding (MVC) by improving quadratic rate-quantitative (R-Q) model based on the just noticeable distortion (JND) model. Firstly, the pixel-JND value of color image in multi-view video is stroked according to the related research in order to be used in the MB layer rate control. The proposed algorithm includes view layer, GOP layer, frame layer and MB layer, respectively. In the MB layer, the JND of the MB and mean absolute difference (MAD) in the quadratic R-Q model are firstly analyzed, the MAD is re-defined as perceptual MAD according to the JND with a pixel adjustment factor, and then QP of MB is computed through the re-defined quadratic R-Q model. Finally, a frequently-used image quality metric, peak signal-to-noise ratio (PSNR), is similarly re-defined as perceptual PSNR according to the JND. Experimental results show that the proposed algorithm can obtain higher image quality while precisely controls the bitrates. Moreover, the proposed algorithm not only can achieve better subjective quality, but also save the bitrates about 14.47% ~ 32.13%.**

Index Terms—**multi-view video coding, rate control, just noticeable distortion**

I. Introduction

With the rapid development of video techniques [1]-[3], three dimensional (3D) contents have become the major driving force governing today's dynamics of the consumer electronic market [4]. Moreover, 3D video services being brought into mobile are also becoming a reality [5] along with the popularization of mobile phone supporting stereoscopic display. In multi-view video coding (MVC), disparity compensated prediction and motion compensated prediction are exploited to reduce redundancies [6], [7]. However, the bit allocation and rate control (RC) are also needed in orienting to transmission and applications [8].

RC problem had been widely studied, such as MPEG-2 TM5, H.263 TMN8, MPEG-4 VM8 and H.264/AVC RC algorithm [9]. Recently, a number of projects have begun work on RC in MVC research areas. A RC algorithm for MVC was proposed to allocate bitrates among views based on statistical analysis [10]. Some characteristics of MVC were considered to allocate proper bitrates for B frames and quantization parameters (QP) values of B frames were taken into account when deciding the initial QP of group-of-picture (GOP) [11]. A joint buffer-related RC algorithm was presented in [12]. In image evaluation, there are two objective metrics, peak signal-to-noise ratio (PSNR) and mean square error (MSE). However, the traditional fidelity criteria do not reflect perceptual distortion well. Some video coding methods aiming to account for human visual system (HVS) have then been proposed [13]-[17]. A novel rate-distortion model based on structural similarity (SSIM) index was used to capture the R-SSIM characteristics regardless whether the rate consists of texture and header bits or simply texture bits. In [14], a guidance map was generated to guide the bit allocation strategy through a new constrained global optimization approach. To the best of our knowledge, the human eyes cannot sense any changes below the just noticeable distortion (JND) threshold around a pixel due to their underlying spatial/temporal sensitivity and masking properties. In video compression schemes, JND can be used to improve quantizes or to facilitate the rate-distortion, motion estimation [15], [16]. A perceptual video encoder architecture based on JND model under energy resource constraint was bailed [17], the JND was extended to temporal domain so as to determine perceptual cue in unit of macroblock (MB) and provides the guideline of resource allocation in MB's.

Obviously, it is imperative for us to design the RC algorithm based on an appropriate JND model aims at the lowest bitrate for signal representation at certain level of perceptual quality, or the highest perceptual quality with a given bitrate. In this paper, an improved quadratic RQ model based on the JND model is proposed. Firstly, the pixel JND value of color image is stroked according to the related research in order to be used in MB layer rate control. The proposed algorithm consists of four levels for rate bits control more accurately. In the MB layer, the total bitrate of MB is set and QP of MB is computed by improving the quadratic RQ model according to the JND model. Experimental results show that the proposed algorithm can not only achieve good objective quality, but also achieve better subjective quality when obtain accurate control accuracy.

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This paper is organized as follows: In Section II, we briefly describe the just noticeable distortion model. The multi-view video rate control algorithm is proposed in Section III. Then, the experimental results are analyzed in Section IV. Finally, the conclusions are given in Section V.

II. JUST NOTICEABLE DISTORTION MODEL

JND provides cues for measuring the visibility of HVS. In JND estimators, several major factors are usually considered, namely, contrast sensitivity function (CSF), luminance adaptation, and contrast masking. JND model can be derived by summing the effects of the visual thresholds in sub-bands, and considering all the relevant factors [18]. The overall DCT-JND of the (i,j)-th DCT subband, denoted as f_{JND}, can be determined by the base visibility threshold T due to the spatial CSF, the luminance adaptation factor b_{Lum} and the contrast masking factor b_e

$$f_{JND}(x,y,i,j)=T(i,j)\cdot b_{Lum}(x,y)\cdot b_e(x,y,i,j) \quad (1)$$

where (x,y) denotes the location of a DCT-block in image.

The base visibility threshold T for image can be determined by

$$T(i,j)=\xi_{i,j}\cdot N\cdot T^o(i,j) \quad (2)$$

$$\text{and } \xi_{i,j}=\begin{cases}1, i=j=0\\ 1/\sqrt{N}, i=0, j=0\\ 1/2, i,j\neq 0\end{cases} \quad (3)$$

where N is the dimension of a DCT block, $T^o(i,j)$ is derived from the CSF.

The quasi-parabola luminance adaptation is modeled as follows [19]

$$b_{Lum}(x,y)=\begin{cases}2(1-\frac{C(x,y,0,0)}{128\cdot N})^3+1, C(x,y,0,0)\leq 128\cdot N\\ 0.8(\frac{C(x,y,0,0)}{128\cdot N}-1)^2+1, otherwise\end{cases} \quad (4)$$

where $C(x,y,0,0)$ is the DC component of the DCT block.

The contrast masking factor be is computed by

$$b_e(x,y,i,j)=\begin{cases}\gamma(x,y),\ for (i,j)\in LF\cup MF, in Edge block\\ \gamma(x,y)\times\max\left\{1,(\frac{C(x,y,i,j)}{T(x,y,i,j)})^{0.36}\right\}, otherwise\end{cases} \quad (5)$$

where $\gamma(x,y)$ denotes the masking effect between the DCT sub-block.

Finally, the JND model is established and its corresponding JND map is shown in Fig. 1, where an image in Ballet multi-view sequence is used as an example. The value of JND is smaller when flat areas are darker according to HVS characteristics that the human eyes have more sensitive to distortion. Meanwhile, the more complicated texture areas at larger JND values can tolerate greater distortion in Fig. 1. In other words, distortion in the texture-rich region is not easily detectable according to HVS characteristics.

(a) Color image of Ballet

(b) JND map

Figure 1. Color images of Ballet and its corresponding JND map

III. THE PROPOSED MULTI-VIEW VIDEO RATE CONTROL ALGORITHM

Fig. 2 shows the hierarchal B picture (HBP) prediction structure in MVC with Joint Multiview Video Coding (JMVC) [20]. The arrows indicate the inter-frame reference relationship, and the horizontal arrows indicate temporal reference while the vertical arrows indicate inter-view reference. I-View uses intra-frame coding without reference to other view, and P-View unidirectional references to I-View, as View2 shown in Fig. 2. Similarly, B-View is bidirectional reference reconstructions of the I-View and P-View, as View1 shown in Fig. 2.

Based on human visual system characteristics, the proposed algorithm includes view layer, GOP layer, frame layer and MB layer.

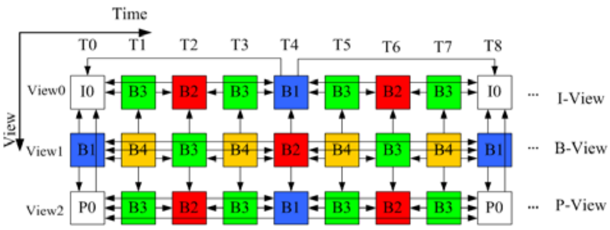


Figure 2. The HBP coding structure of three views in MVC

A. *Target Bitrate for the ViewLevel*

We allocate the bits rationally based on above statistical analysis about rate allocation proportion among views in sequences. Here, the target bit for each view is computed by

$$T_{view}(k)=T_{total}\times w(k) \quad (6)$$

where T_{total} and k denote the total bitrate for all views and the coding order index of view point, respectively. $w(k)$ is rate allocation proportion for each view, which depends on statistical analysis, $T_{view}(k)$ is the target bits for the k-th view.

B. Target Bitrate for the GOP Level and Setting the Initial QP in Each GOP

In the GOP level, the total number of bits allocated to each GOP is computed and the initial QP of each GOP is set. At the beginning of encoding the i-th GOP, the total number of bits allocated for the i-th GOP is computed by

$$T_r(i,0)=\frac{u(i,1)}{F_r}\times N_{GOP}-\left(\frac{B_s}{8}-B_c(i-1,N_{GOP})\right) \tag{7}$$

where N_{GOP} denotes total number of frames in the current GOP, $u(i,1)$ is available channel bandwidth, F_r is frame rate, and $B_c(i\text{-}1, N_{GOP})$ is actual buffer occupancy after coding the (i-1)-th GOP. The buffer occupancy should be kept at $B_s/8$ after coding each GOP.

MVC predicting structure has a large number of B pictures. Hence, QPs of B frames are taken into account when deciding the initial QP of GOP. The initial QP is computed by

$$\hat{Q}_{st\_c}=\frac{Sum_{BQP}}{N_b}-1-\frac{8T_r(i-1,N_{GOP})}{T_r(i,0)} \tag{8}$$

where N_b is total number of B frame in a GOP and Sum_{BQP} is the sum of QPs for all B frames in the previous GOP. The I frame, the P frame in P-view and the first B frame in B-view in each GOP are coded by using $\hat{Q}_{st\_c}$.

C. Rate Control Scheme for Frame Level

In terms of the frame level rate control of JVT-G012, the target bitrate for the j-th frame is a weighted combination of $\hat{f}(i,j)$ and $\tilde{f}(i,j)$

$$f(i,j)=\beta\times\hat{f}(i,j)+(1-\beta)\times\tilde{f}(i,j) \tag{9}$$

where β is a constant and its value is 0.5 when there is no B frame and is 0.9 otherwise in JVT-G012. Here, because the B frames are treated as P frames, β is set to 0.5.

D. Rate Control Scheme for Macroblock Level

The remaining bits are then allocated to all non-coded MBs based on the MADs of all non-coded MBs in the current frame. The target bit for the current MB is given by

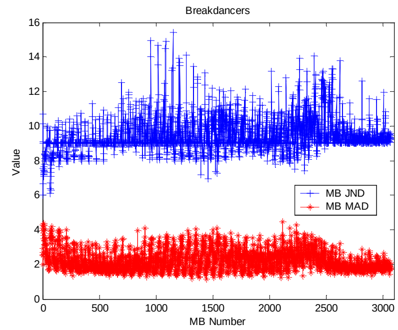
$$f_{mb}(j,k)=T_{mb}(i,j)\times\frac{MAD_{mb}^2(j,k)}{\sum_{l=k}^{N}MAD_{mb}^2(j,l)} \tag{10}$$

The quantization step-size can be computed by the quadratic R-Q model as

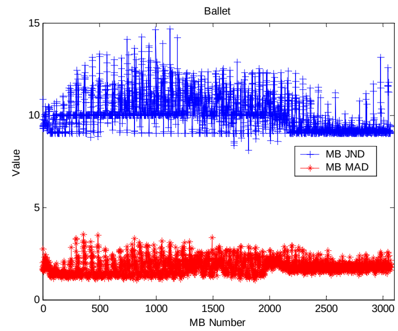
$$f_{mb}(j,k)=\left(\frac{X_1}{Q_s^2}+\frac{X_2}{Q_s}\right)\times MAD_{mb}(j,k) \tag{11}$$

where X_1 and X_2 are the model coefficients, $f_{mb}(j,k)$ denotes the total bits of the current MB, and $MAD_{mb}(j,k)$ is a prediction of the MAD of the current MB.

We analyze the JND and MAD values of the MB in order to take full advantage of HVS characteristics. Breakdancers and Ballet are tested in the experiments, the JND and MAD values of all MBs in one frame are shown in Fig. 3, where the blue and red show the JND and MAD of MB, respectively. Here, MB's JND values are near or greater value at 10 volatility and MAD values are generally fluctuate around 2, so the pixel-JND and MAD are not in a volatile range.



(a) Breakdancers



(b) Ballet

Figure 3. JND and MAD values fluctuation of all MBs in one frame

In order to make better use of JND, a regulator of the JND value is used to adjust the fluctuations range of JND to be in the vicinity of MAD, and the distortion that the human eye can tolerate is treated as zero. This adjustment factor is defined as

$$\lambda(x,y,j,k)=\frac{1}{(x+1)\times(y+1)}\sum_{m=0}^{x}\sum_{n=0}^{y}\mu(m,n,j,k) \tag{12}$$

$$\mu(m,n,j,k)=\frac{\left|I(m,n,j,k)-\hat{I}(m,n,j,k)\right|}{JND(m,n,j,k)} \tag{13}$$

where m and n represent horizontal and vertical coordinates of the pixel, respectively. $I(m,n,j,k)$ and $\hat{I}(m,n,j,k)$ denote the brightness values of the original image and reconstructed image at (m, n) in k-th MB in the j-th frame, respectively. $\lambda(x,y,j,k)$ is adjustment factor, $JND(m,n,j,k)$ is the pixel-JND, and $\mu(m,n,j,k)$ is the proportion of the difference between the original and reconstructed images. MAD in Eq. (11) is defined by

$$MAD(j,k)=\frac{1}{256}\sum_{x=0}^{15}\sum_{y=0}^{15}\left|I(x,y,j,k)-\hat{I}(x,y,j,k)\right| \quad (14)$$

Based on the above analysis, the MAD is re-defined as perceptual MAD, denoted as MAPD, according to the JND with a pixel adjustment factor, and Eq. (14) is adjusted as

$$MAPD(j,k)=\frac{1}{256}\sum_{x=0}^{15}\sum_{y=0}^{15}\left(\left|I(x,y,j,k)-\hat{I}(x,y,j,k)\right|-\lambda(x,y,j,k)*JND(x,y,j,k)\right)*\phi(x,y,j,k) \quad (15)$$

$$\phi(x,y,j,k)=\begin{cases}1 & \text{if } \left|I(x,y,j,k)-\hat{I}(x,y,j,k)\right|\geq\lambda(x,y,j,k)*JND(x,y,j,k)\\ 0 & \text{otherwise}\end{cases} \quad (16)$$

where $JND(x, y, j, k)$ is the pixel-JND value at (x, y) in the k-th MB in the j-th frame.

Finally, Eq. (11) is modified by

$$f_{mb}(j,k)=\left(\frac{X_1}{Q_s^{\,2}}+\frac{X_2}{Q_s}\right)\times\frac{1}{MAPD(j,k)} \quad (17)$$

In the proposed method, the QPs of MBs are computed by using the improved R-Q model in Eq. (17).

IV. Experimental Results

In order to demonstrate the effectiveness of the proposed MVC rate control algorithm, several experiments are performed with 3D video sequences of Breakdancers, Ballet, Doorflowers, and Rena. Breakdancers and Ballet (1024×768) are captured by Microsoft Research, Doorflowers (1024×768) is provided by MERL and Rena (640×480) is provided by Nagoya University. The four test sequences are shown in the APPENDIXE. The test conditions are shown in Tab. I.

In the experiments, we use the revised MVC software JMVC6.0 to implement the proposed RC algorithm. JMVC with the original rate control (MB_RC) and the proposed rate control algorithm (MB_JND_RC) are tested, respectively.

TABLE I.
Test Conditions

Frame Rate	15	Chanel Type	CBR
GOP Length	8	Search Mode	Fast Search
Search Range	32	Frame's No.	81

A. Rate Control Accuracy

We first confirm the accuracy of the proposed multi-view video rate control algorithm. Table II summarizes the matching accuracy between the actual bit-rate and the target ones. In Table II, the target bits and the actual bits are with respect to all of the three views. Rate control error (RCE) is used to measure the rate control accuracy.

$$RCE=\frac{R_{target}-R_{actual}}{R_{target}}\times 100\% \quad (18)$$

where R_{target} *and* R_{actual} denote the target bits and the actual coding bits, respectively.

TABLE II.
Simulation results of rate control accuracy

Sequences	Target bits	MB_RC	MB_JND_RC	RCE	
				MB_RC	MB_JND_RC
Breakdancers	6043.21	6040.54	6031.60	-0.04	-0.13
	2177.39	2178.12	2174.97	0.03	-0.14
	1037.30	1038.15	1036.32	0.08	-0.01
	593.834	590.07	590.93	-0.63	-0.62
Ballet	2506.52	2512.57	2510.63	0.24	0.24
	1145.99	1146.41	1146.23	0.03	0.13
	640.54	635.58	636.57	-0.77	-0.65
	387.17	384.03	380.97	-0.81	-2.16
Doorflowers	3098.5690	3101.7763	3102.2563	0.10	0.11
	1247.1230	1245.7822	1247.3630	-0.11	0.02
	630.9170	625.1185	621.7364	-0.92	-1.45
	359.2592	356.7407	351.8444	-0.70	-2.06
Rena	1546.92	1547.86	1547.51	0.06	0.03
	772.911	773.54	773.62	0.08	0.09
	398.37	398.20	397.26	-0.04	-0.27
	218.76	215.76	215.62	-1.37	-1.43

Table II indicates that the absolute accuracy of the proposed algorithm and the origin RC algorithm are within 2.1%. The proposed algorithm can provide a certain degree of rate control accuracy for 3D video coding.

B. Multi-view Video Quality Comparison

To objectively evaluate performance of rate control algorithms, the PSNR comparison between MB_JND_RC and MB _RC are shown in Table III According to the study shown that PSNR does not well reflect the subjective feelings of the human eye, in the above rate control, the algorithm has modified the quadratic RQ model based on JND. In order to obtain the subjective quality indicators more in line with of the human eye feelings, the frequently-used image quality metric, peak signal-to-noise ratio (PSNR), according to the JND is modified as IPSNR, and they are described by

$$PSNR(t)=10\log_{10}\frac{255\times 255}{\frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N}(|I(x,y,t)-\hat{I}(x,y,t)|)^2} \tag{19}$$

$$IPSNR(t)=10\log_{10}\frac{255\times 255}{\frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N}(|I(x,y,t)-\hat{I}(x,y,t)|-\lambda(x,y,t)*JND(x,y,t))^2*\phi(x,y,t)} \tag{20}$$

where $I(x,y,t)$ and $\hat{I}(x,y,t)$ denote brightness of the original and reconstructed images at (x, y) in the t-th frame, respectively. M and N denote the width and length of image.

Table III shows that the PSNR of the proposed algorithm decreases compared with the original RC algorithm, because the proposed algorithm can tolerate larger distortion at larger JND values, so large distortion in some areas with the large JND in reconstructed image and PSNR decline. In addition, Table III also shows the IPSNR value which is matched to the proposed algorithm, the increasing between IPSNR and PSNR is about 4-5dB.

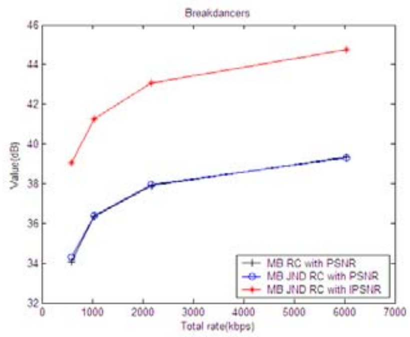
TABLE III.
SIMULATION RESULTS OF THE RECONSTRUCTED IMAGE QUALITY

sequences	PSNR			IPSNR
	MB_RC	MB_JND_RC	Gain	
Breakdancers	39.32	39.29	-0.03	44.75
	37.92	37.94	0.02	43.07
	36.34	36.39	0.05	41.28
	34.06	34.31	0.25	39.06
Ballet	41.21	41.19	-0.02	46.51
	39.76	39.77	0.01	44.71
	37.76	37.71	-0.05	42.15
	35.18	35.18	0.00	39.25
Doorflowers	40.99	40.98	-0.01	45.21
	39.32	39.33	0.01	43.26
	36.96	37.00	0.04	40.64
	34.21	34.56	0.35	37.96
Rena	44.51	44.46	-0.05	49.15
	41.39	41.36	-0.03	45.62
	37.83	37.76	-0.07	41.89
	34.52	34.39	-0.13	38.82

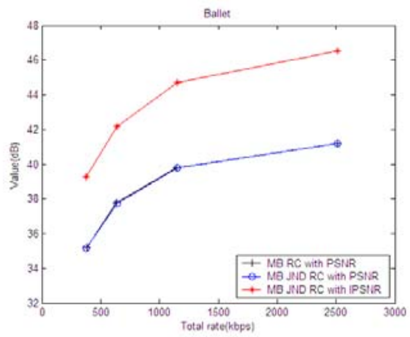
TABLE IV.
SIMULATION RESULTS OF RATE REDUCTION

Sequences	BDPSNR	BDBR	Average bits	Reduction
Breakdancers	5.14	555.14	2461.72	22.55%
Ballet	4.77	375.82	1169.65	32.13%
Doorflowers	3.91	252.26	1332.35	18.93%
Rena	4.24	106.17	733.84	14.47%

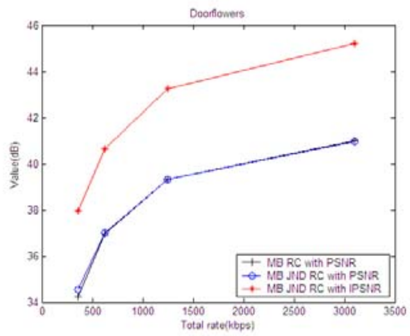
Fig. 4 shows the RD performance comparison between MB_RC with PSNR and MB_JND_RC with PSNR and MB_JND_RC with IPSNR. The black curve in Fig. 4 refers to the RD performance of MB_RC with PSNR, the second blue curve refers to the RD performance of MB_JND_RC with PSNR, and the third red curve refers to the RD performance of MB_JND_RC with IPSNR. Fig. 4 shows that in the PSNR case, the proposed algorithm can almost achieve the comparable the RD performance of the original algorithm, and in the IPSNR case, the RD performance of the proposed algorithm is relatively higher. In the human eye the PSNR quality corresponding to is IPSNR, so if the IPSNR as the standard, then the method can reduce the rate while the accuracy is precise, it is further verified in Table IV.



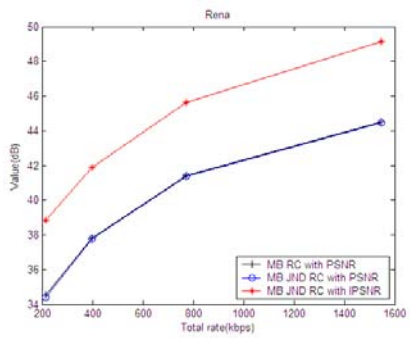
(a) Breakdancers



(b) Ballet



(c) Doorflowers



(d) Rena

Figure 4. The RD performance comparison between MB_RC with PSNR MB_JND_RC with PSNR and MB_JND_RC with IPSNR

In Table IV, BDPSNR and BDBR were the average difference of the PSNR and bitrates between the RD performance of MB_JND_RC with PSNR and MB_JND_RC with IPSNR, respectively. As can be seen from Table IV, the rate of proposed method with IPSNR can save about 14.47%-32.13% for the test sequence. The background scenes of Breakdancers and Ballet are relatively simple and a smaller QP is decided in flat areas with smaller JND value, so that the flat areas have higher quality than the original RC algorithm and it makes significantly higher rate reduced by 20% or more with IPSNR. The background is very complicated and there is a scene change in Doorflowers so it is hard to improve the quality of the flat areas and reduce the rate. The background of Rena sequence without scene changes is more complicated, so the rate reduction between the above two cases.

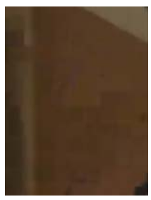
C. Subjective Quality Comparison

The subjective quality comparison between the proposed algorithm and the original RC algorithm are shown in Fig. 5-7. It is obvious that the edge of the dancing man is more clearly in the MB_JND_RC algorithm in Fig.5. And Fig. 6 also more clearly shows the dancer's leg has been completely destroyed in the MB_RC algorithm while the proposed algorithm is clearer. In Fig.7, It is clear that the MB_JND_RC algorithm has less distortion on the visitor's leg compared with the MB_RC algorithm.

(a) Result by MB_RC

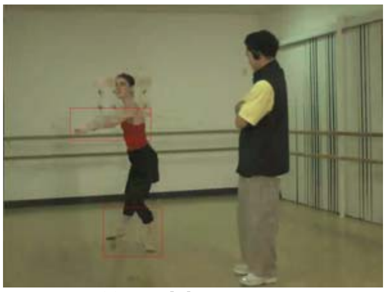
(b) Result by MB_JND_RC

(c) The local area of (a)

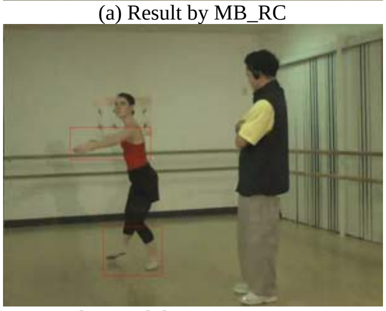


(d) The local area of (d)

Figure 5. Subjective quality comparison for Breakdancers between MB_RC and MB_JND_RC



(a) Result by MB_RC



(b) Result by MB_JND_RC

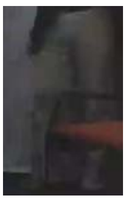
(c) The local area of (a)

(d) The local area of (d)

Figure 6. Subjective quality comparison for Ballet between MB_RC and MB_JND_RC

(a) Result by MB_RC

(b) Result by MB_JND_RC



(c) The local area of (a)

(d) The local area of (d)

Figure 7. Subjective quality comparison for Doorflowers between MB_RC and MB_JND_RC

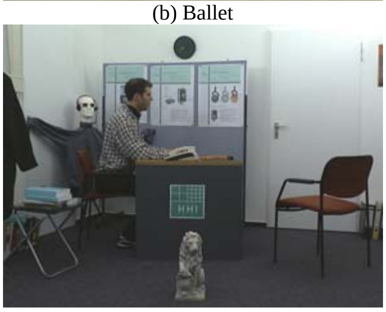
V. Conclusion

In this paper, an improved quadratic R-Q model is proposed based on the JND model. The algorithm consists of four levels for rate bits control more accurately. In the MB layer, the total bitrates of MB are set and QP of MB is computed by improving the quadratic R-Q model according to the JND model which is stroked according to the related research. Experimental results show that the improved algorithm not only can achieve good objective quality, but also can achieve better subjective quality when obtain accurate control accuracy. We will further study the RC problem in MVC by combining JND model. Images can be further divided into texture, smooth and edge according to JND, and then different level areas adopt different bit allocation schemes. Therefore, the different regions at different JND values can achieve the proper subjective visual effect.

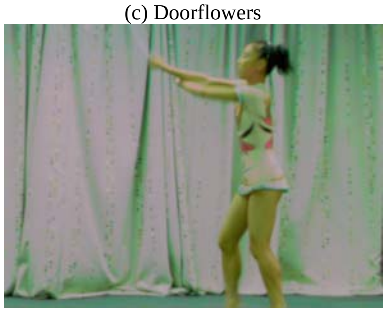
Appendix

(a) Breakdancers

(b) Ballet



(c) Doorflowers



(d) Rena

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