FAST SKIP MODE DECISION WITH RATE-DISTORTION OPTIMIZATION FOR HIGH EFFICIENCY VIDEO CODING

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ABSTRACT

In High Efficiency Video Coding (HEVC), the computational complexity has been increased so that an Early SKIP mode decision method is proposed by using coded block flag of an inter prediction unit (PU) to speed up mode decision with BD-bitrate increase. In this paper, we propose a fast SKIP mode decision algorithm to speed up PU mode decision for HEVC in a rate-distortion (RD) optimization sense. It is based on an adaptive linear predictor for PU mode type and available neighboring SKIP mode units on the quad-tree partition structure in HEVC for adaptive RD optimization. Moreover, the proposed method consists of both local (neighboring PUs) and global (previous PUs in current frame) level schemes on each coding unit (CU) level. In this way, it is possible to exploit high correlations between the RD cost of SKIP mode and spatial characteristics of video sequences by using the distribution of SKIP mode and a linear RD cost predictor. Experimental results show that the encoding computational complexity can be reduced by an average of 36 % with threshold RD cost, when compared to that of the HM 12 reference software.

Index Terms - video coding, visual communications, mode decision, HEVC.

1. INTRODUCTION

High efficiency video coding (HEVC), which is the state-of-the-art video compression standard, utilizes a hierarchical quad-tree structure to provide flexibility in coding, prediction, and transform. While capturing diverse video contents, a coding unit (CU) can be divided into different prediction units (PUs) and modes recursively by performing rate-distortion (RD) cost estimation. Although rate-distortion optimization (RDO) techniques can lead to higher coding efficiency [1], it comes, however, with significantly increase in coding complexity as compared to that of H.264/AVC due to RD cost calculations on all possible PU size selections and their modes. Even though Merge/SKIP mode and an Early SKIP (ES) mode decision method is proposed by using a coded block flag (CBF) of an inter PU, it occurs with BD-bitrate increase [2].

There exists research work to decide PU mode for video coding in order to reduce the computational complexity. It was proposed in [3, 4] a fast INTER mode decision of non-RDO process by checking edge information. For INTER mode decision, RD estimation and a CBF based approach were proposed in [2, 5] and were already applied in HEVC; also, [6, 7, 8] with INTER mode decision based on optimal modes from the previous frame were applied for H.264/AVC. However, there is a drawback from SKIP mode decision in HEVC which is that SKIP modes are decided by zeroed CBF with merge mode instead of the smallest RD cost.

In this paper, we model an adaptive linear RD cost predictor for RD cost and then propose a fast SKIP mode decision algorithm, which is based on an adaptive linear predictor and the probability of SKIP modes at each CU depth globally and locally.

The rest of this paper is organized as follows. A brief note on a linear predictor for the RD cost of SKIP mode calculation in HEVC is presented in Section 2. In Section 3, we illustrate our proposed fast SKIP mode decision algorithm and evaluate its performance in Section 4. Section 5 concludes our work.

2. SEQUENTIAL PREDICTOR OF PU MODES

Even though HEVC adopts CBF-based SKIP mode, it is not accurate enough [2, 9]. In order to increase the accuracy, we need to analyze and utilize the optimized RD model for PU mode decision. In this section, the RD cost of SKIP mode types should be analyzed and estimated in terms of an HEVC quad-tree structure so as to decrease computational complexity and to reduce BD-BR loss. In this paper, we propose a linear predictor from the analysis of probabilities

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for SKIP modes with RD costs based on HEVC quad-tree structure.

2.1. The Probability of SKIP Mode in HEVC

In this section, we describe a linear predictor for the probability of SKIP modes in HEVC. In order to formulate the problem of a linear predictor, HEVC quad-tree structure can be divided based on "local information" and "global information". In addition, we assume that local neighboring PU RD information can be trained by the global previous PU RD information.

We decide a SKIP mode by using a rectangular causal region of size 5 of neighboring PUs as shown in Figure 1 as "local information" and past training sets in Figure 2 as "global information" [10]. Here we define training set as all the previous PUs that select SKIP mode as the best mode in the current frame. This predictor design is related to context modeling of the prediction error and SKIP mode is optimally decided by using a probability of SKIP mode from neighboring units ("local") and a probability of SKIP mode from all previous coding units ("global"), respectively.

In order to obtain the optimal SKIP mode predictor on CU, we formulate the problem of a linear predictor design in order to predict RD cost of the current PU for training set S [10].

$$neigh(x_0) = \sum_{i=1}^{k} a_i \, x_i \qquad (1)$$

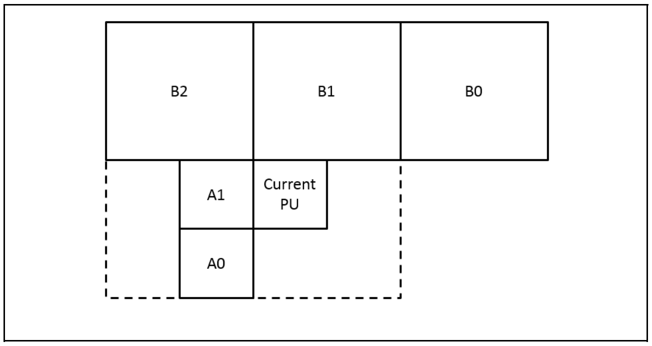


Fig. 1. Neighboring PUs in HEVC.

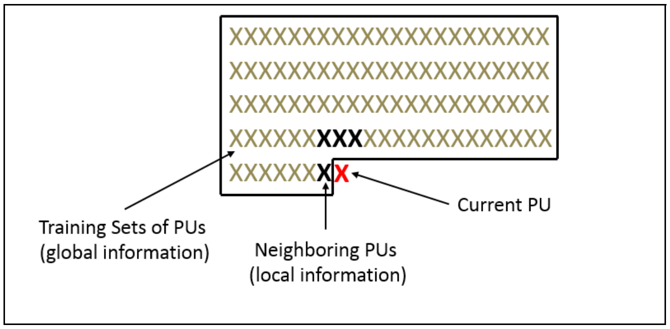


Fig. 2. 2-D linear predictor for the current SKIP mode. X denotes each PU. The 2-D predictor consists of the 4 or 5 neighboring PUs to the current PU mode of Figure 1.

where PU x_0 are predicted from previous PUs $x_1, x_2, x_3, \ldots, x_k$ which are the neighboring PUs causal to x_0 and $a = \{a_1, a_2, a_3, \ldots, a_k\}$ are estimated by training sets of PUs in Figure 2. That is, a_i depends on the number of available neighboring PUs in order to get the average RD cost of neighboring PUs such as 1/k.

However, the linear predictor for SKIP mode is based on PUs and does not consider the order of neighboring PUs as the predictor K. For designing a linear predictor, a rectangular causal region and the size of a causal region K should be defined and in our proposed method, it is dependent on geometry of the current PU type. The geometry of the predictor K of the 2D support is determined by the difference between the size of current PU and that of neighboring PUs. When we utilize a linear predictor, the 2-D template of K units should be defined. Figure 1 shows the characteristics of neighboring PUs according to PU size in terms of CU depth levels. If the size of the current PU is smaller than that of neighboring PUs, we can access neighboring unit $A0$. As a result, when we utilize fixed neighboring units for the current SKIP mode decision as the local information, the linear predictor consists of the RD cost prediction.

2.2. Merge/Skip Mode Operation

To make a decision on whether the optimal mode of a given PU is SKIP mode, HEVC exploits the fact that SKIP modes are dependent on zeroed CBF and for PUs that are merged with neighboring units [11]. In ES mode, SKIP mode is selected when there exist zeroed CBF and zeroed differential motion vector (DMV). From this observation, it is possible to predict the probability of SKIP modes for ES since SKIP mode should be selected as a PU mode when *CBF* value and DMV is zero.

$$Pr(SKIP) = Pr(CBF = 0, DMV = 0) \qquad (2)$$

where *CBF* is the coded block flag, *DMV* is the merged motion vector from neighboring units.

3. PROPOSED GLOBAL AND LOCAL LEVEL BASED FAST SKIP MODE DECISION METHOD

In this section, we propose a global and local level based fast SKIP mode decision algorithm (GLFS), which is based on an adaptive linear predictor by using the maximum probability of SKIP modes at each CU depth. We analyze the probabilities of SKIP mode corresponding neighboring PUs at each CU depth, and utilizes them for the current SKIP mode decision. Merge/Skip Mode Operation in section 2.2 is executed and evaluated on each CU level. That is, the distortion part of RD cost for current SKIP mode is related to the SKIP mode of neighboring units and CU depth level due to zero coded block flag (CBF). However, it should reflect the RD cost and merge mode characteristics on each CU depth level of SKIP mode.

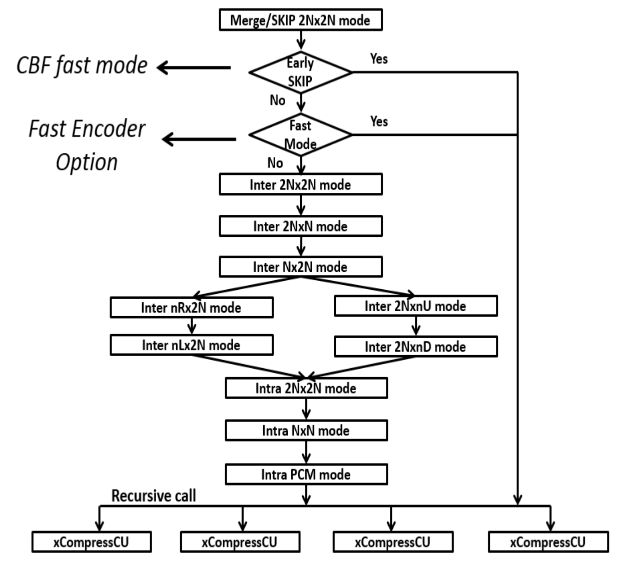


Fig. 3. PU mode decision flow considering SKIP mode.

To reduce computational complexity and to exploit the fact that SKIP modes are spatially related, we propose an adaptive RD cost based linear mode prediction by using the probability of SKIP modes at each CU depth in Figure 4. In the proposed method, SKIP modes for the current PU mode are considered to be decided. During Merge/SKIP mode decision, SKIP flag value is determined by CBF value [2, 9].

If CBF value is zero, the SKIP flag will become true. However, it is possible to be SKIP mode when CBF is not zero and the RD cost is small. It is possible to model the SKIP mode decision in terms of the probability of SKIP mode at each CU depth from following equations:

$$Pr(SKIP) = Pr(RDcost < neigh(RDcost), Local(SKIP) > Globel(SKIP)) \qquad (3)$$

where *neigh* denotes a linear predictor for the RD cost from the neighboring unit PUs. From this equation, it is possible to obtain the potential SKIP mode through *Pr*(*SKIP*) in Eq. (3) and Figure 2. That is, if we know the probability of SKIP mode with a given CU depth level, it will be possible to predict a SKIP mode.

3.1. Global and Local Level Mode Decision

In order to decide contexts, the threshold-based mode prediction can be applied to any video coding schemes, especially for RDO in HEVC.

Our proposed method predicts mode based on probability between global (CU depth levels) in Eq. (4) and local (PU mode types) information in Eq. (5) so that the limitation of independency can be overcome by using them as training sets for a linear predictor.

We define global and local probabilities *Global*(*t*) and *Local*(*t*) of the current PU mode according to zig-zag scanning order as follows:

$$Global(t) = P(Global(0), \dots, Global(t-1)) \qquad (4)$$

where *t* is current CU

$$Local(k) = P(Local(x-1,y-1), Local(x,y-1), Local(x+1,y-1), Local(x-1,y), Local(x-1,y+1)) \qquad (5)$$

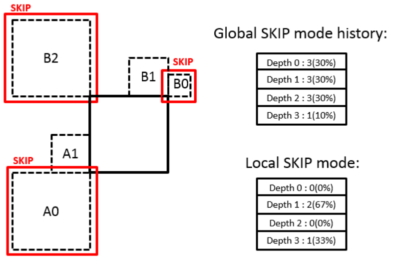
where *m* represents the PU mode type, $k = (x, y)$ and $x \in [0, \text{width})$, $y \in [0, \text{height})$ and (width, height) denotes the number of PUs in the horizontal and vertical directions.

3.2. RD Cost for Global and Local Level Schemes

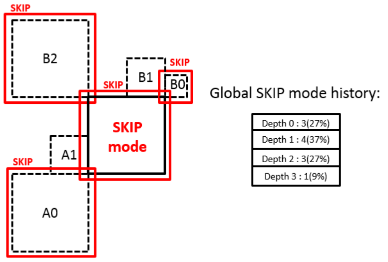
In this paper, we consider the case when an average RD cost is an RD cost prediction for SKIP mode in Figure 4. We apply threshold $TH_i(M)$ (M=*SKIP*) for PU mode decision by using information from neighboring SKIP modes and previous SKIP mode selections so that $TH_i(M)$ is selected by observing that there exists a high correlation between the current unit and previous/neighboring units. Therefore, for the i^{th} CU in the current frame, the threshold value $TH_i(M)$ of RD cost on mode M is defined as follows for each depth:

$$TH_i(M) = \alpha \times (\overline{TH}_{global,i}(M)) + (1-\alpha) \times (\overline{TH}_{local,i}(M)) \qquad (6)$$

where $\overline{TH}_{global,i}(M)$ denotes the average RD cost threshold for mode M in the all previous units of the current frame; $\overline{TH}_{local,i}(M)$ denotes the average threshold of the neighboring units with mode M, and α is a control parameter. From our empirical study, α assumes 0 for SKIP mode seemed to be reasonable due to the way SKIP modes are typically distributed in an inter frame.



(a) Before SKIP mode decision.

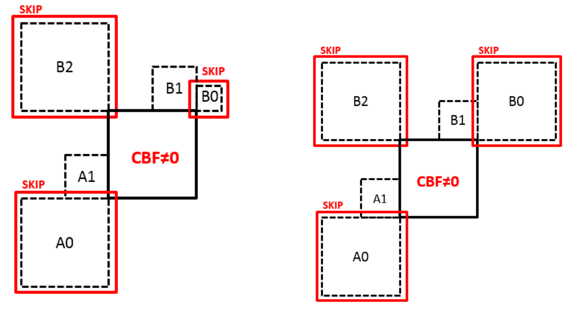


(b) After SKIP mode decision.

Fig. 4. SKIP mode decision method.

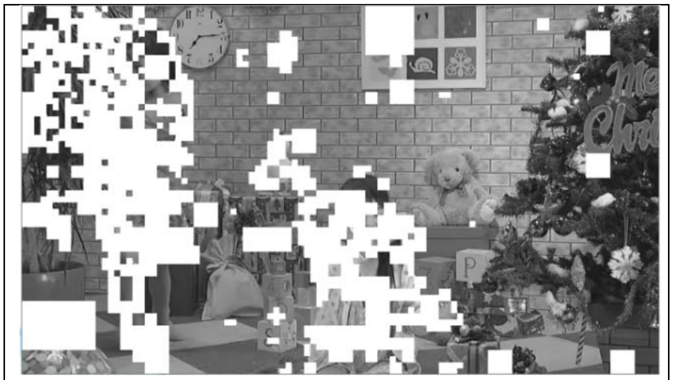
3.3. CU Depth Level-Based Mode Decision

In order to reduce computational complexity in Figure 3, we consider SKIP mode decision. This section proposes an adaptive SKIP mode decision method by using the probability of CU depth level and average RD costs to reduce computational complexity. We define the probability of SKIP mode from neighboring SKIP mode at CU depth level L and the global SKIP modes. Thus, we should optimize mode decision with the maximum probability among neighboring units.



(a) Case 1 (b) Case 2

Fig. 5. SKIP mode with neighboring units.



(a) The skipped area with anchor

(b) The skipped area with the proposed GLFS method

Fig. 6. The area detected by the proposed fast SKIP mode.

We therefore propose a fast SKIP mode decision scheme after Merge/SKIP mode decision. The SKIP mode decision on proposed process is summarized as follows for each possible depth level d of the CU:

$$Decision = \begin{cases} 1, Local(SKIP) > Global(SKIP) \text{ and\& } RD\ cost < TH_i(SKIP) \\ 0, otherwise \end{cases} \quad (7)$$

where *Local(SKIP)* and *Global(SKIP)* denote the probabilities for the number of SKIP modes in Figure 4.

Table 1. The increased SKIP mode ratio at CU depth

Sequence		Depth0	Depth1	Depth2	Depth3
NebutaFestival (A)	ES	1.268	0.643	0.490	0.581
	GLFS	1.077	1.295	1.918	2.034
StreamLocomotive (A)	ES	1.035	0.686	0.645	0.590
	GLFS	1.010	1.115	1.117	1.145
Traffic (A)	ES	1.054	0.783	0.698	0.658
	GLFS	0.998	1.158	1.352	1.533
PeopleOnStreet(A)	ES	1.090	0.984	0.957	0.892
	GLFS	1.018	1.060	1.118	1.230
BasketballDrive (B)	ES	1.033	0.862	0.868	0.906
	GLFS	1.015	1.107	1.137	1.120
Cactus (B)	ES	1.031	0.869	0.796	0.852
	GLFS	1.013	1.165	1.299	1.315
Kimono (B)	ES	1.081	0.824	0.756	0.857
	GLFS	1.021	1.123	1.185	1.107
Basketball Drill (C)	ES	1.037	0.957	0.858	0.793
	GLFS	1.024	1.084	1.161	1.267
BasketballDrillText (C)	ES	1.042	0.955	0.863	0.814
	GLFS	1.031	1.076	1.138	1.272
BQMall (C)	ES	1.065	0.961	0.884	0.785
	GLFS	1.010	1.092	1.197	1.322
PartyScene (C)	ES	1.243	0.855	0.800	0.748
	GLFS	1.062	1.159	1.348	1.531
Race Horses (C)	ES	1.149	1.008	0.887	0.808
	GLFS	1.031	1.111	1.194	1.407
BQSquare (D)	ES	1.251	0.951	0.859	0.688
	GLFS	0.998	1.132	1.287	1.519
Basketball Pass (D)	ES	1.082	1.008	0.898	0.714
	GLFS	1.040	1.048	1.104	1.274
Blowing Bubbles (D)	ES	1.304	0.907	0.831	0.768
	GLFS	1.091	1.103	1.173	1.428
Vidyo1 (E)	ES	1.022	0.667	0.878	0.687
	GLFS	1.001	1.228	1.146	1.497
Vidyo3 (E)	ES	1.024	0.780	0.834	0.640
	GLFS	1.009	1.179	1.228	1.851
Vidyo4 (E)	ES	1.021	0.744	0.892	0.777
	GLFS	1.006	1.198	1.108	1.367
ChinaSpeed (F)	ES	1.074	0.900	0.830	0.784
	GLFS	1.019	1.140	1.216	1.236
FourPeople (F)	ES	1.022	0.737	0.868	0.679
	GLFS	1.004	1.163	1.095	1.349
Johnny (F)	ES	1.024	0.635	0.869	0.714
	GLFS	1.006	1.154	1.124	1.468
KristenAndSara (F)	ES	1.025	0.658	0.872	0.659
	GLFS	1.005	1.226	1.156	1.756
Total Average	ES	1.090	0.835	0.824	0.745
	GLFS	1.022	1.142	1.218	1.410

In Figure 4, there are two neighboring SKIP modes at depth 1 and one SKIP mode at depth 3, respectively. Before deciding the current SKIP mode, the probabilities of SKIP mode in training set of PUs and neighboring PUs are compared. When the probability of locally neighboring PUs at CU depth level is larger than the probability of globally training set of PUs at CU depth level, SKIP mode for the current PU is selected. Otherwise, SKIP mode is not selected. Figure 5 depicts two cases when the number of SKIP modes is different according to CU depth level so that the average RD cost is different as well.

4. EXPERIMENTAL RESULTS

We conducted experiments on 22 test sequences and the test sequences selected by the JCT-VC have been encoded using the HEVC configuration [12] with quantization parameters 22, 27, 32, and 37. The test platform was Intel® CPU 3GHz with 8 cores, 24 GB RAM, with Windows 7 Professional 64-Bit operating system. The experimental condition shown in Table 3 is aligned with the common test conditions recommended by the JCT-VC [12, 13].

Table 1 compares the number of SKIP modes over HM 12 anchor on each CU level of our proposed method with that of ES mode in HM 12 when we utilize at least two neighboring PUs of SKIP mode in Figure 5 so as to predict a RD cost. The increased SKIP mode over that of HM 12 on each depth is given by

$$SK = Proposed\_Skip \,/\, Anchor\_Skip. \tag{8}$$

Our proposed method chose more SKIP modes than ES for depth 1 to depth 3 even though ES usually increases the number of SKIP modes rather than the HM 12 anchor only at depth 0. Figure 6 shows the example of a linear predictor with PartyScene test sequence. As one can see, SKIP modes from zeroed CBF which are labeled by red circles are merged and SKIP modes from RD cost are located near the SKIP modes from zeroed CBF.

Table 2. RD cost at each CU depth level on QP 37

Sequence		Depth0	Depth1	Depth2	Depth3
Class A	HM 12	276814	72104	19692	5748
	ES	276700	78351	23437	7265
	GLFS	292018	74697	19983	5716
Class B	HM 12	123407	35683	10899	3622
	ES	123041	46086	16559	6319
	GLFS	132100	37416	11112	3630
Class C	HM 12	302217	77298	21214	6513
	ES	301082	81852	25078	9898
	GLFS	317677	81349	22098	6635
Class D	HM 12	344275	82752	23054	6787
	ES	348177	83647	28076	10706
	GLFS	374172	88610	23860	6908
Class E	HM 12	73683	20618	5894	1820
	ES	73773	36794	11233	4806
	GLFS	78048	21433	6022	1847
Class F	HM 12	101390	27366	7588	2366
	ES	101299	38625	10774	4926
	GLFS	106098	28467	7782	2392
Total Average	HM 12	203631	52637	14724	4476
	ES	204012	60893	19193	7320
	GLFS	216686	55329	15143	4521

Tables 4 and 5 show the comparison results between the proposed algorithm and the anchor HM 12 with Early SKIP mode in terms of Bjontegaard differences in bit-rate (*BD-BR*), peak-signal-to-noise ratio (*BD-PSNR*), and time-saving *TS* (complexity reduction) given by

$$TS = (T_{HM} - T_{proposed}) \,/\, T_{HM} \times 100. \tag{9}$$

where T_{HM} denotes the execution time on HM 12 and $T_{proposed}$ denotes the execution time on the proposed method. As one can see, experimental results (Table 5) show that the proposed algorithm can provide an average of almost 36 % saving on overall encoding time over HM 12. On the average, the bit-rate change is 0.06 % and the BD-PSNR change is 0.001 dB. In particular, it was observed that video sequences for a SKIP mode decision are classified into three groups: CBF-preferred, RD cost-preferred, non-preferred. Nebuta Festival, Vidyo3, Vidyo4, and Johnny sequences belongs to CBF-preferred class since their BD-BR increase with Early SKIP mode over zeroed CBF and zeroed DMV is smaller than those of our proposed fast SKIP mode decision. However, the BD-BR performance of BasketballPass and KristenAndSara sequences for Early SKIP mode is almost same as those for our proposed fast SKIP mode. The rest of video sequences show the preference for RD costs regarding SKIP mode decision in HEVC.

In Table 2, RD cost shows the accuracy of SKIP mode decision methods since smaller RD cost leads to more accurate SKIP mode for PUs. However, our proposed method of fast SKIP mode decision works well for higher depths such as depth 2 and depth 3 compared to that of ES. That is, The RD cost of our proposed method is similar to that of HM 12 compared to the RD cost of ES at depth 2 and depth 3. For depth 0, the RD cost of ES shows the similar accuracy to that of HM 12 anchor. From Tables, we conclude that CBF-preferred method is good for large 2N×2N PU and RD cost-preferred method works well for small 2N×2N PU as a SKIP mode predictor.

Moreover, it was observed that more time was saved in the higher QP condition such as Classes E and F. That is, higher QP makes the detail of unit contents flat. It will utilize reference frames which are highly quantized and there will exist more SKIP modes than that with low QP. In other words, the proposed method will work well since the method is based on neighboring units with SKIP modes. The BD performance of the proposed algorithm is almost the same as that of HM 12 software, while the encoding complexity of the proposed scheme is reduced.

Under random access condition, the proposed method achieves 41% time saving with 0.01% BD-PSNR loss and 0.266% BD-BR gain whereas ES saves 38% time complexity with 0.016% BD-PSNR loss and 0.417% BD-BR gain.

5. CONCLUSION

This paper presents a global and local level based fast SKIP mode decision algorithm for HEVC using RD optimization and motion characteristics of video sequences to trim the decision tree at SKIP boundaries. We observe that the performance of causality-based mode prediction can be improved by partitioning the signal into local and global information. The technique provides on average 36 % reduction in encoding complexity with very minor RD performance changes. The encoder is more likely to adopt the neighboring SKIP mode history at each CU depth. From the information, local SKIP mode decision leads to greater time saving.

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Table 3. Experimental conditions

# of total frames	100
Max CU depth	4
LCU size	64×64
QP	22, 27, 32, 37
GOP Structure	Low Delay P-frame
The proposed GLFS method	At least 2 neighboring SKIP mode units
Comparison	HM 12 and Proposed method

Table 4. Experimental results of Early Skip Mode comparing with low delay P-frame

Sequence (class)	BD-PSNR [Y] (dB)	BD-BR (%)	TS (%)
NebutaFestival (A)	-0.004	0.082	7.127
StreamLocomotive(A)	-0.007	0.330	29.906
Traffic (A)	-0.014	0.443	37.646
PeopleOnStreet(A)	-0.014	0.304	15.921
BasketballDrive (B)	-0.008	0.377	20.530
Cactus (B)	-0.010	0.470	26.727
Kimono (B)	-0.008	0.239	22.692
BasketballDrill (C)	-0.010	0.280	19.854
BasketballDrillText(C)	-0.014	0.360	23.021
BQMall (C)	-0.013	0.334	19.321
PartyScene (C)	-0.012	0.277	17.520
Race Horses (C)	-0.005	0.121	10.042
BQSquare (D)	-0.021	0.524	23.179
BasketballPass (D)	-0.009	0.203	20.781
Blowing Bubbles (D)	-0.019	0.476	16.607
Vidyo1 (E)	-0.007	0.136	44.738
Vidyo3 (E)	-0.023	0.761	40.270
vidyo4 (E)	2.84E-06	0.006	42.2501
ChinaSpeed (F)	-0.016	0.292	19.607
FourPeople (F)	-0.007	0.092	46.647
Johnny (F)	-0.002	0.343	48.343
KristenAndSara (F)	-0.011	0.318	47.237
Average	-0.011	0.308	27.271

Table 5. Experimental results in GLFS compared with low delay P-frame

Sequence (class)	BD-PSNR [Y] (dB)	BD-BR (%)	TS (%)
NebutaFestival (A)	-0.0054	0.1286	13.8788
StreamLocomotive (A)	0.0027	-0.0345	36.5341
Traffic (A)	-0.0002	0.0042	44.829
PeopleOnStreet(A)	-0.0001	0.0062	21.0742
BasketballDrive (B)	-0.0011	0.1030	30.0277
Cactus (B)	-0.0069	0.3095	34.8187
Kimono (B)	0.0082	-0.2176	29.1561
BasketballDrill (C)	0.0028	-0.0732	28.8597
BasketballDrillText(C)	0.0138	-0.3422	29.9744
BQMall (C)	-0.0079	0.1855	29.3817
PartyScene (C)	0.0019	-0.0544	26.8959
Race Horses (C)	-0.0007	-0.0007	20.6733
BQSquare (D)	0.0083	-0.251	35.9889
BasketballPass (D)	-0.0098	0.1883	32.0192
Blowing Bubbles (D)	-0.0083	0.1922	28.9840
Vidyo1 (E)	0.0032	-0.1724	56.133
Vidyo3 (E)	-0.0291	0.8963	51.5
vidyo4 (E)	-0.0048	0.2481	51.0403
ChinaSpeed (F)	0.0173	-0.3146	24.5259
FourPeople (F)	0.0025	-0.2030	54.4026
Johnny (F)	-0.0058	0.4244	57.0425
KristenAndSara (F)	-0.0090	0.3000	55.5163
Average	-0.0013	0.0601	36.0571