NOVEL MEDICAL VIDEO COMPRESSION METHODS OVER LOSSLESS HEVC CODER

Yao-Jen Chang, Pei-Hsuan Tsai†, and Chun-Lung Lin**

*Industrial Technology Research Institute (ITRI), Chutung, Hsinchu, Taiwan (R.O.C.)
†National Cheng Kung University, Tainan, Taiwan (R.O.C.)
YJChang@itri.com

ABSTRACT

To realize the medical video applications, this paper proposes several lossless compression methods over high efficiency video coding (HEVC). A generalized intra block copy (GIBC) is first proposed to predict the coding unit by a reference block, whose samples could be fully or partially reconstructed. A cyclic block padding technique is also proposed to predict the unreconstructed samples in the reference block by geometrically co-located blocks. Based on the feature distribution analyses for palette coding, we further propose an HEVC-based medical video coder (HMC), which combines the GIBC, line-coded palette coding and intra palette predictor without mutual conflicts. Experimental results show that, compared to the lossless HEVC, the proposed GIBC and HMC respectively save up to 13.9% and 22.3% bits over medical videos.

***Index Terms*—** HEVC, lossless coding, medical video

1. INTRODUCTION

A mobile health system [1] is under developing to wirelessly share the medical information such as physical monitoring data and medical images/videos with the physicians. It will improve the treatment and increase the survival in the emergent conditions [2]. However, the medical videos [3]-[5] occupy the most transmission bandwidths and storage capacities. Note that the medical regulations in many countries require to keep the medical information in storages for many years. Hence, the compression of medical videos is a key to fully realize the system. High Efficiency Video Coding (HEVC) [4-8] is a promising video coder to provide a better performance than the classical H.264/AVC and MPEG-4 standards without compromising on the diagnostic accuracy [4-5]. Since some medical objects such as organs, texts and lines feature sharp edges and/or non-smooth textures, the HEVC intra prediction has become inefficient to these medical images. Therefore, this paper proposes novel lossless compression methods: generalized intra block copy (GIBC) and HEVC-based medical video coder (HMC).

The GIBC is first proposed to predict the coding unit (CU) by a reference block (RB) selected out of the neighboring blocks, each of whose samples have been fully or partially reconstructed. A cyclic block padding (CBP) technique is further proposed to exploit two geometrically co-located block candidates to predict the unreconstructed samples of the RBs. We further contribute analyzing the feature distribution of the run length-coded palette coding (RPC) [9] and line-coded palette coding (LPC) [10] over the medical videos. Based on the analyzing results, we propose the HMC by combining the GIBC, LPC and intra palette predictor (IPP) [11] into the HEVC without mutual conflicts. Compared to the lossless HEVC, the experimental results show that the GIBC and HMC can substantially improve the compression gains up to 13.9% and 22.3%, respectively. The proposed GIBC, combined LPC and IPP, and IPP, respectively, contribute up to 11.9%, 10.8% and 2.6% bit saving to the proposed HMC.

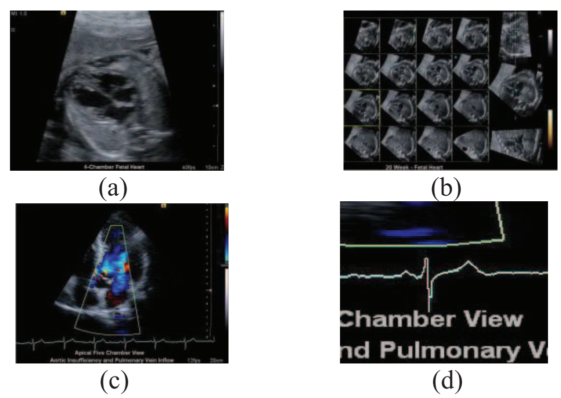


Fig. 1. 800x400 medical videos (a) FH scenario (b) VFH scenario (c) CD scenario (d) Medical objects clipped from (c)

2. TEST CONDITION FOR MEDICAL VIDEO COMPRESSION

Three medical videos provided by Siemens Healthcare [12] are used as the test sequences in this paper. Fig. 1 shows the first pictures of different medical videos. Fig. 1(a) is the fetal heart (FH) scenario to show a full image of a 4-chamber heart. Fig. 1(b) is the varying FH (VFH) scenario to show the heart at different moments. Fig. 1(c) is a color Doppler (CD) scenario to view a regurgitation or an acceleration around the aortic outflow tract. We proceeded all experiments on top of the HEVC reference software, HM 14 [13], with the configuration of lossless all-intra coding. Note that the HM 14 is a codec software obeying the HEVC standard.

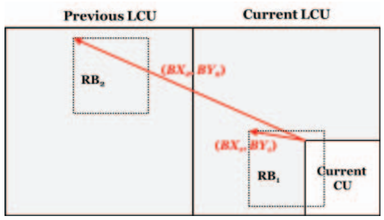
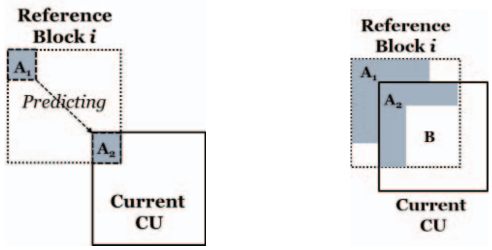
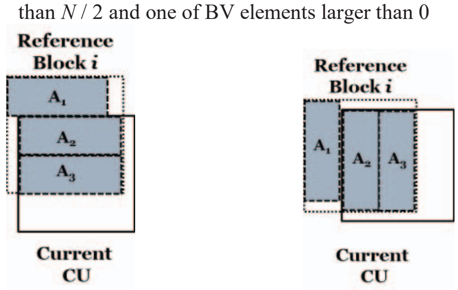


Fig. 2. Examples of the RBs considered in the proposed GIBC



(a) (b)

Fig. 3. The unreconstructed region (a) The BV elements smaller than N and one of BV elements larger than N / 2 (b) Both BV elements smaller than N / 2 and one of BV elements larger than 0



(a) (b)

Fig. 4. The unreconstructed areas $\mathbf{A_2}$ and $\mathbf{A_3}$ cyclically padded with the geometrically co-located block $\mathbf{A_1}$ (a) geometric horizontal block for $BX_i \leq BY_i$ (b) geometric vertical block for $BX_i > BY_i$

3. THE PROPOSED HEVC-BASED MEDICAL VIDEO CODER

3.1. Generalized intra block copy (GIBC)

The intra prediction mode (IPM) [6] in HEVC exploits the reconstructed pixels adjacent to the CU to predict the CU along a specified direction. However, the IPM cannot efficiently compress some of medical images featuring the sharp edge with irregular directions and/or non-smooth textures as shown in Fig. 1(d). To address this kind of medical objects, a GIBC is proposed to exploit the pixels inside an $N\times N$ RB to predict the pixels inside the current $N\times N$ CU, where the RB is selected out of fully or partially reconstructed blocks. The GIBC is operated in a CU basis, and the largest CU (LCU) defined in HEVC is 64×64.

The following assumptions are made: The coordinates of the most top-left samples inside the current CU, the current LCU and the selected RB relative to the most top-left sample inside the picture are, respectively, specified as (x, y), (s, t) and (p, q), where x, y, s, t, p and q are non-negative integers. The proposed search range of the elements in the coordinate (p, q) for the RB are defined as follows:

$$p = [s - 64, \min(s + 64 - N, W - N)], \quad (1)$$

$$q = [t, \min(t + 64 - N, H - N)], \quad (2)$$

where W and H are the width and height of the video. Each RB is assigned a block vector (BV) defined as (BX, BY) to indicate the differences between the RB and the current CU:

$$(BX, BY) = (x - p, y - q). \quad (3)$$

Note that $(BX, BY) = (0, 0)$ is not allowed. To achieve the lossless compression for medical videos, the RBs that are perfectly identical to the current CU in terms of pixel values are selected as the candidates for the best RB. Then the best RB with lowest bit cost will be selected out of the candidates. Instead of signaling the whole pixel values inside the current CU, the proposed GIBC technology only signals the elements of (BX_b, BY_b) of the best RB to the decoder to indicate which RB is copied to the current CU.

If the differences in horizontal and vertical axes between the i-th RB and the current CU are all smaller than the width or height of the RB, i.e., $BX_i < N$ and $BY_i < N$, partial samples inside this i-th RB will be unreconstructed due to overlapping with the current CU. In Fig. 2, two RBs, (BX_1, BY_1) and (BX_2, BY_2) are demonstrated under the assumption of the current CU located at the most right-bottom in the current LCU. Note that all samples of the current and previous LCU in Fig. 2 have been reconstructed except for those of the current CU. The BV elements BX_1 and BY_1 of RB_1 are all smaller than N, and thus partial pixels in RB_1 are unreconstructed. More specifically, the samples in the overlapped region between the RB_1 and current CU are null pixels. To solve the null-pixel problem of the RB associated with $BX_i < N$ and $BY_i < N$, we propose the CBP technique to predict the null pixels by the geometrically co-located pixels that are inside the RB itself. As shown in Fig. 3(a), the region $\mathbf{A_2}$ in the current CU is geometrically predicted by the top-left region $\mathbf{A_1}$ of the RB_i. Therefore, the proposed CBP exploit the top-left region $\mathbf{A_1}$ of the RB_i itself to predict the unreconstructed region $\mathbf{A_2}$ of the RB_i due to high similarity of pixels between geometrical co-locations.

However, another issue occurs in the RBs associated with $BX_i < (N / 2)$ and $BY_i < (N / 2)$ as shown in Fig. 3(b). The unreconstructed region of the RB_i is composed of the grey sub-region $\mathbf{A_2}$ and the white sub-region $\mathbf{B}$. Although the top-left region $\mathbf{A_1}$ can predict the sub-region $\mathbf{A_2}$, the pixels inside the sub-region $\mathbf{B}$ are still null (unknown). To address the unreconstructed regions for the RB_i associated with $BX_i < (N / 2)$ and $BY_i < (N / 2)$, the CBP technique proposes to exploit one of two geometrically co-located block candidates in the top-left rectangular region of the RB itself to cyclically predict the unreconstructed pixels. Fig. 4 is examples to depict two geometrically co-located block candidates: one is the geometric horizontal block $\mathbf{A_1}$ in Fig. 4(a), and the other one is the geometric vertical block $\mathbf{A_1}$ in Fig. 4(b). The unreconstructed regions $\mathbf{A_2}$ and $\mathbf{A_3}$ can be cyclically predicted by one of block candidates. If $BX_i \leq BY_i$, the geometric horizontal block as shown in Fig. 4(a) is selected as the geometrically co-located block for predictions; otherwise, the geometric vertical block as shown in Fig. 4(b) is selected. Define the symbol $v(m, n)$ as the pixel value at the coordinate (m, n) relative to the most top-left sample of the current picture. Then the proposed CBP predicts the unreconstructed pixels in the i-th RB as follows:

$$v(p+g,q+h)=\begin{cases} v(p+g-BX_i,q+(h-BY_i)\%BY_i), & if\ BX_i \le BY_i \\ v(p+(g-BX_i)\%BX_i,q+h-BY_i), & otherwise \end{cases} \quad (4)$$

where $(p + g, q + h)$ is the coordinate of the unreconstructed samples in the i-th RB, $g = BX_i, BX_i + 1, \ldots, N - 1$, $h = BY_i, BY_i + 1, \ldots, N - 1$, and the symbol % indicates the remainder of the division.

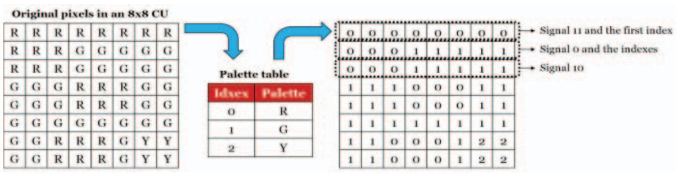
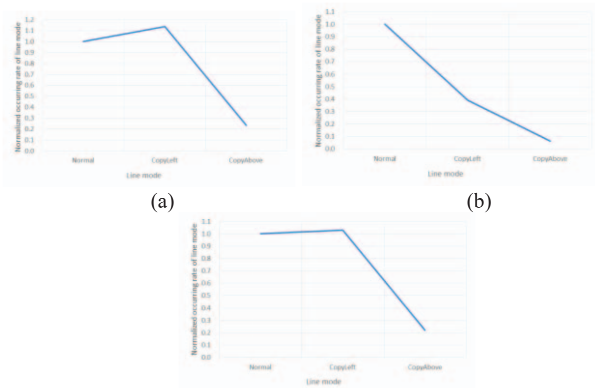


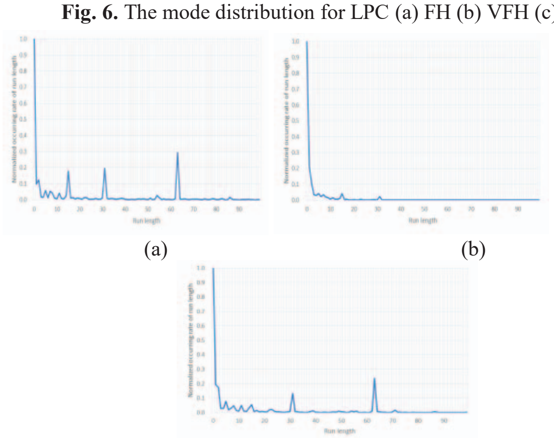
Fig. 5. Example of the palette coding technology



(a) (b)

(c)

Fig. 6. The mode distribution for LPC (a) FH (b) VFH (c) CD



(a) (b)

(c)

Fig. 7. The run distribution for RPC (a) FH (b) VFH (c) CD

The behavior of the proposed GIBC is similar to that of the traditional IBC [14]. However, the candidates for the RB in the traditional IBC are constrained to be the previously-coded block whose samples are all reconstructed. Instead, the candidates for the RB in the proposed GIBC with the CBP could be any block no matter whether all of the samples inside the block region are reconstructed or not. Therefore, the proposed GIBC can obtain more RB candidates than the traditional IBC, and thus result in better compression gains as well. Besides, the prediction manner of the GIBC technology is not constrained by a specified direction like the traditional IPM technology, and is helpful to the medical images with sharp edges and/or non-smoothing texture. The improved compression performance will help realize the medical video applications over mobile health systems.

3.2. HEVC-based medical video coder (HMC)

Based on the feature distribution analyses, the HMC is further proposed to improve the HEVC by integrating the proposed GIBC and the combined LPC [10] and IPP [11]. The LPC is one of palette coding methods [9]-[10] originally designed for screen content coding. The basic idea of the palette coding includes three steps at the encoder: 1) Select M pixel values out of N^2 samples in the $N \times N$ current CU to be the palettes and establish a palette table, in which each palette has one palette index. 2) Convert each sample of the current CU to a palette index by looking up the palette table. 3) Signal the number of palettes, the palettes and the converted palette indexes to the decoder. The left diagram in Fig. 5 shows an original 8×8 CU, in which there are only three colors, i.e., R, G and Y. The middle diagram shows the colors R, G and Y in the original 8×8 CU are selected as palettes to establish the palette table. Then each pixel value in the original 8×8 CU is converted to an index through looking up the palette table as depicted in the right diagram.

The LPC [10] signals the palette indexes by a line-by-line coded method. The RPC [9] is another kind of palette coding, and signals the palette indexes by a run-length coded method. The right diagram in Fig. 5 shows the line-by-line based coding method for LPC: If the current line is identical to the above line, it will only signal '10', e.g. the third line of the right diagram in Fig. 5. If the current line has the same index, it will signal '11' and 'the first index', e.g. the first line of the right diagram in Fig. 5. Otherwise, it will signal '0' and the indexes in the line, e.g. the second line of the right diagram in Fig. 5. As to the run-length coding method for RPC, it will signal 'the palette index' and 'the run length'. To compare the capabilities of the LPC and RPC, we contribute analyzing the feature distribution of different palette index coding methods as shown in Fig. 6 and Fig. 7.

Fig. 6 analyzes the normalized occurring rates of line modes in the LPC for different medical videos. The results show that the LPC achieves high normalized occurring rates up to 110% to code a pixel line with simple copying above or copying left. Fig. 7 analyzes the normalized occurring rates of run lengths in the RPC for different medical videos. The results show that the normalized occurring rates of no run is much higher than the other rates of runs. This implies that the run-length coding method cannot efficiently compress the medical content in the lossless condition. To verify the perspective on the compression efficiency, we compare the compressed bits of LPC and RPC on top of the HEVC as shown in Table 1, where the changed compression rate (CCR) defined in (5) is employed as the metrics. It shows that the LPC is superior to the RPC with up to 10.7% compression gain.

Based on the above analyses, the combined LPC and IPP [11] is proposed to be integrated into the proposed HMC. The IPP can further compress the medical palettes by reusing the palette table from the spatially neighboring CUs. If the decoder receives the bits '10', it will establish the palette table by directly reusing the palettes in the left CU; If the decoder receives the bits '11', it will establish the palette table by directly reusing the palettes in the above CU; If the decoder receives the bits '0, it will establish the palette table by the original method, which requires receiving the pixel values for each component in the palettes. In summary, the proposed HMC integrates the following coding tools on top of the HEVC: GIBC and the combined LPC and IPP. The LPC can also address the images with the sharp edges and non-smooth texture which are common in the medical videos. The IPP is expected to be able to further compress the palettes in the LPC.

4. EXPERIMENTAL RESULTS

The proposed GIBC and HMC are experimented under the lossless medical compression condition as introduced in Section II. Several coding methods are also simulated for comparisons. The CCR of the proposed method is evaluated by computing the increased percentage of the compressed bits of the proposed method relative to the anchor:

$$R_C = (B_P - B_A)/B_A \, , \tag{5}$$

where B_P is the compressed bits of the proposed method and B_A is the compressed bits of the anchor. Lower CCR R_C implies better compression performance. The anchor is one of the state-of-the-art methods, such as HEVC [6], HEVC with IBC [14], and HEVC with IBC and LPC [10].

Table 2 shows the CCRs of the proposed GIBC on top of HEVC relative to different anchors. The experimental results show that the GIBC can further reduce 6.7% ~ 13.9% compressed bits compared to the HEVC. Besides, the results also show that the GIBC with fewer restrictions to the RB is much better than the traditional IBC in terms of the amount of compressed bits, where up to 7.9% gap between the GIBC and traditional IBC are shown. Table 3 shows the CCRs of the proposed combined LPC and IPP on top of the HEVC with IBC compared to different anchors. The results show that the proposed combined method can further compress 5.9% ~ 21.4% bits compared to the HEVC, and 0.7% ~ 14.8% bits compared to HEVC with IBC. Moreover, the results also show that the IPP can improve up to 3.5% compression gain on top of the LPC.

Table 4 shows the CCRs of the proposed HMC relative to different anchors. The results show that the proposed HMC can excellently address the medical videos with 7.4% ~ 22.3% saving of the compressed bits compared to the HEVC, and 4.3% ~ 15.8% saving of the compressed bits compared to the HEVC with IBC. Table 5 disables different proposed methods on top of the HMC to analyze the compression contributions to the HMC. For example: HMC–GIBC indicates the HMC disables the GIBC. The experimental results show that the GIBC, the LPC+IPP, and the IPP, respectively, contribute up to 11.9%, 10.8%, and 2.6% compression gains to the HMC. It is worth noting that there is no mutual conflict on compression performance.

Table 1. CCRs of the LPC relative to the RPC anchor

SEQUENCE	FH	VFH	CD
CCR	**-0.6%**	**-1.1%**	**-10.7%**

Table 2. CCRs of GIBC on top of the HEVC relative to various anchors

Sequence	Anchor	
	HEVC	HEVC+IBC
FH	**-12.8%**	**-7.9%**
VFH	**-6.7%**	**-3.6%**
CD	**-13.9%**	**-6.6%**

Table 3. CCRs of the combined LPC and IPP on top of the HEVC+IBC relative to various anchors

Sequence	Anchor		
	HEVC	HEVC+IBC	HEVC+IBC+LPC
FH	**-5.9%**	**-0.7%**	**-0.1%**
VFH	**-4.6%**	**-1.5%**	**-0.4%**
CD	**-21.4%**	**-14.8%**	**-3.5%**

Table 4. CCRs of HMC relative to various anchors

Sequence	Anchor	
	HEVC	HEVC+IBC
FH	**-13.0%**	**-8.2%**
VFH	**-7.4%**	**-4.3%**
CD	**-22.3%**	**-15.8%**

Table 5. The CCRs of the different coders when the proposed HMC is regarded as an anchor

Sequence	Coder		
	HMC-GIBC	HMC-LPC-IPP	HMC-IPP
FH	**+11.9%**	**+0.3%**	**+0.1%**
VFH	**+4.6%**	**+0.8%**	**+0.2%**
CD	**+1.5%**	**+10.8%**	**+2.6%**

5. CONCLUSION

This paper proposes the GIBC to exploit a selected RB to reconstruct the current CU. With the aid of the CBP using two geometrically co-located block candidates, the RB of the GIBC could be more generalized than the RB of the traditional IBC. Moreover, the feature distribution for the RPC and LPC are also analyzed to further propose a brand-new HMC, which integrates the GIBC, LPC and IPP on top of the HEVC. Under the lossless medical compression condition, the experimental results show that the proposed GIBC saves up to 13.9% compressed bits than the HEVC, and the proposed HMC improves the compression gains up to 22.3% compared with the HEVC. The GIBC, combined LPC and IPP, and IPP, respectively, contribute 11.9%, 10.8%, and 2.6% compression gains to the HMC without mutual conflicts. The proposed video compression methods and the contributed analyses can accelerate the realization of the medical video applications in the mobile health systems.

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