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Hierarchical Coding Algorithm for Medical Video Based on H.265/HEVC

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Abstract. *In modern medical communication systems, the high-efficiency video compression technology is of great significance to the storage and transmission of digital medical videos. To further improve the compression performance of the medical ultrasound videos, two innovative technologies based on diagnostic region-of-interest (ROI) extraction with the High Efficiency Video Coding (H.265/HEVC) standard are proposed in the paper. First, an image-texture-feature based ROI extraction algorithm is proposed to strengthen the applicability of the ROI detection results in the H.265/HEVC quad-tree coding structure. Second, a hierarchical coding algorithm based on the adaptive transform coefficient adjustment and the quantization parameter selection process is designed to implement the otherness encoding for ROI and non-ROI. Experimental results show that the proposed method can improve the coding performance by achieving BD-BR savings of 13.52% on average compared to H.265/HEVC (HM15.0).*
Keywords: H.265/HEVC; Medical video coding; ROI extraction; Quad-tree structure.

1. **Introduction.** With the development of the digitalization processing in modern hospitals, digital medical videos are playing an increasingly important role in the diagnosis and treatment of diseases. Thus, large amounts of medical data are produced with the widespread application of digital imaging device, which have brought a serious challenge to the storage and transmission of medical videos [1]. As the result, the research on high-efficiency video coding techniques is significant in medical video compression domain.

Under this background, the High Efficiency Video Coding (H.265/HEVC) standard [2], which was established and developed by the Joint Collaborative Team on Video Coding (JCT-VC), is expected to provide higher efficiency for medical video compression. Compared to mainstream medical video coding standards such as JPEG and JPEG2000, H.265/HEVC can provide a 61.63% and 20.26% reduction respectively in bit-rate requirements with equivalent visual quality [3]. Given the growing demand on compression efficiency of medical videos and the excellent performance improvement in H.265/HEVC, Panayides [4] creatively introduced H.265/HEVC to the Mobile Health (M-health) Communication System, which improved the coding performance with an acceptable visual quality. Further Panayides [5] utilized H.265/HEVC to encode the medical ultrasound videos and verified the coding performance of H.265/HEVC in medical applications.

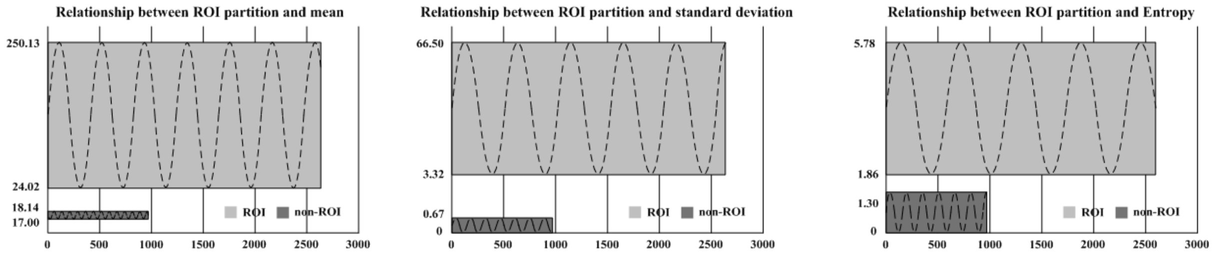
Thereafter, Shenthil et al. [6] improved the coding performance by introducing a modified Sample Adaptive Offset (SAO) technology to the medical video compression method based on H.265/HEVC. As reported in [7], Panayides et al. utilized a pre-filtering procedure before medical video coding in H.265/HEVC coding framework. In addition, a series of developments was proposed to better cope with the new challenges from the medical video compression domain [8] in H.265/HEVC. In a word, the researches and proposals have provided a important theoretical foundation and feasibility support for the application of the H.265/HEVC standard in digital medical video coding domain. However in above algorithms, H.265/HEVC standard was only directly applied to medical video compression domain and these algorithms rarely considered the characteristics of the digital medical images. But the neglected particularities in medical videos can also provide an opportunity to further remove redundant data for video coding standards.

For medical videos, only a few regions are related to the clinical diagnosis, which can be described as the diagnosis-ROI (d-ROI, hereafter referred to ROI). On this basis, ROI-based medical video hierarchical coding technologies with respect to the JPEG standard have been extensively studied. For instance, Sridhar [9] and Moorthi [10] implemented different encoding strategies for ROI and non-ROI with the JPEG coding standard to reduce the coding bit-rate of medical videos. However, the ROI extraction results in traditional algorithms were usually defined as regular-shaped regions (rectangles, sectors, etc.), or irregular-shaped regions (which overlapped with the edge of tissues and organs) by artificial selection. This might produce an obstacle for the particular quad-tree coding structure in H.265/HEVC when the traditional shaped ROI are directly used. Hence, it is important to design a hierarchical coding mechanism based on the properly shaped ROI extraction strategy for medical video coding. Therefore, for the purpose of reducing the coding bit-rate with a better visual quality, two key techniques with respect to ROI extraction and hierarchical coding are proposed for H.265/HEVC in this paper. First, a ROI extraction strategy based on H.265/HEVC quad-tree structure is introduced. Second, a hierarchical coding mechanism based on transform coefficient adjustment and quantization parameter selection process is designed.

The remainder of this paper is organized as follows. The second and the third part explain the key techniques including ROI extraction and hierarchical coding in detail. The fourth part presents the experimental results of the proposed method. Final part draws the conclusions.

2. **ROI Extraction.** The ROI extraction method, which is appropriate for both the characteristics of medical images and the special coding structure in H.265/HEVC, is the foundation for optimizing coding performance. According to the human visual selective attention mechanism, prominent texture regions can draw more attention than sparse texture regions. Particularly in medical videos, quantitative changes in texture information usually reflect the pathologic variations [11], and also provide a crucial reference for clinical diagnosis. Thus, texture information can be an important principle for detecting ROI.

2.1. **Texture Feature Vector Selection.** Choosing what parameters to define the texture information of medical images is the first step for ROI extraction. In the field of digital image processing, the mean, standard deviation, and entropy, are commonly used to describe the texture information. Supposing $I(i,j)$ represents the pixel value of the current region at position (i,j) and NxN represents the size of the current region. Then, the physical significance and calculation formulas of the following three texture features are as follows.



(a) Mean (b) Standard Deviation (c) Entropy

FIGURE 1. Relationship between the ROI partition and the three texture features

- **Mean** (μ) reflects the tendency of pixel values in the current region. For medical images, the non-ROI shows up as approximate black area, so μ has a lower value.

$$\mu = \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N} I(i,j); \tag{1}$$

- **Standard Deviation** (σ) reflects the discrete degree of each pixel value in the current region. For medical images, the non-ROI has high homogeneity, so σ has a lower value.

$$\sigma^2 = \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N} I(i,j-\mu)^2; \tag{2}$$

- **Entropy (H)** reflects the uncertainty of the information distribution in the current region. For medical images, there is little information in the non-ROI, so H has a lower value.

$$H = -\sum_{i=0}^{255} p_i \log(\mathrm{p_i}); \tag{3}$$

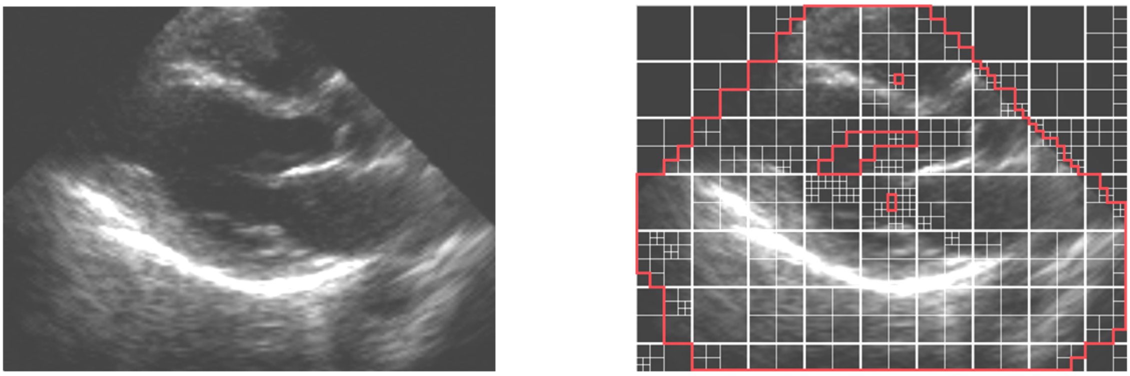
In the above equation, p_i represents the proportion of pixel values i in the current region.

The effectiveness of ROI extraction using those three texture features can also be demonstrated by the experimental results. The μ, σ, and H of 3640 8×8 pixel regions (including 2664 ROIs and 976 non-ROIs) were calculated in the experiment. Figure 1 showed the relationships between the three texture features and the ROI partition.

As shown in Figure 1, the statistical results stated that the values of μ, σ, and H were concentrated in the intervals of [17.0000 18.1406], [0 0.6659], and [0 1.3019], respectively, for non-ROI. The corresponding values were widely distributed in the intervals of [24.0156 250.1250], [3.0249 66.4984], and [1.8552 5.7813], for ROI. Therefore, it can be observed that there was a significant distinction in the distribution of μ, σ, and H, which may provide an effective evidence for the segmentation of ROI and non-ROI.

2.2. **Quad-tree Shaped ROI Extraction.** Based on the above experimental findings, $[\mu, \sigma, H]$ was utilized to describe the texture information in the current coding units (CUs). Then, the calculation and classification procedures of $[\mu, \sigma, H]$ were performed as follows.

- **Step 1.** To-be-encoded CU was segmented into the smallest coding unit (SCU) with a size of 8×8;
- **Step 2.** Supposing $SCU(i)$ is the $i-th$ SCU of the to-be-encoded CU, then the texture feature vector $T_{SCU}(i) = [\mu, \sigma, H]$ of the current SCU was calculated according to formulae (1) $\sim$ (3);
- **Step 3.** The normalized $T_{SCU}(i)$ was sent to the NN classifier for calculating the category *C(SCU(i))* of the current *SCU(i)*.



(a) Original Frame (b) ROI based on Quad-tree coding structure

Figure 2. The ROI Extraction result based on the H.265/HEVC Quad-tree coding structure

Furthermore, the category C(CU) of the current CU was derived from the classification result of each SCU based on formula (4). Supposing $2N \times 2N$ represents the size of CU, where $N \in \{4, 8, 16, 32\}$. $\|\|$ represents the process to obtain the number of the elements in the current set. Then, the C(CU) was calculated by

$$C\left(CU\right) = \begin{cases} ROI, \text{ if } 8 \times 8 \times \|i\,|C\left(SCU\left(i\right)\right) = ROI\| \,/\left(2N \times 2N\right) \geq 1/4 \\ non - ROI, \text{ if } 8 \times 8 \times \|i\,|C\left(SCU\left(i\right)\right) = ROI\| \,/\left(2N \times 2N\right) < 1/4 \end{cases} \tag{4}$$

Thus, if the proportion of ROI SCUs was ¡ 1/4, the to-be-encoded CU will be categorized as non-ROI. Otherwise, the to-be-encoded CU will be categorized as ROI. As described in the ROI extraction procedure, it can be observed that the ROI was composed of every ROI CUs. Compared to the traditional ROI, the proposed ROI extraction strategy can be more suitable for the flexible quad-tree coding structure in H.265/HEVC and provide convenience for the implementation of the subsequent hierarchical coding. Figure 2 described the ROI extraction result based on the H.265/HEVC quad-tree coding structure.

3. **Hierarchical Coding.** The hierarchical coding strategy is the specific implementation procedure for reducing the coding bit-rate with a better visual quality. Transform and quantization processing is an integral part of H.265/HEVC, which can remove data redundancy by transforming and quantifying the prediction residuals. Meanwhile, the quality of the reconstructed videos and the coding bit-rate are directly related to the transform and quantization process. Thus, for the reduction of the coding bit-rate and the improvement of the visual quality, a hierarchical coding scheme was proposed in this paper with respect to the transform and quantization process in the H.265/HEVC coding framework.

3.1. **Transform Coefficient Adjustment.** The transform coefficient is the concrete manifestation of image pixel information in the transform domain. The value of the transform coefficients not only directly reflects the overall distribution of image brightness and energy but also contains the detailed information of image texture and edge. Therefore, it can be observed that the transform coefficient is of great significance to the reconstructed quality. However, the Discrete Cosine Transform (DCT) and Discrete Sine Transform (DST) with fixed transform matrices were introduced to calculate the transform coefficients of the prediction residual in H.265/HEVC. A number of transform coefficients with lower values were set to zero after the quantization process. This may lead to the loss of image details and the lack of human visual contrast. Hence in order to selectively highlight the texture information in medical videos, the method of the image enhancement based on frequency-domain were introduced to the transform coding of the prediction residual in H.265/HEVC.

The transform coefficients of the prediction residual were adjusted by the construction of the transform coefficient equilibrium matrix. The specific procedure was performed as follows.

- **Step 1.** The Texture Density Parameter T_D was adopted to describe the variation degree of the texture information in the medical videos based on the ROI extraction results.

$$T_D = \begin{cases} 2, if\ C\left(CU\right) \in ROI, \text{ and } Intra\ Mode \in Intra\ Angular \\ 1 \quad if\ C\left(CU\right) \in ROI, \text{ and } Intra\ Mode \in Intra\ DC \text{ or } Intra\ Planar \\ 0, \quad if\ C\left(CU\right) \in non-ROI \end{cases} \tag{5}$$

Intra Mode is the intra prediction mode of the current prediction unit (PU). For ROI, if intra prediction mode is angular, it can be considered that there is directional-variation texture information in current PU, then $T_D = 2$; otherwise, if intra prediction mode is Planar or DC, it can be considered that there is slow-variation texture feature in current PU, then $T_D = 1$. For non-ROI, $T_D = 0$.

- **Step 2.** Transform coefficients were adjusted by the Transform Coefficient Equilibrium Matrix .

$$\Omega = \left(m_{ij}\right)_{n\times n} = \begin{bmatrix} m_{11} & \cdots & m_{1n} \\ \vdots & \ddots & \vdots \\ m_{n1} & \cdots & m_{nn} \end{bmatrix},\ n \in \{4, 8, 16, 32\}\,; \tag{6}$$

where the matrix element m_{ij} of current transform coefficient equilibrium matrix was defined as follows according to texture density parameter T_D.

$$m_{ij} = \begin{cases} -0.05T_D,\ if\ C\left(CU\right) \in ROI \\ 0.1,\ if\ C\left(CU\right) \in non-ROI \end{cases},\ T_D \in \{0, 1, 2\}\,; \tag{7}$$

During the transform coefficient adjustment procedure, if $T_D = 0$, then weakening the transform coefficients. Otherwise enhancing the transform coefficients if $T_D = 1$ or $T_D = 2$.

- **Step 3.** According to , the transform coefficient adjustment process is described as follows.

$$\hat{H} = \lfloor H \otimes |1 - \Omega| \rfloor\,; \tag{8}$$

where $\hat{H}$ represents the transform coefficients after the adjustment process and H denotes the transform coefficients calculated by the H.265/HEVC standard.

Thus far, the contrast of texture-significant regions in medical videos was indirectly enhanced by the revision of the transform coefficients in the frequency domain, which can maintain the reliability and accuracy of medical videos for clinical diagnosis and disease treatment.

3.2. **Quantization Parameter Selection.** As is well known, the visual quality and compression ratio of the reconstructed videos are closely related to the selection of the Quantization Parameter (QP) in the H.265/HEVC standard. A lower QP value improves the reconstructed video quality and decreases the compression efficiency. Conversely, a

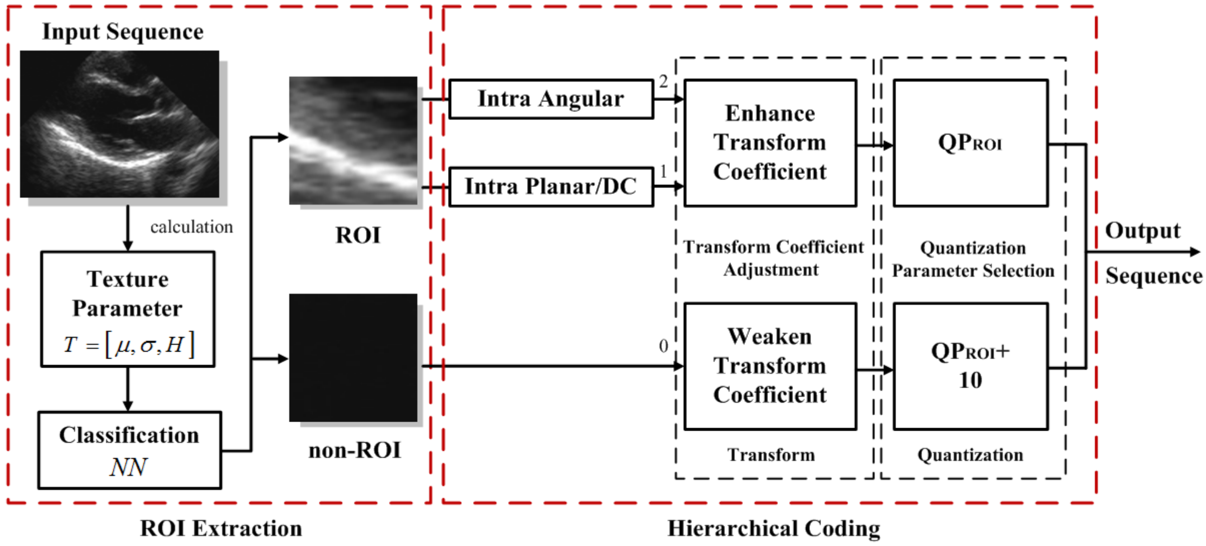


FIGURE 3. The hierarchical coding framework of the proposed method

larger QP value decreases the reconstructed video quality and increases the compression efficiency.

Hence for the purpose of guarantying the visual quality of ROI and reduce coding bit-rate cost integrally, the ordinary QP value (the QP selection in ROI refers to [7]) was selected to encode the transform coefficients of ROI in medical videos after the transform process, whereas the QP value in non-ROI was added by 10 ($QP_{non-ROI} = QP_{ROI} + 10$).

The integrated hierarchical compression framework based on two important techniques, including transform coefficient adjustment and quantization parameter selection, was shown in Figure 3.

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4. **Results and Comparison.** The experimental environment and results are described as follows.

4.1. **Experimental Configuration.** To validate the coding performance of the proposed method, gain or loss was calculated based on the H.265/HEVC test model (HM15.0) under all intra (AI) coding mode. Meanwhile, the coding performance was measured by different medical ultrasound videos [15] with spatial resolution of 560 × 416 and 640 × 480 at 30 frames per second (fps). For each video, 4 different coding bit-rates were generated by varying the Quantization Parameters (QPs) at 22, 27, 32, and 37.

4.2. **Experimental Results and Performance Analysis.** The experimental results and performance analysis were stated here in terms of bit-rate saving, Rate-Distortion (R-D) performance, and video quality.

4.2.1. *Bit-rate Saving:* For demonstrating the superiority in bit-rate saving, the statistical results in TABLE 1 showed the coding bit-rate consumption of the proposed hierarchical medical video coding strategy compared to HM15.0 and the H.265/HEVC algorithm combined with the modified SAO process in [6].

Table 1. Comparison of the coding bit-rate with the H.265/HEVC standard

Sequence (Resolution)	QP	HM15.0	[6]		Proposed	
		Bit-rate (Kbps)	Bit-rate (Kbps)	Bit-rate (%)	Bit-rate (Kbps)	Bit-rate (%)
Ultrasound video (560416)	22	3425.8	3402.6	-0.68	2973.24	-13.2
	27	2220.1	2206.85	-0.6	1908.68	-14.03
	32	1386.75	1374.3	-0.9	1160.04	-16.35
	37	817.15	805.65	-1.41	671.72	-17.8
	Average results					
	-	-	-	-0.9	-	-15.35
Ultrasound video (640480)	22	8962.5	8914.6	-0.54	8017.8	-10.54
	27	6306.75	6264.9	-0.66	5408.05	-14.25
	32	4342.85	4304.85	-0.88	3713.88	-14.48
	37	2959.75	2924.3	-1.2	2475.43	-16.36
	Average results					
	-	-	-	-0.82	-	-13.9

Table 2. Comparison of the BDBR and BDPSNR with the H.265/HEVC standard

Sequence (Resolution)	[6]		Proposed	
	BDBR (%)	BDPSNR (dB)	BDBR (%)	BDPSNR (dB)
Ultrasound video (560416)	-0.59	0.04	-14.2	1.01
Ultrasound video (640480)	-0.28	0.03	-12.83	1.32

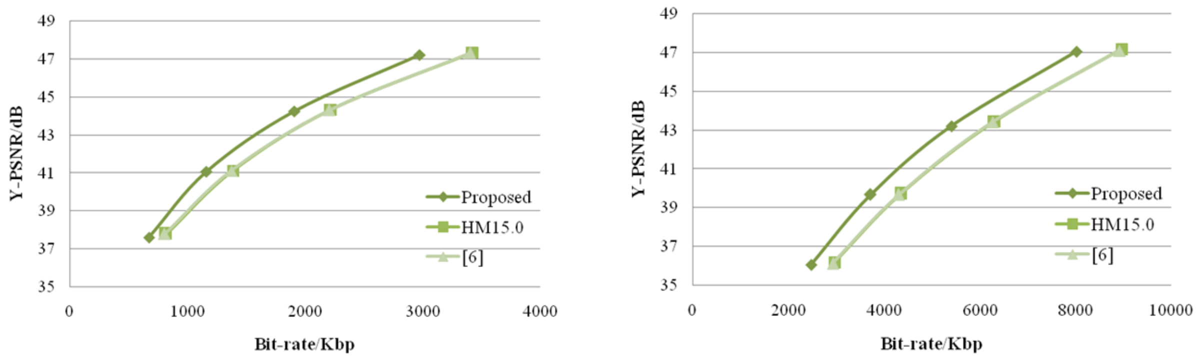
As shown in TABLE 1, compared to HM15.0, the proposed method can reduce the coding bit-rate by 13.90% to 15.35% on average, whereas the video coding algorithm in [6] only reduced the coding bit-rate by 0.82% to 0.90% on average.

4.2.2. *Rate-Distortion (R-D) Performance:* With the purpose of evaluating the R-D performance, Bjntegaard delta bit-rate (BDBR) was used to quantify the bit-rate gains achieved by H.265/HEVC. Bjntegaard delta peak signal-to-noise rate (BDPSNR) was used to measure the objective quality improvements of the encoded medical videos [16]. TABLE 2 shows BDBR and BDPSNR results compared with the H.265/HEVC standard [6] and the proposed method.

As shown in TABLE 2, the modified algorithm in [6] achieved an average bit-rate gain of 0.41% compared to HM15.0, whereas the average bit-rate saving was 13.5% in the proposed method. The proposed method achieved an average PSNR gain of 1.16 dB compared to HM15.0 when providing an equivalent coding bit-rate, whereas the average value was 0.035 dB in [6]. Thus, it can be found that the proposed method is able to achieve better encoding performance improvement according to BDBR and BDPSNR than the method in [6].

For intuitional illustration purposes, the R-D performance curves of the three algorithms (HM15.0, modified algorithm in [6], and the proposed algorithm) were drawn with resolutions of 560×416 and 640×480, respectively, in Figure 4.

The R-D performance of the proposed algorithm outperformed H.265/HEVC and the algorithm in [6]. Performance improvement was mainly due to the utilization of transform coefficient adjustment and the quantization parameter selection strategy in the hierarchical coding process.



(a) Medical ultrasound video (560×416) (b) Medical ultrasound video (640×480)

FIGURE 4. Comparison of the R-D performance

TABLE 3. Comparison of SSIM with the H.265/HEVC standard

Sequence (Resolution)	QP	HM15.0	Proposed	HM15.0 (ROI)		Proposed (ROI)	
		SSIM	SSIM	SSIM	SSIM	SSIM	SSIM-ROI
Ultrasound video (560416)	22	0.992	0.9922	0.0002	0.9922	0.9927	0.0005
	27	0.985	0.9855	0.0005	0.985	0.9859	0.0009
	32	0.9706	0.9717	0.0011	0.9696	0.971	0.0017
	37	0.9426	0.9454	0.0028	0.9406	0.9441	0.0035
	Average results						
	-	-	-	0.0012	-	-	0.0016
Ultrasound video (640480)	22	0.9878	0.988	0.0002	0.9868	0.9873	0.0005
	27	0.9708	0.9718	0.001	0.969	0.9705	0.0015
	32	0.9185	0.9201	0.0016	0.915	0.918	0.003
	37	0.854	0.8578	0.0038	0.8476	0.8533	0.0057
	Average results						
	-	-	-	0.0017	-	-	0.0026

4.2.3. *Video Quality:* The Structural Similarity Index Measurement (SSIM) [17] is a widely used quality assessment metric with high consistency to the subjective human visual system. Here, SSIM was employed to evaluate the visual quality both of the entire video and the ROI-layer video.

As shown in TABLE 3, for the entire medical videos, the improvement of SSIM indexes were 0.0012 and 0.0017 on average with the resolutions of 560×416 and 640×480, respectively. The corresponding increases were 0.0016 and 0.0026 for ROI-layer videos, respectively. Although the SSIM gains with higher QP values were not significant in the order of magnitude, the positive effects can be enhanced with the increase of QP values. This means better gains will be devoted to low bit-rate application in medical video compression domain. The important reason of visual quality improvement was the proposal of the adaptive transform coefficient adjustment strategy in the hierarchical coding process. On this basis, the proposed algorithm can provide a better contrast for the human visual system compared to H.265/HEVC by enhancing the transform coefficients in ROI, but weakening the transform coefficients in non-ROI.

In general, the experimental results indicated that our proposed method can provide a significant bit-rate reduction for medical ultrasound video compression with a preferable visual quality. Note that the development in the proposed method was inside the

H.265/HEVC encoder, there is no effect on combining with other pre-process algorithms, such as de-speckle filtering for medical videos [7]. Hence, the coding performance can be further improved by adding medical video pre-processing in our framework.

5. **Conclusions.** The distinction between human visual attentions in different regions of videos has provided a growing demand on ROI-based high efficiency video coding. In this paper, an innovative method for diagnostic-ROI based hierarchical coding strategy is proposed for medical ultrasound videos to solve the low efficiency problem in recent medical communication systems represented by the JPEG or JPEG2000 coding standard. Initially, the ROI was accurately obtained by utilizing the texture information, which can improve the applicability between the traditional ROI-based coding technology and the H.265/HEVC quad-tree coding structure. Thereafter, according to ROI extraction results, the otherness encoding was performed by transform coefficient adjustment and quantization parameter selection. Experimental results showed that the proposed method achieved 13.52% bit-rate saving on average and guaranteed better visual quality compared to H.265/HEVC (HM15.0). The proposed method can satisfy the requirements of real-time and high-resolution compression in modern medical communication systems. The enhancement of the adaptability for quantization parameter selection processing will be further studied in our future work.

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