

# Adaptive Scanning Based on a Morphological Representation of Coefficients for H.264/AVC

Kang-Sun Choi and Sung-Jea Ko

**ABSTRACT**—In this letter, an effective scanning method based on a morphological representation of quantized coefficients is proposed for intra coding in H.264. In the proposed scanning method, the scan order for each block is adaptively reconfigured by exploiting a residual correlation beyond the border of the block. An initial scan order for the current block is determined first by using the pattern of nonzero coefficients in the adjacent block. Then, a complete scan order is obtained by performing the dilation operation at each position within the initial scan order. Experimental results show that the proposed method improves the coding efficiency up to 3.7% compared to the conventional zigzag scanning method.

**Keywords**—Scan order; morphological operation; intra coding, H.264/AVC.

## I. Introduction

H.264/advanced video coding (AVC) is the latest video coding standard developed by ITU-T Video Coding Expert Group (VCEG) and ISO/IEC MPEG [1]. The coding efficiency of H.264 intra coding is improved by using directional spatial predictions. According to its directional information, a block to be coded is predicted from adjacent blocks which have been already encoded. The residual signal between the current block and its intra prediction is transformed, and the resultant signal is scanned in a zigzag order to be compressed by an entropy coder.

Considering some properties of the residual signal, several

adaptive scanning methods have been proposed to further improve the coding efficiency of H.264 intra coding [2], [3]. Choi and others [2] observed that H.264 intra prediction can produce directional edges in the residuals according to the selected prediction mode. Based on that observation, they proposed six predefined directional scan orders and a mapping scheme between nine intra prediction modes and the six scan orders. The intra-predicted error of a block is encoded with a specific directional scan order related to the intra prediction mode selected for that block. However, since every directional scan order has a unique fixed scan pattern, they cannot guarantee better coding efficiency than zigzag scanning. Assume that a prediction mode is selected. That means that the mode with the associated directional scan order produces the shortest encoded bits among all modes. Even in this case, however, zigzag scanning can produce shorter bits than directional scan order depending on the distribution of the residual.

Kim and others [3] proposed a condition using the pixel similarity of adjacent block boundary pixels to determine whether the directional scan order is more efficient than zigzag scanning. However, this condition is not sufficient to guarantee coding efficiency improvement, and the performance of the algorithm is also degraded by the previously mentioned problem.

In this letter, we propose an adaptive coefficient scanning method which exploits residual correlations beyond the border of the block to improve coding efficiency. By utilizing a morphological representation with the coefficient pattern of a correlated adjacent block, the distribution of the residual is estimated, and an effective scan order can be generated dynamically.

## II. Proposed Adaptive Scanning Method

Before introducing the proposed scanning method, we

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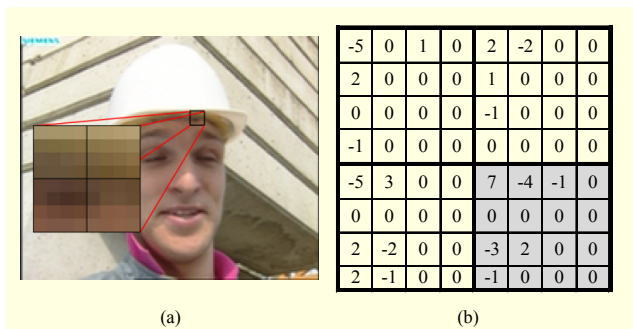


Fig. 1. Example of an image to be coded: (a) 1st frame of Foreman sequence and (b) quantized coefficients of the prediction error resulting from the intra prediction of the enlarged blocks. The block to be coded currently is shaded.

observe some properties of intra-prediction errors. When consistent spatial correlation of the residuals exists over several adjacent blocks, the shape of quantized coefficients of a block resembles that of every other block. That suggests that the nonzero coefficient patterns of correlated neighboring blocks can provide some clues to yield an effective scan order. The significance of a coefficient is defined as the magnitude of the quantized coefficient. Figure 1 shows this similarity between significance patterns of adjacent blocks. Figure 1(b) shows the quantized coefficients of the intra-predicted error of the square-marked region in Fig. 1(a), which shows horizontal correlation. Assume that the gray-shaded 4×4 block in the lower-right corner is the current block of interest to be coded, and the three other blocks have been already coded. The previously mentioned similarity can be found in the lower-left block.

In the proposed scanning method, the significance of each coefficient in the block is estimated, and a scan order is determined by scanning positions in decreasing order of significance. Based on the similarity between significance patterns of adjacent blocks, the significance of each coefficient is first predicted from the significance of the corresponding coefficient in an adjacent correlated block. For the coefficients predicted as insignificant ones, the significance can be estimated from their neighboring significant coefficients because image details such as spatial edges and patterns usually have energies at several frequency bands. This significance propagation is carried out by using the morphological dilation at each position of a significant coefficient. The morphological operation, which is an efficient way to encode arbitrarily shaped regions, has been successfully applied to wavelet image coders such as morphological representation of wavelet data [4] and JPEG 2000 to encode the arbitrarily shaped regions.

The proposed scanning method consists of four steps: initial region traversal, extended region traversal, traversal finalization, and optimal reference selection. Define a reference block and

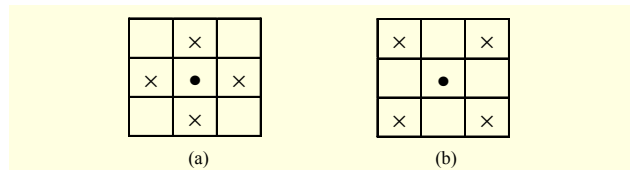


Fig. 2. Structuring elements (SEs): (a) four-connected SE and (b) diagonal four-connected SE.

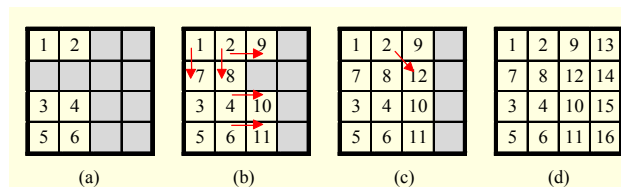


Fig. 3. Example of first three steps for generating a scan order with the left block of the current block in Fig. 1(b). Each block shows the scan order: (a) after the initial region traversal step, (b) after the extended region traversal step with the SE of Fig. 2(a), (c) after the extended region traversal step with the SE of Fig. 2(b), and (d) after the traversal finalization.

initial regions to be an adjacent block showing the similar significance pattern and regions of nonzero coefficients in the reference block, respectively. The initial regions indicate where the significant coefficients are in the reference block.

In the initial region traversal step, we generate a scan order by traversing the initial regions in decreasing order of significance. Here, the positions of the same significance are prioritized in the zigzag scan order. This initial scan order may be incomplete in the sense that all positions within a block may not be visited because the reference block typically contains coefficients of zero values.

In the extended region traversal step, morphological dilation is performed at every position which is visited while we trace the initial scan order. If the dilated position has not been visited yet, the position is appended to the scan order. A dilated position adjacent to a position of higher predicted significance within the initial scan order is visited and appended earlier. This step is divided into two sub-steps performed with two SEs shown in Fig. 2(a) and (b), respectively.

In the traversal finalization step, the remaining positions which have not been visited yet even after the extended region traversal step are scanned in the zigzag scan order.

To clarify the first three steps, we demonstrate the scan order generation procedure in Fig. 3 using the lower-left block in Fig. 1(b) as the reference block. In the initial region traversal step, an initial scan order is generated while the six nonzero coefficients of the reference block are traced in decreasing order of significance. Three positions with the magnitude of 2 are prioritized in the zigzag scan order. The significance propagation

Table 1. Comparison of coding efficiency.

Sequence	QP	H.264	Kim's [3]		Proposed	
		Bitrate (kbps)	Bitrate (kbps)	$\Delta$ bit (%)	Bitrate (kbps)	$\Delta$ bit (%)
Foreman (QCIF)	14	1226.96	1227.98	-0.08	1191.30	2.91
	20	786.62	787.61	-0.13	760.95	<b>3.26</b>
	26	454.64	455.28	-0.14	442.62	2.64
	32	247.44	247.92	-0.19	245.09	0.95
News (QCIF)	14	1110.19	1102.68	0.68	1083.73	2.38
	20	744.93	739.26	0.76	726.94	<b>2.41</b>
	26	473.48	468.88	0.97	463.21	2.17
	32	291.25	288.12	1.07	286.55	1.61
City (CIF)	14	5086.02	5077.81	0.16	4936.714	2.94
	20	3303.72	3296.35	0.22	3180.69	<b>3.72</b>
	26	1927.15	1921.70	0.28	1857.76	3.60
	32	996.46	991.24	0.52	979.73	1.68
Football (CIF)	14	9028.00	9025.85	0.02	8770.07	2.86
	20	5757.00	5758.39	-0.02	5576.28	<b>3.14</b>
	26	3369.51	3368.48	0.03	3283.64	2.55
	32	1823.96	1821.46	0.14	1811.47	0.68
Harbour (4CIF)	14	36645.39	37131.24	-1.33	35662.14	2.68
	20	23013.19	23287.38	-1.19	22202.17	3.52
	26	13535.71	13591.60	-0.41	13047.55	<b>3.61</b>
	32	7741.30	7706.76	0.45	7631.63	1.42

by the dilation in the extended region traversal step is depicted as an arrow starting from the corresponding origin of the SE.

The first three steps generate a scan order for each reference block. In the final step, the optimal reference selection step, we generate the scan orders for all candidate reference blocks and compare these scan orders with the zigzag scan order in terms of bitrate in order to achieve the best coding efficiency. In this work, we used the upper-left, upper, and left blocks of the current block as the candidate reference blocks. A scan order index indicating which scan order is selected is also encoded by entropy coding.

### III. Experimental Results

We implemented the proposed method as well as Kim's algorithm [3] based on the H.264 reference software JM11.0 (Joint Model 11) codec and compared their performance. Five sequences of various sizes were encoded with all intra frames by applying four quantization values. Rate-distortion optimization and CAVLC were used.

As shown in Table 1, the proposed method achieved much

higher coding efficiency than the conventional zigzag scanning method, H.264/AVC, and Kim's algorithm. For the City sequence at QP=20, the proposed algorithm reduced the bitrates by up to 3.7% and 3.5% as compared with the conventional method and Kim's algorithm, respectively, without video quality degradation. The lower bit saving,  $\Delta$ bit, was obtained for the proposed algorithm for the News sequence. However, the bit saving with the proposed algorithm is still much higher than that achieved by the two other methods.

The performance of the proposed scheme tends to be degraded for both low- and high-rate video sequences. For small QPs, most coefficients in the reference blocks are significant. Therefore, the scan order can be almost determined in the initial region traversal step, and the later steps cannot influence the final scan order. If a video is encoded with a large QP, most quantized coefficient values of the reference blocks are zero. In this case, the final scan order is similar to the zigzag scan order; thus, the coding efficiency is not improved much. Also, the number of bits of the coded scan order index increases compared with the total bitrates.

### IV. Conclusion

An adaptive coefficient scanning method which guarantees improved coding efficiency was presented. The positions of significant coefficients are predicted from a neighboring block based on the similarity between adjacent blocks. The significance is propagated into the remaining coefficient positions by using a morphological representation. A scan order can be generated by traversing a block in decreasing order of significance. Experimental results demonstrated that the proposed algorithm can improve the coding efficiency up to 3.7% compared to conventional zigzag scanning methods.

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