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A DCT/DST-based error propagation-free data hiding algorithm for HEVC intra-coded frames ☆

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ABSTRACT

Currently, two error propagation-free discrete cosine transform (DCT)-based data hiding algorithms, one by Ma et al. and the other by Lin et al., were presented for H.264/AVC intra-coded frames. However, the state-of-the-art video codec, high efficiency video coding (HEVC), adopts both integer DCT and discrete sine transform (DST) such that the previous DCT-based algorithms cannot fully utilize available capacity for data hiding in HEVC. This paper presents the first DCT/DST-based data hiding algorithm for HEVC intra-coded frames where the block DCT and DST coefficient characteristics are investigated to locate the transformed coefficients that can be perturbed without propagating errors to neighboring blocks. Experimental results confirm the merits of the proposed algorithm in providing the intra-frame error propagation-free advantage, the quality improvement for marked images, the compression power inherited from HEVC, and the superiority of embedding capacity for low bitrate coding when compared with the previous two algorithms for H.264/AVC.

1. Introduction

With the advance of digital multimedia communication techniques, data hiding becomes important in the authentication, identification, annotation, and copyright protection of digital media items [18,3,10,15], among which digital video is most widely used. However, due to the massive information amount of digital video signals, it needs highly efficient video coding to make video communication feasible. Recently, several transform domain based data hiding algorithms [16,21,14,22,5,8,6,17] have been developed in H.264/AVC [4], where the quantized discrete cosine transform coefficients (QDCTs) of the 4×4 luma blocks in intra-coded frames (IFs) are perturbed so as to carry the hidden data. Unfortunately, these algorithms have the intra-frame error propagation problem due to the improper perturbation strategies for the QDCTs, leading to severe quality degradation for the reconstructed video signals.

To solve this problem, Ma et al. [11] proposed an effective perturbation strategy for the QDCTs of the 4×4 luma blocks based on both the directions of intra prediction modes and the deviation in the pixel values resulted from changing the QDCTs values. Lin et al. [9] proposed to increase the embedding capacity for the 4×4 luma blocks achieved by Ma et al. and to additionally utilize the other 4×4 luma blocks for embedding one bit into each of them. Although the intra-frame error propagation has been tackled in the algorithms [11,9], the inter-frame error propagation is another challenging problem for these transform domain based data hiding algorithms [13,23].

As the application demands higher video signal resolution, the H.264/AVC standard can no longer achieve satisfied compression performance. A state-of-the-art video coding standard, high efficiency video coding (HEVC) [2,19], is developed to improve the compression efficiency for high resolution video signals. When considering data hiding in HEVC video sequences, one intuitive way is to adapt the previous data hiding algorithms used for H.264/AVC to the HEVC standard. However, since the HEVC 4×4 block does not utilize integer DCT for transform coding, the transform domain data hiding algorithms developed based on 4×4 DCT blocks of H.264/AVC cannot be applied to HEVC. Hence, developing a data hiding algorithm that can support the transform coding adopted by HEVC while eliminating the intra-frame error propagation and alleviating the inter-frame error propagation is required, which motivates this research.

In this paper, we propose an error propagation-free data hiding algorithm for HEVC IFs. The main idea of the proposed algorithm is to categorize blocks so as to impose specific quantized coefficient perturbation patterns for intra-frame error propagation-free data hiding under the HEVC framework. For HEVC IFs, we propose a DCT and discrete sine transform (DST)-based coefficient

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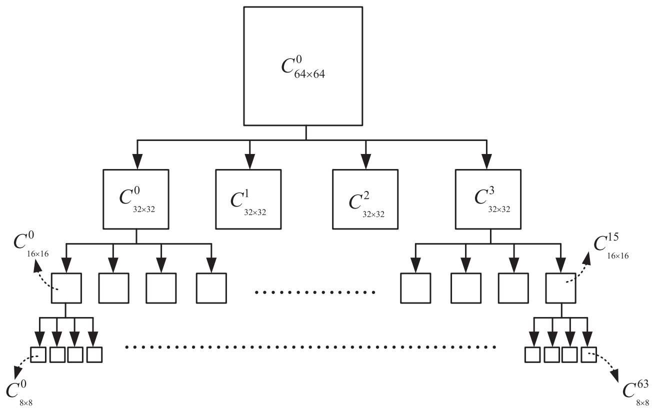

Fig. 1. The quadtree decompositions for one 64×64 coding unit.

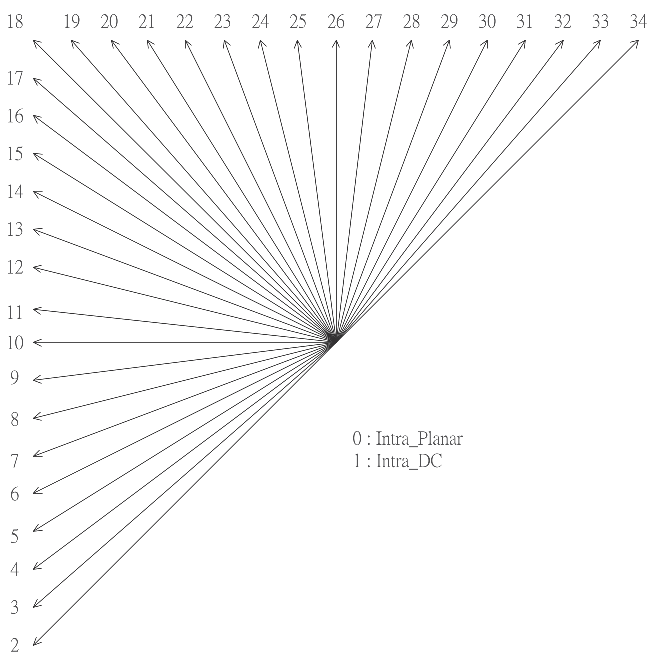

Fig. 2. The 35 intra prediction modes supported by HEVC.

perturbation scheme for embedding hidden bits. The error propagation patterns corresponding to different HEVC intra prediction modes are first classified for imposing different data hiding patterns. These data hiding patterns, which correspond to specific QDCT and QDST coefficient perturbations, are used to embed hidden bits into HEVC IFs without inducing intra-frame error propagation. In addition, one quality improvement scheme is proposed for the reconstructed IFs and meanwhile alleviates the quality degradation due to inter-frame error propagation. Experimental results on ten test videos confirm the merits of the proposed algorithm in providing the intra-frame error propagation-free advantage, the quality improvement for marked images, the compression power inherited from HEVC and the superiority of embedding capacity for low bitrate coding, although the embedding capacity is less than that of the previous two algorithms for H.264/AVC IFs for middle and high bitrate coding. To the best of our knowledge, this is the first time that such a DCT/DST-based data hiding algorithm is presented for HEVC.

The rest of this paper is organized as follows. In Section 2, the HEVC intra coding scheme and related block transform coding operations are reviewed. The proposed DCT/DST-based data hiding algorithm in HEVC and its theoretical analysis are presented in Section 3. Section 4 demonstrates experimental results and performance evaluation. Some concluding remarks are addressed in Section 5.

2. Intra coding scheme and the related transform coding in HEVC

The HEVC intra coding scheme, including block transform coding operations, will be first reviewed, with which the proposed data hiding algorithm can be clearly described.

2.1. Intra coding scheme in HEVC

When compressing video sequences by the HEVC encoder, coding unit (CU) is the basic unit to perform coding for each video frame. One video frame is first split into 64×64 non-overlapping CUs, each of which is further split into smaller ones with a recursive quadtree decomposition, as shown in Fig. 1, where $C^0_{N\times N}, C^1_{N\times N}, \ldots, C^{(64/N)^2-1}_{N\times N}$ denote the $(64/N)^2$ CUs of size $N \times N$ for $N = 64$, 32, 16, 8.

To exploit spatial redundancy for compression, the intra prediction is performed among adjacent blocks for predicting the current block in HEVC. For one $N \times N$ CU with $N \in \{64, 32, 16\}$, there exists only one prediction unit (PU) of size $N \times N$, whereas two PU sizes, 8×8 and 4×4, are available when $N = 8$. In addition to different PU sizes, HEVC supports 35 intra prediction modes, as shown in Fig. 2, while only nine modes are specified in H.264/AVC.

Among 35 intra prediction modes, the planar and DC modes, i.e., modes 0 and 1 in Fig. 2, are, respectively, appropriate for PUs where there exist gradual changes and little variation on the luma values. In addition to DC and planar modes, the rest of prediction modes considering 33 different directions are often used to capture the characteristics of edges in the PU.

For one $N \times N$ PU, the HEVC encoder generates 35 prediction blocks from corresponding neighboring pixels and intra prediction modes. These reference pixels for intra prediction are encoded pixels from upper-right, upper, upper-left, left and lower-left neighboring blocks, as shown in Fig. 3(a). Note that in Fig. 3(b), the reference pixels $\{s_{N+i,0}\}_{i=1,\ldots,N}$ from the lower-left block are unavailable since they are not yet encoded by HEVC at the time when encoding the current PU. Under this condition, these unavailable pixels $\{s_{N+i,0}\}_{i=1,\ldots,N}$ will be set to equal to the nearest encoded reference pixel $s_{N,0}$ to act as reference pixels. For each intra prediction mode, to calculate the RD cost on the corresponding residual signal, coding operations such as transform, quantization, and entropy coding have to be carried out. The intra prediction mode that yields the minimum RD cost is selected as the optimal one to predict and encode the current PU.

Once the optimal intra prediction mode for each PU is determined, HEVC updates the RD cost associated with each CU in Fig. 1. The hierarchical structure corresponding to the CU, $C^0_{64\times64}$, in Fig. 1 will be pruned and merged according to the RD optimization procedure and hence the optimal intra coding partition corresponding to $C^0_{64\times64}$ can be obtained.

2.2. Transform coding related to the luma intra prediction

To obtain the RD cost on the residual signal, HEVC specifies the transform unit (TU) for transform and quantization coding of the prediction residual. In the HEVC intra coding, before determining the optimal intra mode for one PU, to obtain the associated RD costs, for one $N \times N$ PU with $N \in \{32, 16, 8, 4\}$, there exists only one TU of size $N \times N$, whereas four 32×32 TUs are used when $N = 64$. In transform coding of the luma prediction residual, HEVC