A Fast Intra Skip Detection Algorithm for H.264/AVC Video Encoding

Byung-Gyu Kim, Jong-Ho Kim, and Chang-Sik Cho

A fast intra skip detection algorithm based on the rate-distortion (RD) cost for an inter frame (P-slices) is proposed for H.264/AVC video encoding. In the H.264/AVC coding standard, a robust rate-distortion optimization technique is used to select the best coding mode and reference frame for each macroblock (MB). There are three types of intra predictions according to profiles. These are 16×16 and 4×4 intra predictions for luminance and an 8×8 intra prediction for chroma. For the high profile, an 8×8 intra prediction has been added for luminance. The 4×4 prediction mode has 9 prediction directions with 4 directions for 16×16 and 8×8 luma, and 8×8 chrominance. In addition to the inter mode search procedure, an intra mode search causes a significant increase in the complexity and computational load for an inter frame. To reduce the computational load of the intra mode search at the inter frame, the RD costs of the neighborhood MBs for the current MB are used and we propose an adaptive thresholding scheme for the intra skip extraction. We verified the performance of the proposed scheme through comparative analysis of experimental results using joint model reference software. The overall encoding time was reduced up to 32% for the IPPP sequence type and 35% for the IBBPBBP sequence type.

Keywords: H.264/AVC, inter frames, intra mode, inter mode, adaptive thresholding, rate-distortion optimization.

I. Introduction

Developments in video coding techniques have accelerated over the last several years. H.264/AVC video coding is the newest standard defined by the Joint Video Team (JVT) [1], [2] for which various techniques have been adopted to obtain a high coding efficiency compared to previous standards.

Among the new techniques of H.264/AVC video coding, motion estimation has been introduced to improve the previous MPEG H.261, and H.263 [1], [2] video standards. Motion estimation for inter prediction is generally performed on a 16×16 macroblock (MB) and an 8×8 block. Each 16×16 MB and 8×8 block is assigned a suitable motion vector. This method causes minimum block distortion.

A variable block size for inter mode prediction maximizes the coding efficiency based on rate-distortion optimization (RDO) in the H.264/AVC coding standard [2]. The block sizes are 16×16, 16×8, 8×16, 8×8, 8×4, 4×8, and 4×4. In addition, intra mode prediction (nine modes for a 4×4 luma block and four modes for 16×16 luma and 8×8 chroma blocks) follows inter mode prediction to determine the best residual image [1], [2]. Recently, nine intra mode predictions for an 8×8 luma block were added for the high profile. As a result, the complexity and computational load increased dramatically for the inter frame. Therefore, a fast mode decision scheme that can reduce the complexity of the H.264/AVC video encoder is needed.

For any block mode, a motion vector estimation for a minimum residual image is also performed by full search [3] or fast motion search methods [4], [5]. Also, several fast inter mode selection methods have been developed [6]-[10].

There are many algorithms for fast intra mode searches [11]-[17]. We categorize these intra mode decision methods into

two groups. One, the intra mode skip detection approach, is a group that determines whether to skip the intra mode decision procedure [11]. The other, the prediction-mode reduction approach, is a group that decreases the intra search time by reducing the number of prediction directions for the current MB, or by early termination of each directional mode search by thresholding [12]-[17].

Lee and others proposed a selective intra mode search method based on the transformed coefficients of the residual image and upper-row and left-column pixel values [11]. A directional-field-based approach has been reported by Pan and others [12], [13] where several directions are selected by using an edge direction texture histogram according to block types. Also, a method that uses a change in the search routine and an edge direction histogram have been proposed [14] in which intra mode information for the neighboring MB is necessary for the intra mode decision procedure.

Kim and others [15] suggested a method based on a multi-stage sequential mode decision process that uses joint spatial and transformational domain features to filter out unlikely candidate modes. For intra prediction of 4×4 blocks, Cheng and Chang have presented a three step intra prediction algorithm using the correlation between the neighborhood directions [16]. Also, Sim and Kim [17] proposed a method for a fast intra mode search by using an off-line training scheme and the probabilistic characteristic of the neighbor mode information. This is suitable for an I-slice.

As described above, most previous work was based on an I-slice, except for Lee's method [11] which is computationally complex because of transformation of the residual image. For many fast mode decision schemes, the following rate-distortion (RD) optimization has also been used [11]-[17]:

$$J_{RD} = SAD_{Mode} + \lambda \cdot \{R(Header) + R(Residual)\}, \quad (1)$$

where J_{RD} is a bit rate distortion value as a cost function, SAD_{Mode} is the sum of the absolute differences for the given mode, λ denotes the Lagrangian multiplier, $R(x)$ is a bit amount for coding x, $Header$ provides header information, and $Residual$ is the residual data for the given MB.

We propose an adaptive intra mode skip detection algorithm (AISDA) for inter frames to compensate for the noted shortcomings. The proposed algorithm is developed based on the RD costs of the neighboring MBs for the current MB and uses a proposed adaptive thresholding scheme.

In section II, the intra mode search procedure for H.264/AVC is reviewed. Observations and the proposed algorithm are introduced in section III, experimental results are presented in section IV, and conclusions are presented in section V.

II. Overview of Intra Mode Prediction in H.264/AVC

We now review the intra mode prediction scheme for H.264/AVC video coding. Intra prediction for an 8×8 luma block (I8MB) was recently added to the existing 16×16 block (I16MB), the 4×4 luma blocks (I4MB), and the 8×8 chroma block for the high profile.

1. I4MB Prediction Modes

There are nine prediction modes for each 4×4 luma block as shown in Fig. 1(a). Samples a through p for each block are taken using neighboring samples A through M. Eight prediction directions and one DC prediction are checked for the best prediction. Among these prediction block images, a prediction mode is determined that has the minimum distortion for the best coding efficiency for each 4×4 block type. Therefore, this intra prediction search is needed for sixteen 4×4 blocks in an MB.

For example, if we choose Mode 0, then the pixels a, e, i, and m are predicted based on the neighboring pixel A; pixels b, f, j and n are predicted based on pixel B, and so on. Moreover, the plane mode is predicted by a linear spatial interpolation using the upper and left-hand samples of the MB [2]. In the standard, the mode order has been determined through statistical analysis. The probability of occurrence increases as the corresponding MB goes to Mode 0.

2. I16MB and I8MB Prediction Modes

For the I16MB prediction mode, four prediction directions are supported, as illustrated in Fig. 1(b). This is suitable for smooth image regions where a uniform prediction is performed for the entire luma component of an MB.

In recent studies, nine prediction modes for an 8×8 luma block (I8MB) have been adopted for the high profile [18]. This prediction mode is a logical extension of the existing 4×4 luma intra prediction (I4MB). Here, we do not focus on these prediction modes for an 8×8 luma block type, because most of the previous methods are not able to support this mode. This has been described well in [18].
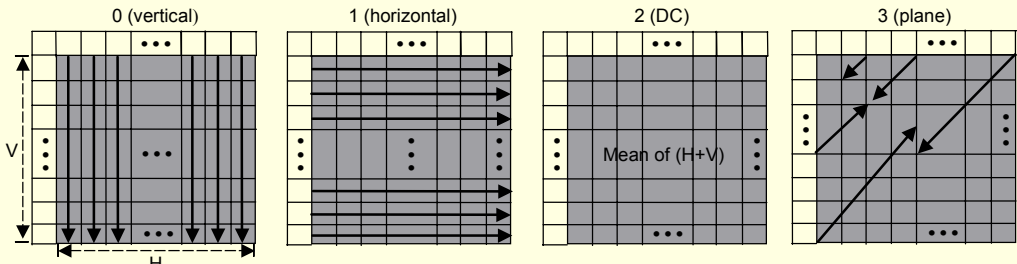
3. 8×8 Chroma Prediction Modes

For a given MB, each 8×8 chroma component is predicted from chroma samples above and to the left that have been previously encoded and reconstructed. Figure 1(d) illustrates four modes that have a different order compared to the I16MB and I8MB prediction modes. The same prediction mode is applied to all chroma blocks.
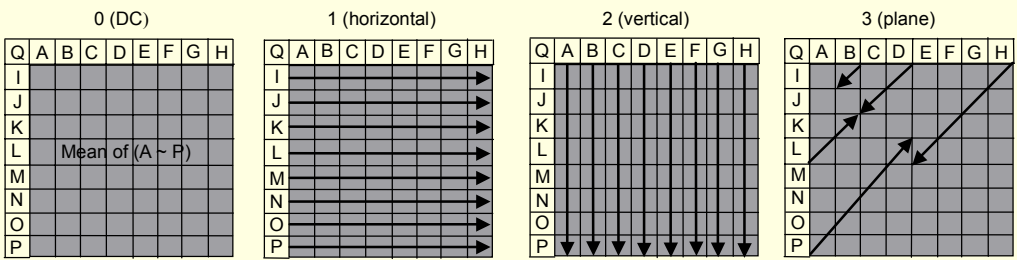
The H.264/AVC standard uses the RDO technique to achieve the best coding performance. This means that the
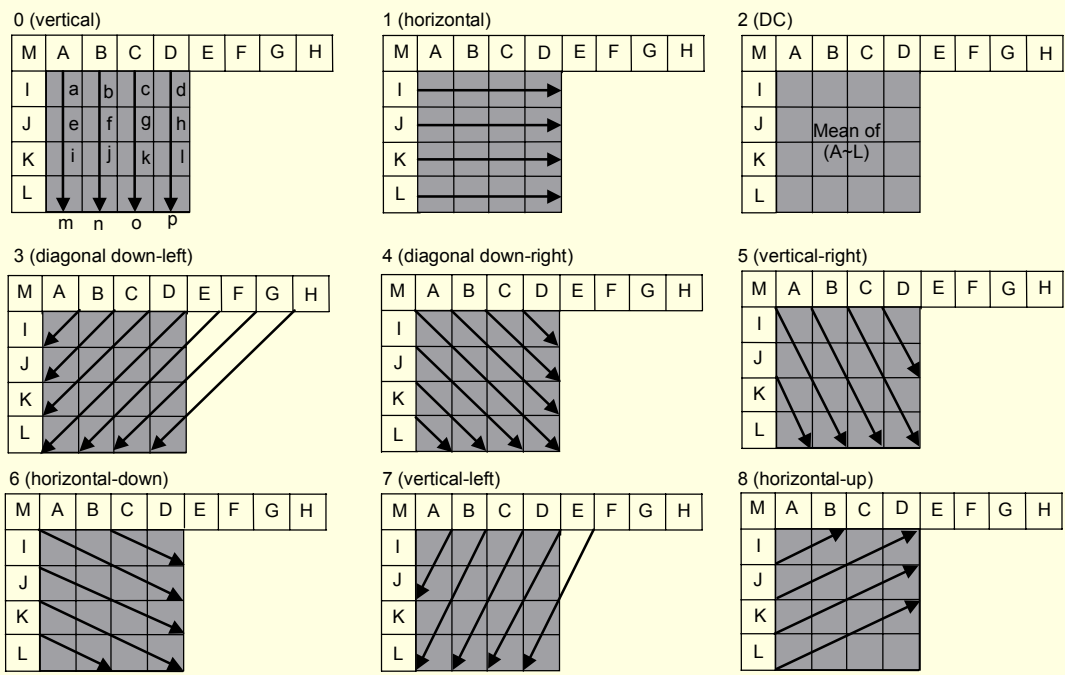
(a) Prediction modes for 8×8 luma block

(b) Prediction modes for 16×16 luma block

(c) Prediction modes for 8×8 chroma block

Fig. 1. Intra prediction modes (directions) according to block types in H.264/AVC coding.

encoder has to encode the intra block using all the mode combinations and determine the one that gives the best RDO performance. Since the choice of prediction modes for chroma components is independent of luma component modes, for each luma prediction mode there are four possible chroma prediction modes. Therefore, the number of mode combinations for luma and chroma components in an MB is BC8×(B4×16+B16+B8×4), where BC8, B16, B8, and B4 represent the number of modes for 8×8 chroma prediction,

I16MB, I8MB prediction, and I16MB prediction, respectively. For an MB, 736 different RD cost calculations are executed for the high profile, and 592 calculations are executed for the main profile in H.264/AVC. This causes a heavy computational load for the encoder.

Intra mode prediction is performed for the I-slice (intra frame) and the P-slices (inter frames) to resolve the best coding gain. As described above, this process is a time-exhaustive search that must be performed in addition to the motion vector
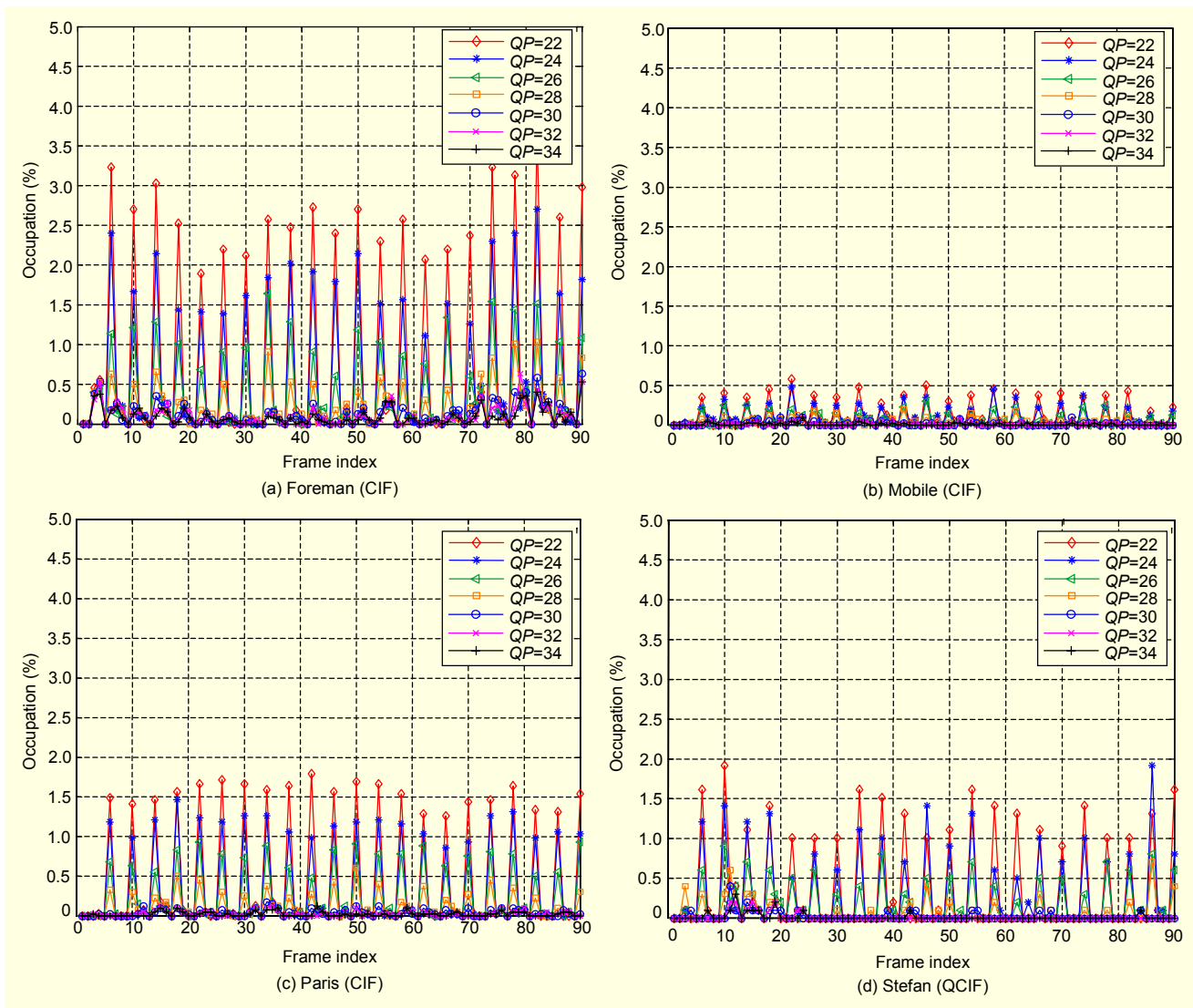
Fig. 2. Occupation of intra mode MBs with various *QP* values.

estimation procedure for inter frames. Therefore, a fast mode decision scheme is needed with a minimum quality loss for inter frames (P-slices).

III. The Proposed AISDA for Inter Frames

An H.264/AVC encoder performs the intra mode prediction for the intra frame and the inter frames. In fact, there are typically only a few intra mode MBs in one inter frame (or slice). In a full intra mode search [19], all combinations of intra mode predictions are executed for the best intra mode prediction, as described in the previous section.

Figure 2 shows the occupation (number) of the intra mode MB as the final MB mode according to various *QP* values and sequences for inter frames (P-frames). We can see from these results that occupation of the intra mode is only a small amount. Also, we can observe that the intra mode occupies less than 2.0%, except for the Foreman sequence, although the *QP* value becomes small. For *QP* variation, the intra mode MBs increase when the *QP* value becomes smaller. For the Foreman sequence, the occupation is approximately 2.5% with a given *QP* value of 22. This means that number of MBs for which the intra mode prediction is more beneficial than the inter mode prediction, increases in terms of the RD as the *QP* value becomes smaller.

Although this is only a small part of the intra mode MBs, all MBs of the given frame or slice must be examined by the intra mode prediction process, thus causing a large computational load for the encoder. From these results, a separate fast intra mode search algorithm is necessary to speed-up the encoding process.

As mentioned in section I, we can classify intra mode decision methods into two categories. An intra mode skip detection approach omits all possible intra mode predictions (I16MB, I8MB, I4MB, and Chroma 8×8) for MBs that satisfy the defined criterion. On the contrary, some candidate modes are selected in the prediction-mode reduction approach. Among these candidates, the best suitable intra mode is determined by search procedure; therefore, an approach that can omit the intra mode search is more suitable for inter frames under the condition that intra mode skip MBs are inclined to be dominant. Also, the RD cost is used in (1) because this technique has been widely recommended for a good trade-off between the bit rates and distortion.

To achieve a fast intra mode skip detection scheme, we use the RD costs of neighboring MBs for the current MB (MB_{kl}) at a position of (k, l) (Fig. 3). Since these neighboring MBs are highly correlated with the current MB, we may get information that will allow the intra mode prediction process to be skipped.
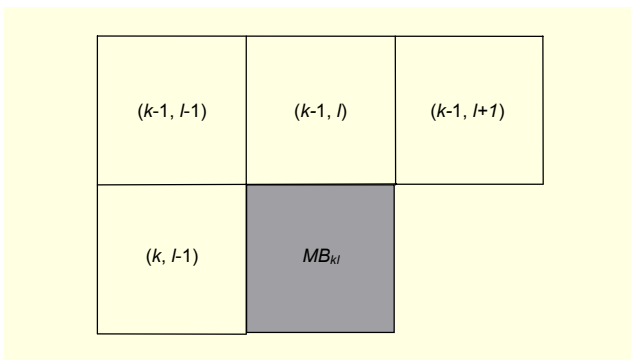

Fig. 3. Neighboring context for the current MB (MB_{kl}).

Based on (1), the following relationship is satisfied well for a given MB_{kl} because $\lambda \cdot \{R(Header) + R(Residual)\} \geq 0$:

$$J_{RD_{kl}} \geq SAD_{Mode}^{kl}, \tag{2}$$

where SAD_{Mode}^{kl} denotes the sum of absolute difference value of MB at (k, l) for any mode.

Under the assumption that the current MB is highly correlated with the defined neighboring MBs, we can modify the above equation as

$$J_{RD_{kl}} \geq SAD_{Inter\ Best}^{kl}, \tag{3}$$

where $SAD_{Inter\ Best}^{kl}$ is defined as the sum of the absolute differences when the best inter mode was determined. This relationship is still valid.

With (3), we introduce an adaptive test criterion using the inter mode information as

$$T_{kl} \geq SAD_{Inter\ Best}^{kl}, \tag{4}$$

where T_{kl} is an adaptive threshold value for MD_{kl} as given by

$$T_{kl} = \min_{RDCost_{ij}} \{RD\ cost\,(m,n)|(m,n) \in Neighbors\}, \tag{5}$$

where neighbors indicate the defined neighborhood as shown in Fig. 3.

If T_{kl} is less than $SAD_{Inter\ Best}^{kl}$ for the given MB, it means that a motion consistency between the two frames is very low. In this situation, it is more desirable to check the intra mode prediction to obtain the better mode with the smaller RD cost. Otherwise, it is desirable to omit the intra mode prediction procedure because we can infer that it may be not possible to determine the intra mode as the final mode for the current MB.

On the basis of these points, we can summarize the proposed algorithm as follows:

Step 1. For the current MB (MB_{kl}), an adaptive threshold value is computed using the RD costs of the neighboring MBs from (5).

Step 2. We obtain the sum of the absolute difference of the best inter mode ($SAD_{Inter\ Best}^{kl}$). Then, we check on whether the intra mode search procedure is on or off based on (4), as follows: If T_{kl} is less than $SAD_{Inter\ Best}^{kl}$, the intra mode search is performed. Otherwise, the intra mode search is skipped.

Joint model (JM) reference software provided by joint video team (JVT) performs the intra mode prediction after the inter mode prediction procedure [20]. Also, both RDO and non-RDO options are supported. In the non-RDO case, the sum of the absolute differences can only be used for motion estimation, including the mode decision process. This structure gives good results for implementation of our algorithm in JM software. The proposed algorithm has low computational complexity compared with other schemes [11], [12] because it requires only 32 bytes (4 double precision) of memory to save both neighbor RD costs and the pre-computed SAD in the inter mode search process.

IV. Results and Discussion

To verify the performance of the proposed fast mode decision algorithm, various MPEG standard sequences were used with common immediate format (CIF) and quarter common intermediate format (QCIF) sizes. Analyses were performed with encoding frames=100, RD optimization enabled, $QP = 24$, 28, and 32, sequence types of IPPP and

IBBPBBP in the main profile using CABAC with a search range of MV = ±16, the number of reference frames = 1, and the size of GOP=50 frames. Also, the Hadamard transform option was turned on.

As a reference code, JM 9.6 reference software by JVT was used [20] for evaluation of the encoding performance. All algorithms for comparison were run on an HW platform of a Pentium 4 PC with a 3.4 GHz CPU and 1.0 Gbyte of RAM.

We defined several measures for evaluating the encoding performance, including average $\Delta PSNR$, average $\Delta Bits$, and an encoding-time saving factor, ΔT. The average $\Delta PSNR$ is the difference in decibels between the average PSNR of the proposed method and the corresponding value of another method. As performance improves, this criterion becomes larger. The average $\Delta Bits$ is the bit rate difference expressed as a percentage between compared methods. Performance improves with a larger value. Finally, the encoding-time saving factor ΔT is defined for complexity comparison as

$$\Delta T = \frac{\text{Consumed } T_{ref} - \text{Consumed } T_{proposed}}{\text{Consumed } T_{ref}} \times 100 \ (\%), \quad (6)$$

under the condition that the full mode search (FMS) is optimum (reference performance). As this value increases, the performance speed is increased. Also, it must be noted that positive values for the PSNR and $\Delta Bits$ indicate increments, and negative values indicate decrements. A positive ΔT value indicates decrements for the encoding time.

Differences between PSNR and bit rate are calculated according to the numerical averages between the RD-curves derived from the JM 9.6 original encoder and the proposed fast algorithm, respectively. The detailed procedures for calculating these differences can be found in a JVT document by Bjontegaard [21], which is recommended by the JVT Test Model Ad Hoc Group [22].

We used two methods for an objective comparison of the encoding performance: Lee's [11] and Pan's [12] methods, which are well known as fast intra mode search techniques. As described in section I, Lee's method skips the intra mode search in the inter frame (P-slices); however, Pan's scheme can be used for the intra frame (I-slice) and the inter frame (P-slices) to reduce the search number of the intra prediction. Therefore, Pan's method was applied only to the inter frame since our algorithm was used for the inter frame. That is, all intra frames (I-slices) used the full intra mode search to generate the best residual image.

1. Analyses of IPPP Sequences

It should be noted that, in H.264/AVC coding, MBs in inter frames also use intra coding as the coding mode for the RDO operation. Thus, a great time saving was expected with use of a fast intra coding algorithm.

Figure 4 illustrates the RD curves for several sequences. From these results, we can see that the proposed AISDA has an RDO performance similar to the JM 9.6 original encoder with
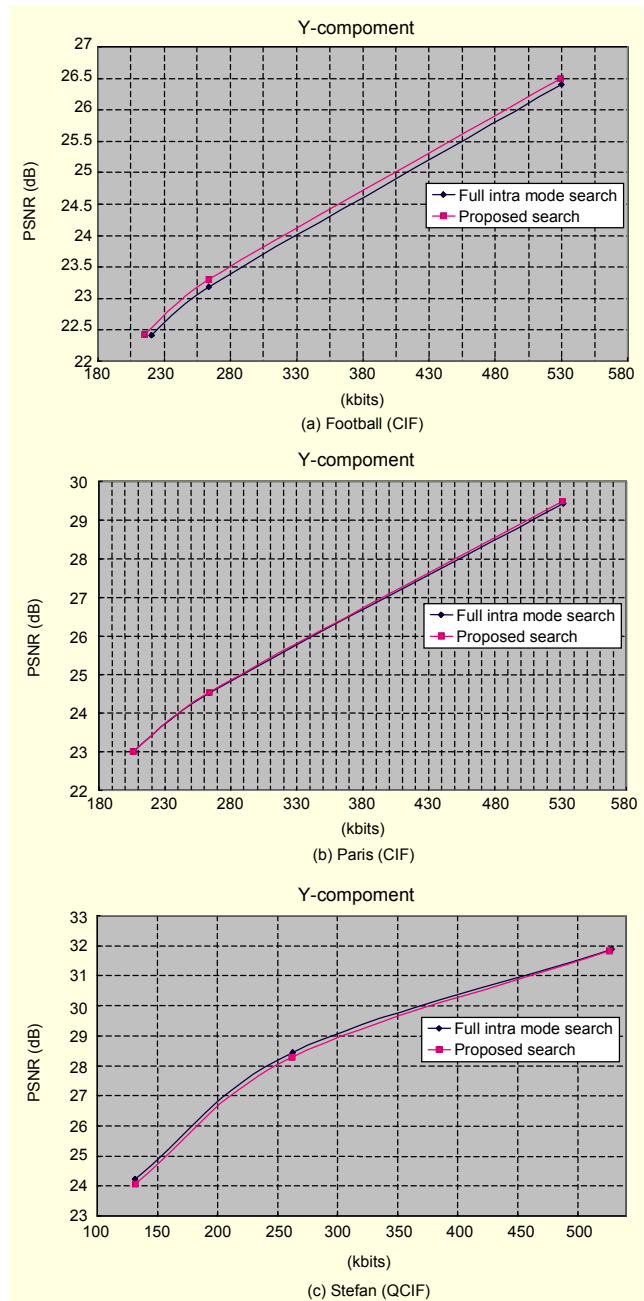

Fig. 4. RD curves for $QP = 28$: (a) $\Delta PSNR = 0.040$ dB, $\Delta T = 20.1\%$, $\Delta Bits = -0.35\%$; (b) $\Delta PSNR = -0.002$ dB, $\Delta T = 25.8\%$, $\Delta Bits = 0.073\%$; and (c) $\Delta PSNR = -0.001$ dB, $\Delta T = 27.8\%$, $\Delta Bits = -0.03\%$.

Table 1. Performance comparison of the proposed AISDA on the JM 9.6 reference encoder for IPPP sequences.

Contents		QP=24			QP=28			QP=32			Average values		
		$\Delta PSNR$	$\Delta Bits$	ΔT	$\Delta PSNR$	$\Delta Bits$	ΔT	$\Delta PSNR$	$\Delta Bits$	ΔT	$\Delta PSNR$	$\Delta Bits$	ΔT
Stefan (QCIF)	Lee's	-0.001	-0.002	29.35	0.000	-0.0o4	27.25	0.000	0.006	21.52	-0.0003	0.000	26.04
	Pan's	-0.004	0.908	22.35	0.007	1.266	23.82	-0.006	1.676	20.11	-0.0010	1.283	22.09
	Proposed	-0.001	-0.027	27.85	0.001	-0.024	29.61	-0.001	-0.044	23.47	-0.0003	-0.031	26.97
Carphone (QCIF)	Lee's	-0.013	-0.079	34.79	0.000	-0.041	29.18	0.001	-0.024	29.24	-0.0040	-0.048	31.07
	Pan's	0.006	1.831	29.54	-0.008	2.555	20.43	0.004	3.101	18.70	0.0006	2.495	22.89
	Proposed	-0.005	0.163	31.44	-0.001	0.0247	24.07	0.004	-0.028	21.88	-0.0006	0.054	25.79
Mobile (CIF)	Lee's	-0.003	0.003	30.72	0.000	-0.013	19.60	-0.001	0.004	25.82	-0.0013	-0.002	25.38
	Pan's	-0.003	0.558	23.83	-0.002	0.745	23.95	0.004	1.106	25.09	-0.0003	0.803	24.29
	Proposed	0.001	-0.024	32.14	0.001	-0.033	33.22	-0.001	0.000	29.67	0.0003	-0.019	31.67
Table tennis (CIF)	Lee's	-0.004	-0.062	25.05	-0.002	-0.021	25.87	-0.015	-0.002	24.15	-0.0053	-0.028	25.02
	Pan's	-0.008	0.742	21.81	-0.040	1.192	19.40	0.000	1.538	16.29	-0.0150	1.157	19.16
	Proposed	-0.004	-0.172	31.53	-0.018	-0.067	29.35	-0.035	-0.439	25.56	-0.0190	-0.226	28.81
Football (SIF)	Lee's	-0.001	0.000	15.18	-0.001	0.0009	15.84	-0.001	-0.010	14.73	-0.0010	0.000	15.25
	Pan's	-0.005	0.72	23.52	-0.002	0.833	17.35	-0.007	0.94	21.42	-0.0056	0.831	20.76
	Proposed	-0.005	-0.067	25.42	-0.011	-0.46	25.44	-0.013	-0.366	23.51	-0.0096	-0.297	24.79
Garden (CIF)	Lee's	-0.002	-0.016	30.82	0.000	-0.003	22.86	0.000	0.000	23.10	-0.0006	-0.006	25.59
	Pan's	-0.008	0.363	23.28	-0.002	0.533	22.67	0.000	0.716	20.79	-0.0033	0.537	22.24
	Proposed	-0.001	-0.019	25.62	0.000	-0.002	25.65	0.000	-0.008	23.94	-0.0003	-0.009	25.07
Bus (CIF)	Lee's	-0.001	0.044	26.65	-0.001	0.001	23.62	-0.003	0.040	24.13	-0.0016	0.028	24.80
	Pan's	-0.002	0.726	23.43	-0.002	0.960	22.40	-0.004	1.231	20.00	-0.0026	0.939	21.94
	Proposed	0.001	0.068	29.70	-0.002	0.069	32.38	-0.009	0.001	29.65	-0.0033	0.046	30.57
Paris (CIF)	Lee's	-0.001	-0.011	35.37	-0.001	0.001	33.40	0.000	-0.007	33.50	-0.0006	-0.005	34.06
	Pan's	-0.001	1.670	23.31	-0.002	2.359	22.19	-0.001	2.694	20.00	-0.0013	2.236	21.83
	Proposed	-0.001	-0.050	27.74	-0.001	-0.027	27.15	-0.001	-0.046	25.71	-0.0010	-0.041	26.86

the full intra mode search. For the "Football" sequence, the AISDA achieves better PSNR performance (Y-component) with lower bit rates. In Fig. 4(a), we focus on the PSNR at 380 kbps. At this bit rate, the PSNR value of the full search mode is 24.6 dB while the proposed algorithm achieves approximately 24.7 dB, indicating that the proposed algorithm is better than the full intra mode search.

Table 1 shows the results of all algorithms for the IPPP sequence type. The proposed algorithm achieves a better bit rate saving with a similar loss of image quality. In most sequences, Pan's method yields an increment of the bit rate. For QP=28, the increase in the bit rate is more than 0.7% for all sequences. However, the proposed scheme requires fewer bits for good image quality.

Lee's method achieves a slightly larger speed-up factor for the "Carphone" and "Paris" sequences. Thus, Lee's method can cope with sequences that have a stationary background.

However, it does not detect intra skip MBs as well as our method with global motion or very large object motion. The proposed AISDA achieves an improvement of up to 32% in total encoding time compared with the full intra mode search. In terms of the average performance shown in Table 1, the proposed algorithm improves the encoding speed by a factor of 1% to 6% with fewer bits and little loss of image quality.

2. Analyses of IBBPBBP Sequences

The IBBPBBP-type sequences have two B-frames between I- or P-frames. Figure 5 shows the RD curves for several sequences. AISDA achieves a performance that is similar to or better than RDO with the JM 9.6 original encoder for the full intra mode search.

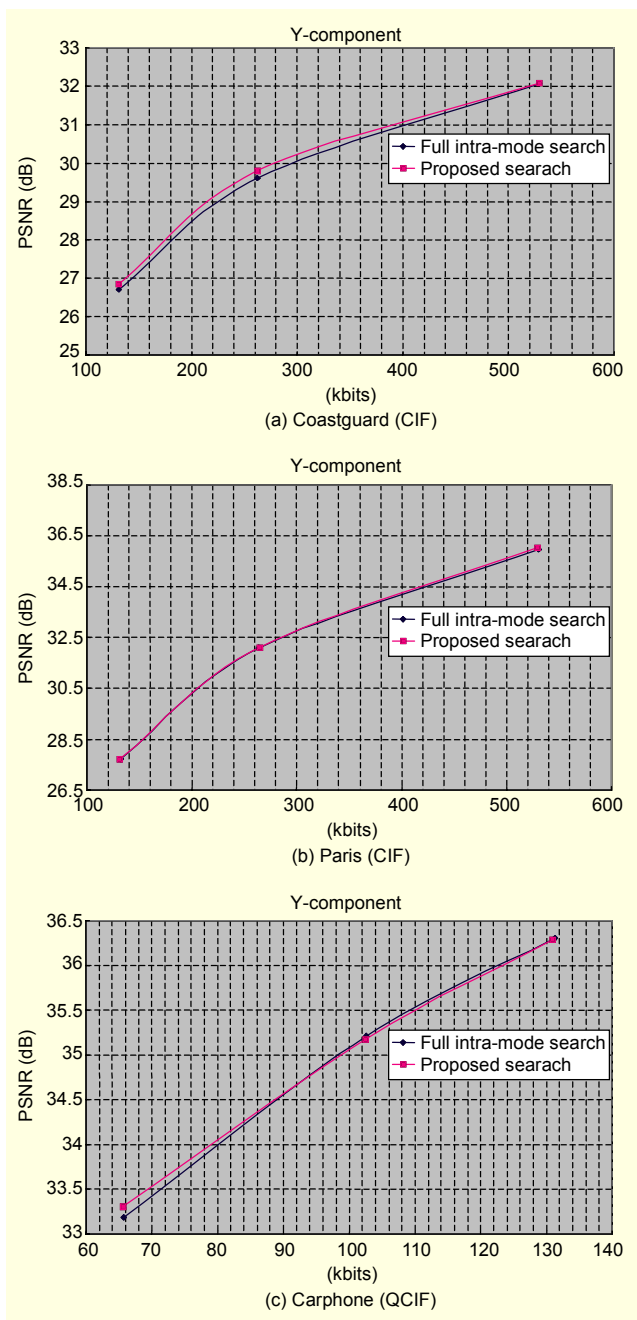For the "Carphone" sequence, there is a small gain in both PSNR and the bit rate at low bit rates. Also, for the

Fig. 5. The RD curves for *QP* = 28: (a) Δ*PSNR* = -0.013 dB, Δ*T* = 20.57%, Δ*Bits* = -0.619%; (b) Δ*PSNR* = 0.001 dB, Δ*T* = 7.06%, Δ*Bits* = -0.023%; and (c) Δ*PSNR* = 0.003 dB, Δ*T* = 7.54%, Δ*Bits* = 0.085%.

"Coastguard" sequence, AISDA is superior to the JM 9.6 original encoder for the overall bit rate. Samples of correct formats for various types of references are as follows.

Results for IBBPBBP sequences are shown in Table 2. The purpose of testing the IBBPBBP sequences was to determine whether the proposed algorithm was effective with a P-frame period longer than for the IPPP sequence type. Results showed that the devised algorithm was useful for the IBBPBBP

sequences. The encoding time saving factor (Δ*T*) becomes smaller for the IPPP sequence type due to the fact that in H.264/AVC coding, B-frames do not use intra coding and B-frame coding motion estimation requires more time than in P-frame coding.

The proposed algorithm achieves better performance for IBBPBBP sequences compared with other schemes for each *QP*. Lee's method achieves poor performance in terms of the encoding time saving factor (Δ*T*) and for the full intra mode search, mainly because B-frames do not use intra coding in H.264/AVC coding. For encoding B-frames, the P-frame is usually encoded and reconstructed first. The interval between the adjacent P-frames is longer than for the IPPP sequence type, causing greater error in the residual image. Since Lee's method is based on the discrete cosine transform (DCT) of the residual image and on boundary pixel values of the current MB, the intra mode search should be applied to most MBs based on their skip detection criterion. For this reason, the gains are poor for Lee's algorithm in Table 2.

Compared with Pan's method, our algorithm yields more bit rate and encoding time saving effects with a similar image quality. Also, we can verify that our algorithm decreases the encoding time by a maximum of 35% compared with the original JM 9.6 software. Our proposed algorithm also achieves a speed improvement of 2% to 12% with fewer bits and little loss of image quality as regards the average performance.

We checked the effect of multiple reference frames as various *QP* values in IPPP sequence format. Figure 6 shows results for multiple reference frames (1, 3, 5). The graphs show the ratio of the encoding time for multiple reference frames to the time for one reference frame (100%). There is a linear relationship between the number of reference frames and the encoding time. This is a valuable characteristic that allows estimation of the encoding time based on the number of reference frames. It is also known that the encoding time becomes longer as the increment of a given *QP* increases. That is, the time difference between the encoding time using one reference frame and the time using multiple reference frames increases as the *QP* value increases. Thus, the proposed algorithm becomes slower with an increase in *QP* due to more distortion of the reconstruction frame as a reference picture. Therefore, our method provides better performance at a high bit rate (lower *QP*).

V. Conclusion

We have proposed an efficient intra mode skip detection algorithm (AISDA) for the inter frame (P-slices) in H.264/AVC video coding. To reduce the computational load of

Table 2. Performance comparison of the proposed AISDA on the JM 9.6 reference encoder for IBBPBBP sequences.

| Contents		QP=24			QP=28			QP=32			Average values		
		$\Delta PSNR$	$\Delta Bits$	ΔT	$\Delta PSNR$	$\Delta Bist$	ΔT	$\Delta PSNR$	$\Delta Bits$	ΔT	$\Delta PSNR$	$\Delta Bits$	ΔT
Stefan (QCIF)	Lee's	-0.001	0.000	1.85	0.000	0.000	0.00	0.000	0.000	0.34	-0.0003	0.000	0.73
	Pan's	-0.021	0.366	15.93	-0.024	0.143	14.08	0.000	-1.142	12.45	-0.0150	-0.211	14.15
	Proposed	-0.021	-0.578	14.95	-0.022	-0.554	14.36	-0.001	-1.706	12.07	-0.0146	-0.946	13.79
Carphone (QCIF)	Lee's	0.000	0.000	1.71	0.000	0.000	2.77	0.000	0.000	0.90	0.0000	0.000	1.79
	Pan's	-0.007	0.649	13.74	-0.001	1.245	10.31	0.000	1.816	5.88	-0.0026	1.236	9.97
	Proposed	-0.003	0.035	8.93	0.003	0.085	7.54	-0.003	-0.082	3.16	-0.0010	0.012	6.54
Mobile (CIF)	Lee's	0.000	0.000	7.50	0.000	0.000	0.25	0.000	0.000	4.65	0.0000	0.000	4.13
	Pan's	-0.132	0.885	24.69	0.013	1.429	23.44	-0.034	2.92	20.28	-0.051	1.744	23.33
	Proposed	-0.006	-0.345	36.39	-0.017	-0.694	35.35	-0.020	-0.548	35.44	-0.0143	-0.529	35.72
Table tennis (CIF)	Lee's	0.000	0.000	0.55	0.000	0.000	0.00	0.000	0.000	0.58	0.0000	0.000	0.56
	Pan's	-0.008	0.644	10.01	-0.004	0.992	6.64	-0.010	1.341	3.69	-0.0073	0.992	6.78
	Proposed	-0.005	-0.066	12.59	-0.005	0.322	8.75	-0.006	0.486	6.12	-0.0053	0.267	9.15
Football (SIF)	Lee's	0.000	0.000	5.51	0.000	0.000	6.29	0.000	0.000	2.17	0.0000	0.000	4.65
	Pan's	-0.027	0.222	19.42	-0.020	0.373	17.52	-0.012	0.660	14.81	-0.0196	0.420	17.25
	Proposed	-0.018	-0.887	19.27	-0.020	-0.199	20.47	-0.026	0.067	16.77	-0.0213	-0.339	18.83
Garden (CIF)	Lee's	0.000	0.000	0.02	0.000	0.000	0.81	0.000	0.000	0.01	0.0000	0.000	0.01
	Pan's	-0.006	0.195	17.05	-0.002	0.343	17.09	-0.588	0.426	11.05	-0.1986	0.321	15.06
	Proposed	0.001	-0.005	17.43	0.000	-0.004	21.57	0.000	0.012	14.28	0.0003	0.001	17.76
Bus (CIF)	Lee's	0.000	0.000	5.76	0.000	0.000	1.25	0.000	0.000	1.11	0.0000	0.000	2.70
	Pan's	-0.013	0.159	16.37	-0.010	0.404	14.01	-0.001	0.447	12.17	-0.0080	0.337	14.18
	Proposed	-0.001	0.098	18.82	-0.004	0.44	17.79	-0.001	-0.316	14.84	-0.0020	0.074	17.15
Coastguard (CIF)	Lee's	0.000	0.000	2.00	0.000	0.000	0.81	0.000	0.000	2.00	0.0000	0.000	1.62
	Pan's	-0.019	-0.238	17.10	-0.006	-0.067	14.53	-0.002	0.165	8.90	-0.0090	-0.047	13.51
	Proposed	-0.020	-0.316	23.36	-0.013	-0.619	20.57	-0.002	-0.948	12.01	-0.0116	-0.627	18.64
Paris (CIF)	Lee's	0.000	0.000	2.28	0.000	0.000	2.15	0.000	0.000	4.06	0.0000	0.000	2.83
	Pan's	-0.003	1.135	9.31	0.000	1.756	7.07	-0.002	2.273	4.34	-0.0016	1.721	6.90
	Proposed	-0.002	-0.120	6.36	0.001	-0.023	7.06	-0.001	-0.052	3.98	-0.0006	-0.065	5.80
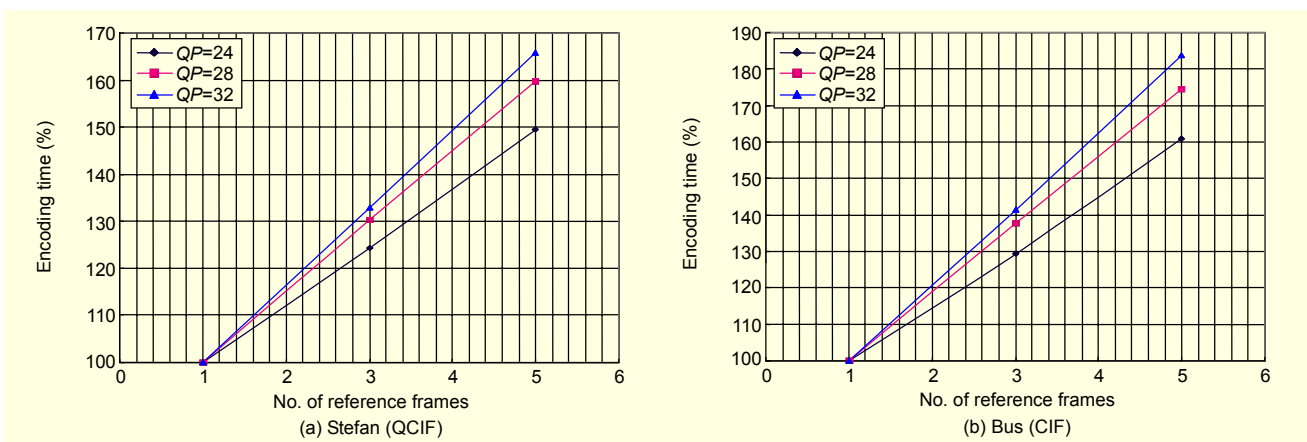
Fig. 6. Encoding time (%) as various QPs and the number of reference frames: (a) Stefan and (b) Bus sequences.

the intra mode search at the inter frame, the RD costs of the neighborhood MBs for the current MB were used with a proposed adaptive thresholding scheme for intra mode skip extraction. We verified the performance of the proposed scheme through comparative analysis of experimental results using JM reference software. Compared with the full intra mode search method, the overall encoding time was reduced up to 32% for the IPPP sequence type and up to 35% for the IBBPBBP sequence type with little loss of image quality.

Acknowledgements

References

[1] ISO/IEC 14496-10, "Information Technology--Coding of Audio-Visual Objects--Part 10: Advanced Video Coding," Dec. 2003.

[2] T. Wiegand, G.J. Sullivan, G. Bjontegard, and A. Luthra, "Overview of the H.264/AVC Video Coding Standard," *IEEE Trans. Circuit Syst. Video Technol.*, vol. 13, July 2003, pp. 560 - 576.

[3] S.M. Kim, J.H. Park, S.M. Park, B.T. Koo, K.S. Shin, K.B. Suh, I.K. Kim, N.W. Eum, and K.S. Kim, "'Hardware-Software Implementation of MPEG-4 Video Codec," *ETRI Journal*, vol. 25, no. 6, Dec. 2003, pp. 489-502.

[4] H. Jia and L. Zhang, "Directional Diamond Search Pattern for Fast Block Motion Estimation," *Electronics Letters*, vol. 39, no. 22, 2003, pp. 1581 - 1583.

[5] B.G. Kim, S.T. Kim, S.K. Song, and P.S. Mah, "Fast-Adaptive Rood Pattern Search for Block Motion Estimation," *Electronics Letters*, vol. 41 no. 16, Aug. 2005, pp. 900-902.

[6] D. Wu, S. Wu, K.P. Lim, F. Pan, Z. G. Li, and X. Lin, "Block Inter Mode Decision for Fast Encoding of H.264," *Proc. of IEEE Int'l Conf. on Acoustics, Speech, and Signal Processing (ICASSP)*, vol. 3, 2004, pp. 181-184.

[7] X. Jing and L.-P. Chau, "Fast Approach for H.264 Inter Mode Decision," *Electronics Letters*, vol. 40, no. 17, Sep. 2004, pp.1050-1052.

[8] C. Crecos and M.Y. Yang, "Fast Inter Mode Prediction for P Slices in the H264 Video Coding Standard," *IEEE Trans. Broadcasting*, vol. 51, no. 2, June 2005, pp. 256 - 263.

[9] Y.H. Kim, J.W. Yoo, S.W. Lee, J. Shin, J. Paik, and H.K. Jung, "Adaptive Mode Decision for H.264 Encoder," *Electronics Letters*, vol. 40, no. 19, Sep. 2004, pp.1172-1173.

[10] B.G. Kim and S.K. Song, "Enhanced Inter Mode Decision Based on Contextual Prediction For P-Slice in H.264/AVC Video Coding," *ETRI Journal*, vol. 28, no. 4, Aug. 2006, pp. 425-434.

[11] J.Y. Lee and B.W. Jeon, "Fast Mode Decision for H.264," *Proc.*

of IEEE Int'l Conf. on Multimedia and Expo (ICME), vol. 2, 2004, pp. 1131 - 1134.

[12] F. Pan, X. Lin, S. Rahardja, K.P. Lim, Z.G. Li, D. Wu, and S. Wu, "Fast Mode Decision Algorithm for Intraprediction in H.264/AVC Video Coding," *IEEE Trans. Circuit Syst. Video Technol.*, vol. 15, no. 7, July 2005, pp. 813 - 822.

[13] F. Pan, X. Lin, S. Rahardja, K.P. Lim, and Z.G. Li, "A Directional Field Based Fast Intra Mode Decision Algorithm For H.264 Video Coding," *Proc. of IEEE Int'l Conf. on Multimedia and Expo (ICME)*, vol. 2, 2004, pp. 1147 - 1150.

[14] F. Fu, X. Lin, and L. Xu, "Fast Intra Prediction Algorithm in H.264/AVC," *Proc. of the 7th Int'l Conf. on Signal Processing (ICSP)*, vol. 2, 2004, pp. 1191 - 1194.

[15] C. Kim, H.H. Shih, C.C.J. Kuo, "Feature-Based Intra Prediction Mode Decision for H.264," *Proc. of Int'l Conf. on Image Processing (ICIP)*, vol. 2, 2004, pp. 769 - 772.

[16] C.C. Cheng and T.S. Chang, "Fast Three Step Intra Prediction Algorithm for 4×4 Blocks in H.264," *Proc. of IEEE Int'l Symp. on Circuits and Systems (ISCAS)*, vol. 2, 2005, pp. 1509 - 1512.

[17] D.G. Sim and Y.M. Kim, "Context-Adaptive Mode Decision for Intra block Coding in H.264/MPEG-4 Part 10," *Real-Time Imaging*, vol. 11, 2005, pp. 1 - 6.

[18] S. Gordon, D. Marpe, and T. Wiegand, "Simplified Use of 8x8 Transforms - Updated Proposal and Results," JVT-K028 at the 11-th Meeting, Munich, Germany, 15-19 Mar., 2004.

[19] K.B. Suh, S.M. Park, and H.J. Cho, "An Efficient Hardware Architecture of Intra Prediction and TQ/IQIT Module for H.264 Encoder," *ETRI Journal*, vol. 27, no. 5, Oct. 2005, pp. 511-524.

[20] Joint Model (JM) - H.264/AVC Reference Software, http://iphome.hhi.de/suehring/tml/download/

[21] G. Bjontegaard, "Calculation of Average PSNR Differences between RD-curves," presented at the 13-th VCEG-M33 Meeting, Austin, TX, Apr. 2001.

[22] JVT Test Model Ad Hoc Group, "Evaluation Sheet for Motion Estimation," Draft version 4, Feb. 2003.

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