INTRA PREDICTION WITH ENHANCED INPAINTING METHOD AND VECTOR PREDICTOR FOR HEVC

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ABSTRACT

As the successor to H.264/AVC, High Efficiency Video Coding (HEVC) will provide 50% reduction on compression data compared to H.264/AVC. In this paper, we propose an intra prediction method based on inpainting algorithms and vector predictor for HEVC. Our method utilizes a combination of two important inpainting algorithms: Laplace partial differential equation (PDE) and total variation (TV) model. Experiment results show that, compared to HEVC Test Model (HM) 2.0, our proposal achieves an average of 1.65% bitrate reduction .

***Index Terms*—** HEVC, Intra prediction, Inpainting, TV model

1. INTRODUCTION

HEVC stands for the next generation video compression standard after H.264/AVC[1]. It is a draft standard under joint development by the ISO/IEC Moving Picture Experts Group (MPEG) and ITU-T Video Coding Experts Group (VCEG). MPEG and VCEG have established a Joint Collaborative Team on Video Coding (JCT-VC) to develop the HEVC standard. The target of HEVC is to further reduce by 50% the data rate needed for high quality video coding, as compared to the current standard. As a key tool to exploit the spatial correlation within a frame, intra prediction is adjusted to provide better performance. One of the adjustments is that up to 34 prediction directions are available for the current block, compared to only 9 prediction directions in H.264/AVC. Available intra prediction directions for different Prediction Unit (PU) sizes are illustrated in Table 1.

Inpainting originally refers to the restoration of cracks and other defects in works of art. In Computer Vision, the seamless regeneration of missing information in an image is usually referred to as inpainting. There are two main algorithms of inpainting. One is texture synthesis (TS) for generating large regions with complex textures, the other is inpainting based on solving partial differential equations (PDEs), and is more suitable for restoration of small regions. In recent years, many inpainting-based intra prediction methods have been proposed. Texture synthesis by template matching and Laplace PDE based inpainting were combined together in intra prediction in [2], Liu etc al. [3] proposed an image compression scheme with edge-based inpainting aiming at subjective quality. Meanwhile, another work based on objective quality was presented in [4].

Table 1. Number of supported intra directions according to PU size in HEVC

PU size	Number of intra modes
4	17
8	34
16	34
32	34
64	5

In this paper, we propose an inpainting and vector predictor based intra prediction method inspired by the work in [2]. In our proposal, the PDE-based inpainting algorithm is a combination of Laplace PDE and TV model[5] to improve prediction accuracy. Besides, in order to utilize non-local similarity, we also combine a vector predictor scheme into our proposal.

The rest of the paper is organized as follows: Section II describes traditional intra prediction in HEVC, while Section III describes our PDE-based intra prediction. In Section IV, a concrete description of the intra prediction based on our vector predictor scheme is proposed. Simulation results and further analysis are given in Section V.

2. INTRA PREDICTION IN HEVC

In this section, we will give a brief description of the intra prediction in HEVC, as well as related concepts.

First, instead of macro-block and sub-block concepts in H.264/AVC, Coding Unit (CU) and Prediction Unit (PU) are

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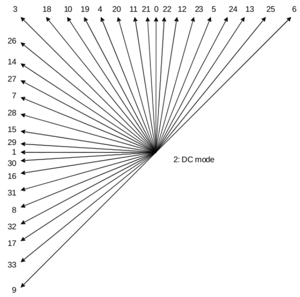


Fig. 1. Intra prediction directions in HEVC

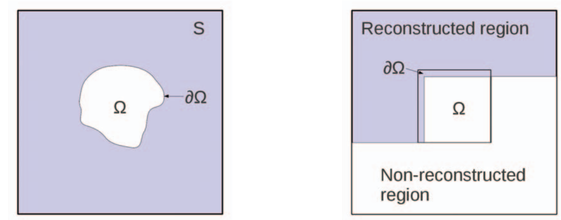
introduced in HEVC. CU is the basic unit of region splitting for inter/intra prediction, always square and may take a size from 8×8 luma samples up to the size of the treeblock. It allows recursive splitting into four equally sized blocks, starting from the treeblock, which gives a content-adaptive coding tree structure. PU is the basic unit used for carrying the information related to the prediction process. In order to facilitate partitioning, it is not restricted to being square in shape. However, each PU in intra prediction is always square. Each CU may contain one or more PUs.

Second, intra prediction in HEVC is a combination of Arbitrary Direction Intra (ADI) and Angular Intra Prediction (AIP) methods. Up to 34 directional prediction modes are provided in HEVC, as illustrated in Fig.1[6]. For PU sizes of 4×4, 8×8, 16×16, 32×32, 64×64, there are 17, 34, 34, 34, and 5 prediction modes available respectively, as illustrated in Table 1. The prediction directions have the angles of +/- [0, 2, 5, 9, 13, 17, 21, 26, 32]/32. The angle is determined by displacement of the bottom row of the PU and the reference row above the PU in case of vertical prediction, or displacement of the rightmost column of the PU and the reference column left of the PU in case of horizontal prediction.

As can be seen from above, in order to improve compression rate, the main idea of traditional intra prediction is to increase the number of prediction directions and use more adaptive partition scheme. As a result, overhead of expressing partition result as well as prediction mode of each partitioned subblock becomes larger compared to that of H.264/AVC. Besides, since all these prediction directions are fixed and in a straight line style, it can not deal with natural images adaptively. One of the solutions is inpainting-based intra prediction.

3. INTRA PREDICTION BY PDE-BASED INPAINTING

In this section, we describe two important PDE-based inpainting methods: Laplace PDE-based inpainting and TV model-based inpainting. Meanwhile, how inpainting is applied in intra prediction is also illustrated. In the end, a description of the combination of these two methods is given.



(a) (b)

Fig. 2. (a) General case of the inpainting problem, (b) Notations for intra prediction with inpainting method.

3.1. Laplace PDE-based Inpainting

As indicated in Fig.2a, we define f^* as a known function over the domain $S(S \in R^2)$, and f is an unknown function defined over the unknown area $\Omega \in S$. $\partial\Omega$ represents the boundary of Ω. Then, the aim is to find f using the information available in $S \setminus \Omega$. For instance, in Laplace PDE-based inpainting problem, this is a boundary value problem and can be expressed as:

$$\Delta f = 0 \tag{1}$$

with boundary condition

$$f|_{\partial\Omega} = f^*|_{\partial\Omega} \tag{2}$$

where, Δ represents the Laplacian operator. Corresponding application in intra prediction is expressed in Fig.2b. In practice, Equation (1) is solved by an iterative method:

$$f^{(t+1)} = f^{(t)} + c^{(t)}(\Delta f)^{(t)}, t = 0, 1, 2, ... \tag{3}$$

where, $c^{(t)}$is the step size. When $||f^{(\tau+1)} - f^{(\tau)}||$ is less than a threshold, the fuction $f^{(\tau)}$ is regarded as the solution to (1).

3.2. TV Model-based Inpainting

When applying Laplace PDE-based inpainting alogrithm, we are actually assuming that the current block is smooth. However, this is not always the case in actual image. TV model is another algorithm used in inpainting problem and its advantage is that it provides a satisfied performance for inpaintings involving the restoration of narrow broken smooth edges. As a result, TV model generally gives a better prediction compared with the Laplace PDE. However, its computational complexity becomes larger at the same time compared to Laplace PDE algorithm, so we integrate them together as an enhanced inpainting algorithm. Here we will give a description of TV model, more details can be found in [5, 7].

As indicated in Fig.3, we let Ω be an inpainting domain with piecewise smooth boundary $\partial\Omega$, and E any fixed closed

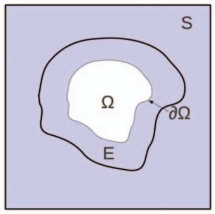


Fig. 3. TV model

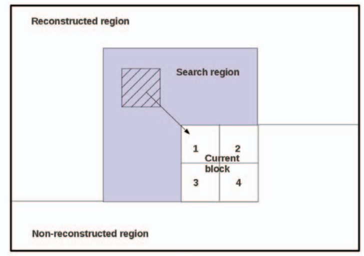


Fig. 4. Vector predictor based intra prediction

domain in the complement $S \setminus \Omega$, so that $\partial\Omega$ lies in the interior of $E \cup \Omega$. We also define f^* as a known function over S. Besides, we assume that $f^*|_E$ is contaminated by homogeneous white noise. The aim of TV model inpainting is to find a function f on the extended inpainting domain $E \cup \Omega$, such that it minimizes an appropriate regularity function:

$$R[f] = \int_{E\cup\Omega} |\nabla f| dxdy \tag{4}$$

under the fitting constraint on E

$$\int_E |f - f^*|^2 dxdy = \sigma^2 * area(E) \tag{5}$$

where, σ is the standard deviation of the white noise. This is a constrained variational problem. However, It is more convenient to solve the unconstrained TV inpainting problem:

$$J_\lambda[f] = \int_{E\cup\Omega} |\nabla f| dxdy + \frac{\lambda}{2}\int_E |f - f^*|^2 dxdy \tag{6}$$

where λ plays a role of the Lagrange multiplier. The Euler-Lagrange equation for the energy function J_λ is:

$$-\nabla \cdot (\frac{\nabla f}{|\nabla f|}) + \lambda_e(f - f^*) = 0 \tag{7}$$

where, $\lambda_e = \lambda$ in E, and $\lambda_e = 0$ in Ω. In our numerical implementation, noise is not taken into account for simplicity, so λ is set to ∞, and E is set to $\partial\Omega$, according to the suggestion in [5].

Before one block is predicted by TV model algorithm, prediction with Laplace PDE algorithm is applied to determine whether this block is suitable for PDE-based inpainting method by the calculation of RD cost. If so, TV model algorithm will be applied.

4. INTRA PREDICTION BY VECTOR PREDICTOR

There are usually some repetitive or similar patches over a natural image. However, since traditional intra predictions just use surrounding pixels, it can not make use of this character. To solve this problem, we propose a vector predictor based intra prediction. In our proposal, template matching (TM) is applied to determine a vector. TM is a technique in digital image processing to find small parts of an image which match a template image, and can be subdivided between two approaches: feature-based and template-based matching. In our proposal, template-based matching is applied.

Our vector predictor based intra prediction is illustrated in Figure.4. First, the current block is divided into four equal parts, denoted as subblock 1, 2, 3 and 4. Then, a part of the reconstructed region which is next to the current block is selected as search region, where each subblock is searched by order. The matching criteria in our proposal is:

$$SAD = \sum_{i=1}^{N} |S_{target}(i) - S_{template}(i)| \tag{8}$$

where N is the number of pixels in a subblock. The search result is expressed by a vector, which points to the location of the matched block. After each search, the search region is enlarged to include the processed subblock. For example, when subblock 2 is in the search process, subblock 1 is part of the search region.

To speed up the search process, two methods are used in our proposal. First, we will search in the down-sampled image before the original one. In this way, we can get the most probable location in the search region of the original image. Then, locations nearby the most probable one will be checked to find the one with the least SAD claculation. Second, if the SAD is smaller than a certain threshold, search process will stop right now.

Algorithm 1 Vector predictor algorithm

Step 1 Down-sample search region and current block.
Step 2 Search down-sampled subblock in down-sampled search region by template matching. If SAD is less than a threshold, go to next step, else halt.
Step 3 Calculate SAD results of surrounding corresponding positions in original search region. Block with the least SAD calculation is regarded as the target block.
Step 4 Calculate verctor and update search region. Go to Step 2 until all subblocks are predicted. Halt.

Table 2. Bitrate Reduction with Frames=10, QP=32

Sequence	Size	CU Size/Depth	Vector Predictor	Laplace	TV Model	Vector Predictor+TV Model
Flowervase	416×240	16/2	-0.21%	-2.93%	-4.05%	-4.51%
BasketballPass	416×240	16/2	-0.59%	-0.39%	-0.43%	-1.14%
Mobisode2	832×480	32/3	-0.01%	-0.79%	-1.45%	-1.40%
vidyo1	720p	32/3	-0.09%	-0.65%	-0.80%	-0.90%
vidyo3	720p	32/3	-0.07%	-0.20%	-0.13%	-0.28%
Average			-0.19%	-0.99%	-1.37%	-1.65%

Table 3. PSNR Results with Frames=10, QP=32

Sequence	HM2.0	VP+TV	ΔPSNR
Flowervase	40.269	40.256	-0.013
BasketballPass	35.706	35.758	+0.052
Mobisode2	43.626	43.621	-0.005
vidyo1	39.730	39.722	-0.008
vidyo3	39.472	39.474	+0.002

5. SIMULATION CONDITIONS AND RESULTS

We integrated our new intra prediction mode into the HEVC reference software, version HM2.0. To be specific, we implemented the new mode on the top level of the CU structure of the current block as an add-on mode and mode decision is made by the criteria of RD cost. We use five video sequences to evaluate our new mode. The experiments are conducted with the settings below: TU max depth of intra is 3, TU min size is 4, TU max size is 32, CABAC entropy coding and RDOQ is on. Besides, each sequence is encoded by all-intra mode, so Intra Period and GOP Size are both set to 1. The luma PSNR as well as the bitrate are calculated and provided by HM software itself. Note that only luma is taken into account in our implementation and experiment. For simplicity, the encoding and compression of vectors in vector predictor based intra prediction mode is not implemented, and will be part of our work in the future.

In Table 2, coding results of the proposed scheme for five sequences with different resolutions are given. The bitrate reduction results are calculated compared to HM2.0. From the results, we can observe that the performance of TV Model is obviously better than that of Laplace PDE, which proves that TV model inpainting algorithm can provide better prediction compared to Laplace PDE inpainting algorithm. For the Vector Predictor, although overhead of vectors is not taken into account, bitrate reduction is yet slight. When we combine Vector Predictor and TV Model together, up to 4.51% bitrate reduction is achieved, with an average result of 1.65%. PSNR results are given in Table 3. According to Table 2 and 3, our new intra prediction method achieves an averate of 1.65% bitrate reduction with PSNR remains the same.

6. CONCLUSION

Although HEVC intra prediction achieves quite high coding efficiency, its complex recursive quadtree CU structure and up to 34 prediction modes require more bits to express. Traditional inpainting-based intra prediction has provided a good performance in coding efficiency. However, potential of improvement still exists. This paper presented a new HEVC intra prediction mode with enhanced inpainting method and vector predictor method. Compared with HM2.0, better RD performance can be achieved.

7. REFERENCES

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