ISSN:0975-9646

Omprakash Rajankar et al, / (IJCSIT) International Journal of Computer Science and Information Technologies, Vol. 6 (2) , 2015, 1636-1642

Generalized Multiple ROI Prioritization in JPEG2000 for Natural Images

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Abstract— **Every digital image has some spatial regions that are more important in some sense than others are. To provide higher reconstruction quality for the important region, Region of Interest (ROI) based compression methods are developed. In image compression, ROI coding allows to recover the ROI earlier than the rest of the image. JPEG2000 is an international standard for still image compression and provides an extensive set of features including ROI coding. The Maxshift and Implicit are the two ROI coding methods specified in JPEG2000 part-1. They use two different mechanisms, modifying wavelet coefficients, and rate-distortion optimization respectively. These methods have some advantages and disadvantages. The paper proposes a multiple region of interest prioritization coding method for JPEG 2000, to overcome the drawbacks of these methods. The proposed method, improve objective as well as subjective qualities, the Peak Signal to Noise Ratio (PSNR) and the Structural Similarity Index (SSIM) in the ROIs respectively.**

Keywords— **EBCOT, JPEG2000, MAXSHIFT, Implicit, PCRD**

I. INTRODUCTION

Advanced image acquisition sensors capture the images with high resolution in both spatial and bit depth. Hence, the images are becoming more detailed and bulky. Thus, in spite of improvement in storage devices and transmission technology, the need of image compression is ever increasing to reduce storage space and transmission cost for digital images. The main objective of an image compression is to represent an image with a smaller number of bits without introducing noticeable degradation in visual quality of decompressed image. These goals are mutually opposite in nature and one sacrifices for another. In an image all regions are not equally important. Therefore, to provide higher reconstruction quality for the important region, Region of Interest (ROI) based compression methods are developed. ROI methods compress the image with higher quality for the ROI over the background and save the storage space.

Some of the modern image compression standards support ROI coding; in that, they prioritize certain parts of the image over the rest of the image. For example, in the medical field [1] special images like mammogram [2], computerized tomogram [3], digital X-rays , in images of geographic information systems [4], in surveillance images and in general every image may contain more significant regions than the background. In such applications, it is desirable to compress the image with higher quality for the ROI over the background. It is also desirable that when the compressed image is transmitted, the information pertaining to the ROI is transmitted earlier than the information related to the background. Here extraction of the ROI is a crucial task, which may be manual or automatic.

JPEG2000 is a new standard accepted in market for image compression in different fields due to its extensive set of features. ROI coding is one of the important features of JPEG 2000, which is achieved through two mechanisms. They are modifying wavelet coefficients and using rate-distortion optimization techniques. Both the mechanisms have some pros and cone. Modifying wavelet coefficients mechanism obtains an excellent accuracy to delimit ROI areas, it can support multiple ROI, but the dynamic range of wavelet coefficients has to increase in the multiple of the number of ROIs, which is not a practical solution. The second mechanism supports multiple ROI with lossless mode, but, as it works at codeblock level, it fails to achieve the required fine-grain accuracy at low bit rate. A proposed ROI coding method is compliant with JPEG2000 and is able to achieve multiple ROIs prioritization with fine grain accuracy, that too at the same dynamic range of wavelet coefficient as single ROI prioritization with Maxshift method.

The paper is organized as follows: Section II reviews the ROI mechanisms used in JPEG2000; Section III introduces the proposed generalized multiple ROI coding method; Section IV provides numerical and visual results assessing the performance of the method, for multiple ROIs; and Section V concludes with remarks.

II. JPEG2000 AND ROI CODING MECHANISMS

JPEG2000 core encoding is formed by transformations, optional quantization, entropy coding (tier-1 coder), and bit stream organization (tier-2 coder) [5], Fig.1 shows the block diagram of typical JPEG 2000 with ROI coding options. The image input to JPEG 2000 may contain signed or unsigned 1 to 2^{14} components (for example, RGB or YC_bC_r) with a bit depth in the range of 1-38 bits. The transformation of the input image is done through four stages: level shifting, color transformation, tiling and wavelet transform. Level shifting of unsigned sample values in each component becomes necessary to avoid numerical overflow. To de-correlate the color data the level shifted values are subjected to a forward color component transformation. The color transforms are of two types irreversible color transform (ICT) and reversible color transform (RCT). After color transformation, the image is split into tiles. Tiling is particularly useful when the available memory is limited or image size is large. Using small sized tiles can create a blocking effect. The discrete wavelet transforms (DWT) are implemented by the lifting scheme or by convolution. The DWT decomposes the image tiles and offers an expected solution for multi resolution requirements of the JPEG 2000 standard. Daubechies (9,7) floating point and (5,3) reversible integer-to-integer filter-bank are adapted in JPEG 2000. The DWT decompose the source image into high frequency and low frequency subbands. The division of each subband gives rectangular blocks called precincts. Further division of precincts provides smaller blocks called as codeblocks. The width and height of codeblocks are limited to powers of 2, and its size must not exceed 4096. In JPEG 2000 part 1, the codeblock size is same for all sub-bands at all resolution levels, except the blocks on the boundary. Fig. 2 show an example with two levels of decomposition and four precincts per subband (where Precincts describe the same spatial region at two different decomposition levels). Within a precinct, all the spatially consistent code-blocks are grouped together into a packet. The information contained in a packet is distributed across a number of layers. A collection of layers comprises the final JPEG2000 bit stream. In the case of lossy compression, the dead-zone quantizer quantizes the wavelet coefficients of each subband. Then the next stage, encode the quantized wavelet coefficients to form the output bit stream. Embedded block coding with optimize truncation (EBCOT) is a two tire encoder employed in JPEG2000. Where, tier-1and tier-2 especially does the sample data entropy coding and bit stream organization respectively. The rate-distortion optimization is controlled by the rate control block with the help of uniform dead-zone quantizer, and EBCOT. Decompressor is a mirror of the compressor it just undoes the operations in reverse order to reconstruct the original image. Only the decompressor is defined in JPEG2000 standard. Therefore, as long as the output bit stream is decompressible the related compressors are said to be compatible. The information of the precincts, codeblocks, layers, and packets are included in the bit stream. It should be noted here that state-of-the-art compression performance of JPEG2000 is due to EBCOT embedded bit stream algorithm. JPEG2000 support two types of mechanisms for the ROI coding: coefficient scaling based mechanisms and post compression rate-distortion (PCRD) optimization based mechanisms.

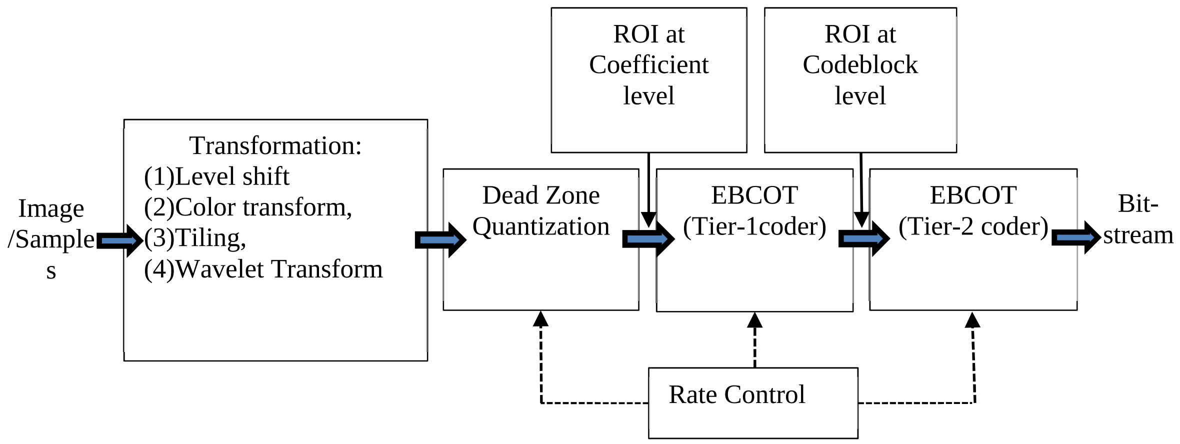

Fig.1 Block diagram of JPEG2000 encoder with ROI

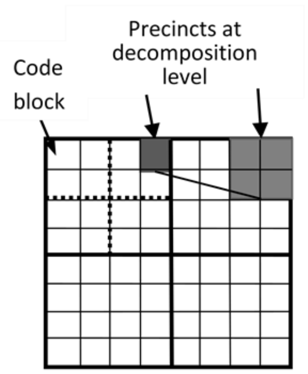

Fig.2 Image with 2 levels of decomposition and 4 precincts per subbands

A. Coefficient scaling based mechanisms

In coefficient scaling based mechanisms, the wavelet coefficients or quantized wavelet coefficients belonging to ROI are up-shifted by bit-plane shift or by multiplying them with a desired priority *R*, which is commonly chosen to be a power of 2. Coefficient scaling based mechanisms gives high fine-grain accuracy but penalizes the coding performance significantly [6]. Non-overlapping and overlapping bit plane are the two types of coefficient scaling based mechanisms. The JPEG2000 (part 1) defines the Maxshift [7] and JPEG2000 (part 2) defines the General scaling [8] methods that are non-overlapping and overlapping bit plane types respectively.

The dynamic range of wavelet coefficients doubles to embed the arbitrary ROI shape in non-overlapping bit plane methods. It arranges ROI and background bit planes one by one. Some modifications of these methods that are compliant with JPEG 2000 proposed in the literature are: Bitplane by Bitplane Shift (BbBShift) [9] and Generalized Bitplane by Bitplane Shift (GBbBShift) [10] .

In the case of overlapping bit plane methods, the dynamic range of wavelet coefficients increases with the ROI priority. In order to differentiate ROI and background, either specific ROI shape or explicit arbitrary binary masks are transmitted along with the code stream. Partial Significance Bitplane Shift (PSBShift)[11], Hybrid Bitplane Shift (HBShift) and Generalized Partial Bitplanes Shift (GPBShift) [12] are the examples of overlapping bitplane methods.

B. Post compression rate-distortion (PCRD) optimization based mechanisms

In JPEG2000, the Post Compression Rate Distortion optimization algorithm (PCRD) [13] is used to organize each codeblock bit stream in an optimal way to minimize the distortion while attaining the required bit rate constraints. ROI coding methods based on modifying the distortion estimation take advantage of the rate-distortion optimization stage. In PCRD the bit stream is independently truncated to a collection of different lengths R_i^n, resulting in distortion of D_i^n in the reconstructed image, in such a way that most of these truncation points lie on the convex hull of the corresponding rate-distortion curve. For each truncation point, *n*, the relevant distortion, and rate are additive, i.e.

$$D = \sum D_i^{n_i} \tag{1}$$

$$R = \sum R_i^{n_i} \tag{2}$$

Where, *D* and *R* represents an overall image distortion and rate respectively, and n_i −denotes the truncation points selected for codeblocks B_i . An additive distortion metric which approximates Mean Squared Error (MSE) is obtained by setting

$$\hat{D}_i^n = w_{b_i}^2 \sum \left(\hat{s}_i[k] - s_i[k]\right)^2 \tag{3}$$

Here, $S_i[k]$ denotes sub-band samples in the codeblock B_i , $\hat{S}_i[k]$ denotes the quantized representation of these samples, w_{b_i} represents the L_2 norm of the wavelet basis functions for the subband b_i , to which code-block belongs. To minimize distortion for a given bit rate, $R_{\max}$ and the optimal selection of the truncation points n_i ,

$$D(\lambda) + \lambda R(\lambda) = \sum (D_i^{n_i^\lambda} + \lambda R_i^{n_i^\lambda}) \tag{4}$$

where, the optimal value of Lagrange's multiplier λ is that value for which the distortion cannot be reduced further without increasing the overall rate and vice-versa.

PCRD can be modified for ROI coding. Codeblocks containing ROI coefficients can be effectively more prioritized than codeblocks containing background coefficients. Advantages of this method are, ROIs need not be given absolute priority over the background and the ROI priority is not restricted to be a power of 2. Method based on this mechanism in JPEG 2000 is the Implicit ROI coding method [14]. Selected other methods based on this mechanism in literature are separated codeblock ROI coding method [15], ROI coding method based on EBCOT [16], Weighted ROI coding method and Sub-block ROI coding method [17]. The Implicit ROI coding method increase the coding pass distortion estimates for every codeblock whose coefficients contribute to ROI by a factor R_w .

$$D_i^{'jk} = \begin{cases} R_w * w_{b_i}^2 \sum_{k \in B_i} \left(\hat{s}_i^{jk}[k] - s_i[k]\right)^2, \ldots ROIcodeblock \\ w_{b_i}^2 \sum_{k \in B_i} \left(\hat{s}_i^{jk}[k] - s_i[k]\right)^2, \ldots otherwise \end{cases} \tag{5}$$

The undesirable feature of this approach is that, it only distinguishes ROI and the background codeblocks on a block by block basis. In addition the same priority R_w is applied to all the ROI codeblocks, irrespective of number of ROI coefficients shared by the codeblock. This rough unfairness between codeblocks belonging to the ROI and background do not achieve fine-grain accuracy. The separated codeblock ROI coding method splits the codeblock into two codeblocks in such a way that in the ROI codeblock all background coefficients are replaced by zero and vice-versa, then encoding is carried out independently. Similar to MAXSHIFT method, here ROI and background cannot be combined finely.

ROI coding method based on EBCOT is variant of the Implicit ROI coding method, where the last *p* bit planes of the background coefficients are truncated to modify the priority of ROI codeblocks [18]. To improve the fine-grain accuracy weighted and sub-block ROI coding methods are proposed in [17], that modify the distortion contributions of codeblocks. Weighted ROI coding method, consider the number of coefficients within the codeblock $C_{count} / sizeof(B_i)$ that belongs to the ROI, to determine distortion contributions according to (6).

$$D_i^{'jk} = \begin{cases} \frac{Count_i}{sizeof(B_i)} * R_w * w_{b_i}^2 \sum_{k \in B_i} \left(\hat{s}_i^{jk}[k] - s_i[k]\right)^2, \ldots ROIcodeblo \\ w_{b_i}^2 \sum_{k \in B_i} \left(\hat{s}_i^{jk}[k] - s_i[k]\right)^2, \ldots otherwise \end{cases} \tag{6}$$

Second method is sub-block ROI coding method. This method modifies the distortion computation at a coefficient level instead of considering the global codeblock distortion. The actual distortion of each coefficient is computed, therefore conceptually the sub-block ROI method should give fine-grain as accurate as the Maxshift method. Further Sub-block and Weighted methods are able to prioritize more than one ROI at different priorities. The paper [19] introduced ROI coding through component (ROITCOP) method. In this method, it is necessary to split the ROIs before encoding and merge the ROIs to reconstruct the image after decoding. This method allocates each ROI to a component and uses the rate-distortion optimization techniques to prioritize the desired ROI. It is claimed that the ROI coding performance of ROITCOP outperforms Scaling, Implicit, and Subblock ROI coding methods. Grayscale medical images with multiple ROI may be coded with this method because it allows progressive lossy-to-lossless recovery for the ROI and the background.

All the methods reviewed have some advantages and disadvantages; the user has to choose one of them as per the requirements. There is a need of generalized multiple ROI coding method for color images that will take care of arbitrary shape single as well as multiple ROIs with and without overlapping, and should provide fine grain accuracy like a Maxshift method without much affecting the coding efficiency.

III. The Generalized multiple ROI coding method

The Generalized multiple ROI coding method proposed is a hybrid of the Maxshift [8] and weighted ROI [20] methods. Therefore, it can provide fine grain accuracy like Maxshift, and multiple ROI like weighted method. This method downshift all the background coefficients by the scaling value, s . Where, s is greater than the most significant magnitude bit-plane, for any background coefficient in any codeblock. This insures that during rate distortion estimation ROI coefficients in the ROI codeblocks will have a greater distortion estimate than background coefficients in the ROI codeblocks. Then, it prioritizes the codeblocks as per the importance value and its ROI contribution within the block. ROIs may or may not be overlapped in the image domain. If a wavelet coefficient is identified as belonging to more than one ROI, it is prioritized with the highest priority of the ROIs it belongs to. The stepwise procedure of the proposed method is as follows

1. Locate arbitrary shaped ROIs from an image by suitable ROI detection method. For example quantized saliency maps or importance maps drawn manually or automatically from the image may be used.
2. Map the ROIs with the image in wavelet domain.
3. To discriminate between ROIs and background, perform Max-shift coefficient scaling on the quantized wavelet coefficients. Thus, minimum importance is assigned to the background.
4. Generate embedded bit-streams for each code-block.
5. Perform rate distortion cost function modulation by weighting the code-blocks distortion with the block importance value obtained in step 2, and scale it with ROI weight, equivalent to the contribution of the ROIs in the codeblock.
6. The modulated distortion estimates are passed to the post compression rate-allocation algorithm to drive the formation of the quality layers. The encoded bits are put into the code-stream in order of importance.

This method is able to prioritize arbitrary ROIs. It completely encodes/decodes the ROIs before the background. For this, on the encoder side R_{shift} parameter is set to a value greater than the most significant bit plane of the background. To implement the proposed ROI coding method in JPEG2000 distortion contributions are modified according to (6) ,

$$D_i^{"jk} = \begin{cases} Rc_i * Rv_i * w_{b_i}^2 \sum_{k \in B_i} \left(\hat{s}_i^{jk}[k] - s_i[k] \right)^2, ROIcodebl \\ w_{b_i}^2 \sum_{k \in B_i} \left(\hat{s}_i^{jk}[k] - s_i[k] \right)^2, otherwise \end{cases} \quad (7)$$

where, the ROI contribution of a block i is,

$$Rc_i = (R_{c_1} + (R_{c_2} / 4) + (R_{c_3} / 8)) / sizeof(B_i)$$

And $R_{c_1}, R_{c_2}, R_{c_3}$ are the contributions of ROI_1, ROI_2 and ROI_3 in the codeblock. An importance value (Rv) is, the maximum value in the respective block of ROI map. For a limited number of ROIs the values may be quantized to 255,127, 63 or 0 for ROI_1, ROI_2, ROI_3 and background (BG) respectively, as per the threshold values shown in fig.3 (b). Equation (7) is a generalized form of distortion estimates; we can derive different ROI coding methods from this equation by making some variations in the parameters. For example, without the term Rc , we get hybrid multiple Maxshift-Implicit ROI coding method, by ignoring the terms R_{shift} and Rc , we derive Implicit multiple ROI coding method. Similarly with little variations we can derive weighted multiple ROI, Hybrid Maxshift-Weighted, Maxshift fine, Implicit, Weighted and IMPJ2K ROI methods from the equation (7).

IV. Performance Evaluations

Images are encoded with different target bit-rates, decoded, and the image quality is assessed separately for the ROI and the background. The image quality is reported in Peak Signal to Noise Ratio (PSNR), and Structural Similarity index (SSIM) which are the measures that accounts for the similarity between the original image and the reconstructed image. Higher PSNR and SSIM represent better quality of the reconstructed image. The performance of the proposed ROI coding method is assessed by comparing it with Maxshift, Weighted, and non ROI methods. The methods have been implemented in JPEG2000 Kakadu version 2.2.3 part-1 implementation [5]. The lowest subband LL is included in the final bit stream to get smooth background along with ROIs. For this R_{level} coding parameter is set to, four levels of 9/7 DWT. To obtain fine grain accuracy for ROIs, codeblock size should be minimized. Table 1 shows performance for an image at 0.5 bpp, it indicates that as the codeblock size reduces the time taken to encode the image increases. Therefore, an optimum choice of codeblock size for ROI coding of any image is 32 x 32 instead of 64x64.

TABLE1

PERFORMANCE FOR DIFFERENT CODEBLOCK SIZES

Code block size	Encode Time (Sec.)	Decode Time (Sec.)	PSNR					SSIM				
			Overall	BG	ROI_1	ROI_2	ROI_3	Overall	BG	ROI_1	ROI_2	ROI_3
16x16	1.12	0.25	30.48	30.18	35.88	31.99	31.29	0.65	0.58	0.99	0.95	0.90
32x32	**0.63**	**0.25**	**30.53**	**30.24**	**34.76**	**31.79**	**31.38**	**0.65**	**0.58**	**0.98**	**0.94**	**0.90**
64x64	0.53	0.24	30.57	30.27	33.13	31.41	31.72	0.65	0.58	0.97	0.92	0.92

In natural images, more than one ROI may exist along with the background. The total ROI size should not exceed 25% of the total image size. Accordingly, ROI_1, ROI_2 and ROI_3 are marked automatically using a saliency map of the image at different thresholds in such way that their maximum sizes are 3, 6 and 16% of the total image size respectively.

Fig.3 shows the performance of the proposed method at different bit rates 0.05, 0.1, 0.5, 1 bpp. As certain objects in an image are meaningful due to its surrounding, the surrounding is equally important. Distortions due to compression may divert our attention from the visually important object or region in an image. So the LL subband of lowest wavelet decomposition is included in the final bit stream, it provides the approximation of the complete image and helps to identify the important objects at low bit rates. Depending on the availability of bit budget the ROI_1, ROI_2, ROI_3 and background are improved in progressive order from lossy to visually lossless.

a) Original image 1125x1125x24 c) 0.05bpp e) 0.1bpp

b) Quantized Saliency Mask d) 0.5bpp f) 1bpp

Reconstructed Images

Fig. 3 Visual results of an image for ROI coding at different bit rates for the proposed method

TABLE2

PERFORMANCE OF ROI CODING METHODS

Rate (bpp)	ROI Method	PSNR				SSIM			
		Background	ROI_1	ROI_2	ROI_3	Background	ROI_1	ROI_2	ROI_3
0.1	Maxshift	33.68	**31.16**	**30.24**	**30.32**	0.85	**0.86**	**0.84**	**0.82**
0.1	Weighted	33.66	30.70	29.73	29.80	0.84	0.79	0.76	0.72
0.1	Generalized Multiple ROI	33.56	30.72	29.72	29.77	0.83	0.80	0.76	0.71
0.1	Non ROI Method	**34.05**	30.98	30.00	30.16	**0.90**	0.84	0.81	0.80
0.5	Maxshift	34.58	35.16	33.99	33.83	0.87	0.97	0.97	0.97
0.5	Weighted	36.17	34.81	33.16	32.76	0.95	0.97	0.96	0.95
0.5	**Generalized Multiple ROI**	**34.49**	**36.41**	**34.07**	**33.07**	0.87	**0.98**	**0.97**	**0.95**
0.5	Non ROI Method	37.39	34.18	32.84	32.81	**0.97**	0.96	0.95	0.95
1	Maxshift	34.75	39.27	38.12	37.89	0.87	0.99	0.99	0.99
1	Weighted	37.74	39.36	37.11	35.48	0.96	1.00	0.99	0.98
1	**Generalized Multiple ROI**	**34.69**	**41.27**	**38.76**	**36.37**	0.87	**1.00**	**0.99**	**0.98**
1	Non ROI Method	40.25	36.50	35.43	35.29	**0.99**	0.98	0.98	0.98
2	Maxshift	34.81	46.27	45.14	44.94	0.87	**1.00**	**1.00**	**1.00**
2	Weighted	39.55	45.30	42.00	40.12	0.97	**1.00**	**1.00**	**1.00**
2	Generalized Multiple ROI	34.80	**50.35**	**46.70**	**43.38**	0.87	**1.00**	**1.00**	**1.00**
2	Non ROI Method	44.50	40.76	39.54	39.31	**1.00**	**1.00**	**1.00**	**1.00**
3	Maxshift	37.17	51.84	51.31	50.91	0.95	1.00	1.00	1.00
3	Weighted	41.26	51.05	48.11	45.72	0.98	1.00	1.00	1.00
3	Generalized Multiple ROI	37.02	**53.15**	**51.88**	**50.04**	**0.94**	**1.00**	**1.00**	**1.00**
3	Non ROI Method	47.87	44.26	42.97	42.80	**1.00**	**1.00**	**1.00**	**1.00**
5	Maxshift	46.42	53.59	52.57	52.10	1.00	1.00	1.00	1.00
5	Weighted	47.80	54.61	53.84	53.10	1.00	1.00	1.00	1.00
5	Generalized Multiple ROI	47.26	**53.59**	**52.57**	**52.08**	**1.00**	**1.00**	**1.00**	**1.00**
5	Non ROI Method	54.53	51.85	51.53	51.39	**1.00**	**1.00**	**1.00**	**1.00**

Table 2 lists the PSNR and SSIM for different regions at different bit rates. The PSNR and SSIM are not uniform throughout the image. The PSNR and SSIM difference curves for the ROIs and background are plotted in Fig. 4 and Fig. 5 where PSNR difference and SSIM difference are the region wise difference of PSNR and SSIM of an ROI method with respect Non ROI method.

Fig. 4, Fig. 5 and Table 2 indicate that at low bit rates (i.e. up to 0.1 bpp) the PSNR and SSIM of Non ROI method are better in all the regions. This is because of the inclusion of entire LL subband coefficients as an ROI in the final bit stream. At a moderate bit rate (0.2 to 2.0) the proposed method shows the best performance in ROI_1, better in ROI_2, good in ROI_3 and fair in background region. At higher bit rates the PSNR and the SSIM differences gradually decreased. If we compare the performance of the proposed method with the Maxshift method, it becomes clear that the quality of their background and ROI_2 regions is approximately same, whereas the quality of ROI_1 is improved on an average by 5db at the cost of ROI_3 region. But still at the moderate bit rate the quality of ROI_3 is better than the weighted ROI method.

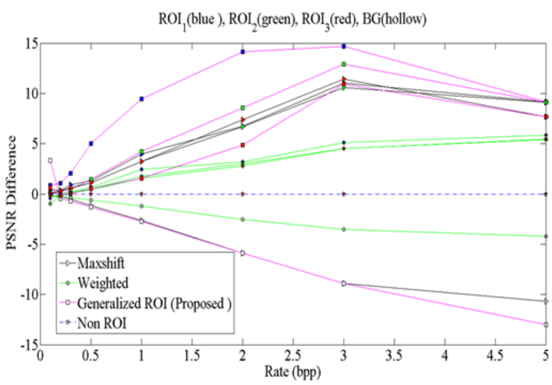

Fig. 4 PSNR Difference w.r.t. without ROI coding method

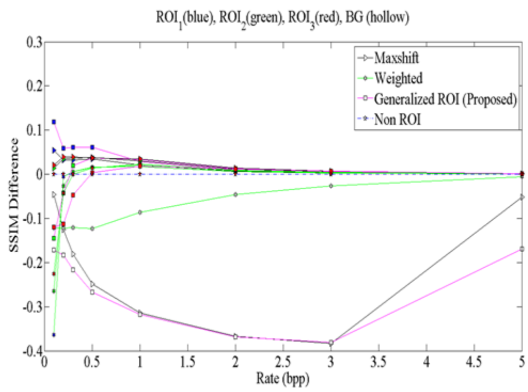

Fig. 5 SSIM Difference w.r.t. without ROI coding method

V. Conclusion

In many natural images, ROI is meaningful due to its surrounding area, the proposed method provides an excellent multiple ROI coding solution in this context. The proposed method is a JPEG2000 compliant generalized ROI coding method. Except the overlapped scaling all other methods can be derived from it. This method tries to preserve ROI and background at low bit rates, improves the quality of ROIs according to the priority at moderate bit rates. It progressively improves the background after achieving the required ROI quality. It approximates the fine-grain accuracy of the Maxshift method without penalizing the coding efficiency. The objective (PSNR) and subjective (SSIM) qualities of higher priority ROIs are better than Maxshift and other ROI methods. Here, extraction of the ROI is a crucial task. To speed up the process of ROI based image compression, ROI may be derived automatically using saliency maps of the image.

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