Rate Distortion Cost Modeling of Skip Mode and Early Skip Mode Selection for H.264

Siwei Ma*[a], Wen Gao[a], Debin Zhao[b]

[a]Institute of Digital Media, Peking University, Beijing, 100871, China
[b]Institute of Computing Technology, Chinese Academy of Sciences, Beijing, 100080, China
{swma, wgao}@pku.edu.cn, dbzhao@jdl.ac.cn

ABSTRACT

This paper proposed a linear rate-distortion (RD) cost model for skip mode in H.264. The proposed RD cost model is derived theoretically based on the quantization scheme of H.264, and the simulation results also verify that the proposed RD cost model can estimate the RD cost of skip mode accurately. Based on the proposed RD cost model, an early skip mode selection algorithm is provided. The proposed early skip mode selection method can terminate the mode selection process adaptively and works well for both low complexity and high complexity video. Experimental results show that the proposed early skip mode selection algorithm can save the encoding time up to 56% with negligible performance loss.

Keywords: skip mode, fast mod decion, rate-distortion cost, quantization

1. INTRODUCTION

H.264 has achieved the significant performance improvement over previous standards, but it is at the cost of increasing encoder computational complexity. In H.264, the macroblock modes can vary from the set {INTRA4x4, INTRA8x8, INTRA16x16, INTER16x16, INTER16x8, INTER8x16, INTER8x8, INTER8x4, INTER4x8, INTER4x4, SKIP, DIRECT}. And a rate-distortion optimization (RDO) coding scheme [1] is used to select the optimal coding mode, which has the minimal rate-distortion cost. As the RDO scheme need to compute the reconstructed distortion and the coding bits for each mode, the encoder complexity has also been increased greatly, and many fast mode decision researches have been done for H.264 to reduce the mode selection complexity, such as [2][3][4] etc.

In [2], a fast coding mode selection algorithm is proposed by using early skip mode decision and selective intra coding. In [3], a transform domain bit-rate estimation and distortion measure scheme is proposed for inter mode decision. In [4], a low complexity skip prediction scheme is proposed by predicting the RD cost of skip mode from the co-located macroblock in the previous frame. Among these fast mode decision algorithms, early skip mode selection is always on the first priority. Because the fast skip mode decision can save much time used for inter modes and intra modes decision. In the state-of-the-art early skip mode selection algorithm, the skip mode is selected when the RD cost of the skip mode is less than a threshold. However, as the RD cost of the skip mode varies with the quantization parameter, the fixed RD cost threshold is not adaptive to the video content, and it would cause coding performance loss.

In this paper, the rdcost of skip mode is studied theoretical based on the quantization scheme of H.264. And a rate-distortion cost model is proposed for the skip mode. Based on the proposed RD cost model, a fast skip mode selection algorithm is proposed.

The rest of this paper is organized as follows, in Section 2, the derivation of the rate-distortion cost model of skip mode is detailed. Section 3 illustrates the proposed fast skip mode selection algorithm and preliminary experimental results are provided. And finally, Section 4 concludes the paper.

2. RATE DISTORTION COST MODELING FOR SKIP MODE

In the H.264 RDO mode selection process, the RD cost of each mode is calculated and the mode with minimal RD cost is selected as the best coding mode. For the skip mode, the skip mode RD cost RD_{skip} is calculated as:

$$RD_{skip} = D_{skip} + \lambda R_{skip}$$

where λ is the lagrangian multiplier. D_{skip} is the distortion of the skipped macroblock, which is SSE (Sum of Squared Error) in the H.264 encoder. R_{skip} is the bits used to denote the skip macroblock type. In general R_{skip} is a very small value near zero and $D_{skip} \gg R_{skip}$. So it is very important to model the distortion of skip mode for RD cost estimation. In the H.264 encoder, the distortion of skip mode is calculated as:

$$D_{skip} = SSE = \parallel O - P \parallel^2$$

where O is the original samples in the current frame. P is the predicted samples in the previous frame. $\parallel \cdot \parallel$ denotes L2 norm. As we know the prediction samples P is selected from the reconstructed reference frame, the distortion of skip mode can be modeled as:

$$D_{skip} = D_n + D_q \tag{1}$$

where D_n is the distortion introduced by noise excluding quantization, such as lighting change, object change. For ideal prediction, e.g. exact prediction, D_n should be zero. D_q is the quantization error introduced by the previous reference frame, which is usually denoted by MSE (Mean Square Error) between the original samples and the reconstructed samples. In general, $D_q \gg D_n$ holds true when skip mode is selected, on the other hand when the best mode is intra mode, $D_n \gg D_q$ holds true. So for skip mode, the key is to model D_q well.

To model the quantization error D_q, we give a study on the relationship between distortion and quantization parameter. In H.264, it has been shown that there is a linear relationship between the $PSNR$ and the quantization parameter, as follows:

$$PSNR = k * QP + b \tag{2}$$

$PSNR$ is calculated as:

$$PSNR = 10 \log_{10} \left(\frac{255^2}{D_q} \right) = 10 \log_{10} \left(\frac{255^2}{MSE} \right) \tag{3}$$

Based on (2) and (3), we can get:

$$D_q = 255^2 * 2^{-k'QP - b'} \tag{4}$$

Here,

$$k' = k * 10 \log_2 10, b' = b * 10 \log_2 10.$$

In H.264, the quantization parameter and the quantization step has the following relationship,

$$Q_{step} = 2^{(QP-4)/6} \tag{5}$$

Replace QP in (4) with (5), and we have:

$$D_q = A Q_{step}{}^{\gamma}$$

Here

$$A = 255^2 * 2^{-4k' - b'}, \gamma = -6k'.$$

So the total distortion of skip mode can be modeled as

$$D_{skip} = A Q_{step}{}^{\gamma} + D_n$$

And the RD cost model of the skip mode is shown as follows:

$$RD_{skip} = A Q_{step}{}^{\gamma} + B \tag{6}$$

$$B = D_n + \lambda R_{skip}$$

To verify the proposed model, we have collected the RD cost of skip mode on test sequences. In the experiments, the average RD cost ARD_{skip} is used:

$$ARD_{skip} = RD_{skip} / 384$$

Here 384 is the total number of samples including 256 luma samples and 128 chroma samples in one macroblock. The sequences are tested with QP range from 24 to 50, which covers the general coding configuration of the quantization parameter. And as we know at the high bit rate, the ratio of skip mode is very low and the time saving of the early skip mode selection algorithm is very limited. The relationship between average RD cost ARD_{skip} and the quantization step is shown in Figure 1.

From the curve, it can be seen that the RD cost of skip mode can be well fitted with a linear model of Q_{step}, which means the model parameter γ in (6) is approximately equal to 1. For the model parameter B, when skip mode is selected, the coding rate R_{skip} and the noise distortion D_n is usually much less than the quantization error D_q and can be neglected.
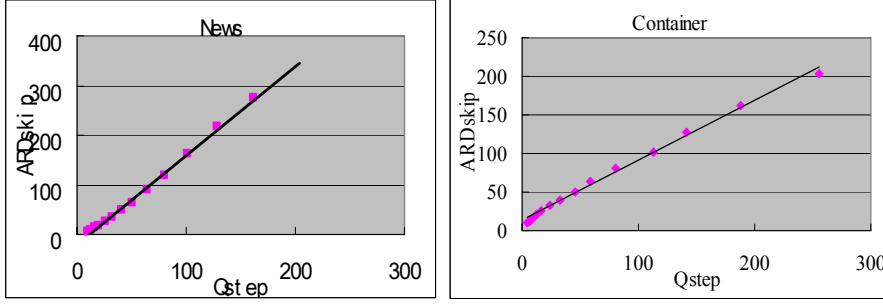

Figure 1. Average skip mode RD cost and the quantization step

The RD cost of skip mode when skip mode is not the best mode is also studied. It was found that the linear RD cost model can still approximate the RD cost of skip mode well, but the slope of the curve is higher when skip mode is not the best mode, as shown in Figure 2. In our experiments, when the best mode is skip mode, the slope of the RD cost curve is usually in the range [0.8, 1.8].
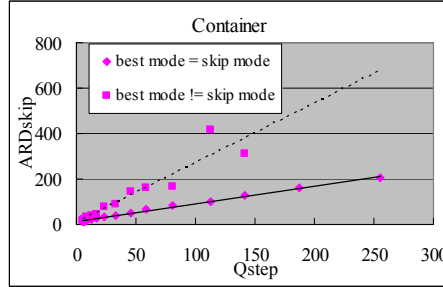

Figure 2. Average skip mode RD cost when the best mode is skip mode or non-skip mode

3.   PROPOSED FAST SKIP MODE SELECTION ALGORITHM

In Section 2, we have derived a RD cost model for skip mode and the simulation results show that the RD cost of skip mode can be well modeled with a linear RD_{skip}-Q_{step} model. And when the best mode is skip mode, the RD_{skip}-Q_{step} curve usually has lower slope. Based on the observation, we proposed an early skip mode selection algorithm. The approximated slope of the RD_{skip}-Q_{step} model is used for fast skip mode selection. The details of the proposed algorithm are shown as follows:

Step 1. For the first P frame, initialize the total skip mode RD cost J of skipped macroblocks J=0 in the coded macroblocks; initialize the skipped macroblock count M=0; initialize the threshold value t=1.0 for early skip mode selection.

Step 2. Calculate the average skip mode RD cost ARD_{skip} for the current macroblock, and calculate the approximated RD cost curve slope as s=ARD_{skip}/Q_{step};

Step 3. Compare the approximated RD cost curve slope s with the threshold value t. If $s<t$, skip mode is selected as the best mode, set $J=J+ARD_{skip}$, $M=M+1$, and end the mode decision process for the current macroblock, otherwise continue the RDO process as that in H.264 encoder. Goto step 2, continue coding the next macroblock until all the macroblocks in the frame are coded;

Step 4: Update the threshold value t as $t=J/(M*Q_{step})$. Goto step 2 to coding next frame.

The proposed early skip mode selection has been implemented into H.264 reference software JM12. As the threshold is updated adaptively, the proposed algorithm works well for both low complexity and high complexity sequences. As shown in Table 1, the complexity reduction is up to 56% with negligible performance loss for baseline profile coding. The average bit rate increasing is less than 2% and PSNR loss is less than 0.1dB even for high motion sequences, such as foreman, bus, etc.

Table 1. Performance comparison for the proposed algorithm

Test Sequence	BDPSNR (dB)	BDBR (%)	Time Saving (%)
Container	-0.05	1.12	56
News	-0.09	1.62	49
Foreman	-0.08	1.65	32
Mother_Daughter	-0.03	0.72	39
Silent	-0.03	0.58	40
Bus	-0.09	1.93	16
Paris	-0.06	1.12	33
Average	-0.06	1.27	39

4. CONCLUSIONS

This paper proposed a linear RD cost model for skip mode. Based on the proposed RD cost model, a fast skip mode selection algorithm is provided, and the encoder complexity was reduced greatly with negligible performance loss. As the model parameter is updated adaptively, the proposed algorithm works well for both low complexity and high complexity sequences. Further performance improvement will be more promising when the proposed early skip mode selection scheme is used together with other fast mode decision algorithms, such as selective intra coding, low complexity RD cost estimation for coding modes.

REFERENCES

[1] T. Wiegand and B. Girod, "Lagrange Multiplier Selection in Hybrid Video Coder Control," Proc. International Conference on Image Processing, ICIP-2001, Thessaloniki, Greece, October 2001.

[2] I. Choi, J. Lee and B. Jeon, "Fast Coding Mode Selection with Rate-Distortion for MPEG-4 Part-10 AVC/H.264," IEEE Trans. on Circuits and Systems for Video Technology, Vol. 16, No. 12, pp1557-1561, December 2006.

[3] Y. Tu, J. Yang and M. Sun, "Efficient Rate-Distortion Estimation for H.264/AVC Coders," IEEE Trans. on Circuits and Systems for Video Technology, Vol. 16, No. 5, pp600-611, May 2006.

[4] C.S. Kannangara, I.E.G. Richardson, M. Bystrom, J. Solera, Y. Zhao, A. MacLennan and R. Cooney, "Low Complexity Skip Prediction for H.264 through Lagrangian Cost Estimation," Volume 16, Issue 2, Feb. 2006 pp202-208.