ρGBbBShift: Method for Introducing Perceptual Criteria to Region of Interest Coding

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Abstract— *This work describes a perceptual method (*ρGBbBShift*) for codding of Region of Interest (ROI) areas. It introduces perceptual criteria to the GBbBShift method when bitplanes of ROI and background areas are shifted. This additional feature is intended for balancing perceptual importance of some coefficients regardless their numerical importance. Perceptual criteria are applied using the CIWaM, which is a low-level computational model that reproduces color perception in the Human Visual System. Results show that there is no perceptual difference at ROI between the* MaxShift *method and* ρGBbBShift *and, at the same time, perceptual quality of the entire image is improved when using* ρGBbBShift. *Furthermore, when* ρGBbBShift *method is applied to* Hi-SET *coder and it is compared against* MaxShift *method applied to both the JPEG2000 standard and the* Hi-SET, *the images coded by the combination* ρGBbBShift-Hi-SET *get the best results when the overall perceptual image quality is estimated. The* ρGBbBShift *method is a generalized algorithm that can be applied to other Wavelet based image compression algorithms such as JPEG2000, SPIHT or SPECK.*

Keywords: Image Coding, JPEG2000, H*i*-SET, region of interest(ROI), bitplane coding, wavelet coding, maximum shift (MaxShift), bitplane-by-bitplane shift (BbBShift), generalized bitplane-by-bitplane shift (GBbBShift).

1. Introduction

1.1 JPEG2000 ROI Coding

Region of interest (ROI) image coding is a feature that modern image coders have, which allows to encode an specific region with better quality than the rest of the image or background (BG). ROI coding is one of the requirements in the JPEG2000 image coding standard [1], [2], which defines two ROI methods[3], [4]:

1) Based on general scaling [3]
2) Maximum shift (MaxShift) [4]

The general ROI scaling-based method scales coefficients in such a way that the bits associated with the ROI are shifted to higher bitplanes than the bitplanes associated with the background, as shown in Figure 1(b). It implies that during a embedded coding process, any background bitplane of the image is located after the most significant ROI bitplanes into the bitstream. But, in some cases, depending on the scaling value, φ, some bits of ROI are simultaneously encoded with BG. Therefore, this method allows to decode and refine the ROI before the rest of the image. No matter φ, it is posible to reconstruct with the entire bitstream a highest fidelity version of the whole image. Nevertheless, If the bitstream is terminated abruptly, the ROI will have a higher fidelity than BG.

The scaling-based method is implemented in five steps:

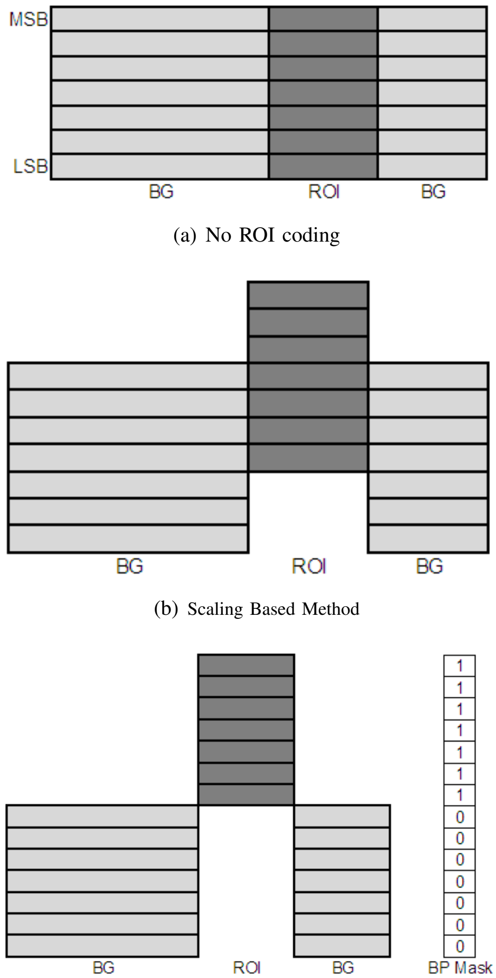
1) A wavelet transform of the original images is performed.
2) A ROI mask is defined, indicating the set of coefficients that are necessary for reaching a lossless ROI reconstruction, Figure 2.
3) Wavelet coefficients are quantized and stored in a sign magnitude representation, using the most significant part of the precision. It will allow to downscale BG coefficients.
4) A specified scaling value, $\tilde{\varphi}$, downscales the coefficients inside the BG.
5) The most significant bitplanes are progressively entropy encoded.

The input of ROI scaling-based method is the scaling value φ, while MaxShift method calculates it. Hence, the encoder defines from quantized coefficients this scaling value such that:

$$\varphi = \lceil \log_2 \left(\max \left\{ \mathcal{M}_{\mathcal{BG}} \right\} + 1 \right) \rceil \qquad (1)$$

where $\max \left\{ \mathcal{M}_{\mathcal{BG}} \right\}$ is the maximum coefficient in the BG. Thus, when ROI is scaled up φ bitplanes, the minimum coefficient belonging to ROI will be place one bitplane up of BG (Fig. 1(c)). Namely, 2^{φ} is the smallest integer that is greater than any coefficient in the BG. MaxShift method is shown in Figure 1(c). Bitplane mask (BP_{mask}) will be explained in section 2.2.

At the decoder side, the ROI and BG coefficients are simply identified by checking the coefficient magnitudes. All coefficients that are higher or equal than the φth bitplane belong to the ROI otherwise they are a part of BG. Hence, it is not important to transmit the shape information of the ROI or ROIs to the decoder. The ROI coefficients are scaled down



(a) No ROI coding

(b) Scaling Based Method

(c) MaxShift method

Fig. 1
JPEG2000 ROI CODING. (A) NO ROI CODING, (B) SCALING BASED ROI CODING METHOD ($\varphi = 3$) AND (C) MaxShift METHOD, $\varphi = 7$. BACKGROUND IS DENOTED AS BG, REGION OF INTEREST AS ROI AND BITPLANE MASK AS BP_{mask}. MSB IS THE MOST SIGNIFICANT BITPLANE AND LSB IS THE LEAST SIGNIFICANT BITPLANE.

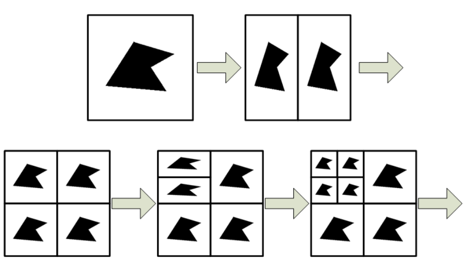


Fig. 2
ROI MASK GENERATION, WAVELET DOMAIN.

φ bitplanes before inverse wavelet transformation is applied.

1.2 Perceptual Coding

1.2.1 Chromatic Induction Wavelet Model

In order to generate an approximation to how every pixel is perceived from a certain distance taking into account the value of its neighboring pixels the Chromatic Induction Wavelet Model (CIWaM) is used. CIWaM attenuates the details that the human visual system is not able to perceive, enhances those that are perceptually relevant and produces an approximation of the image that the brain visual cortex perceives. CIWaM takes an input image $\mathcal{I}$ and decomposes it into a set of wavelet planes $\omega_{s,o}$ of different spatial scales s (i.e., spatial frequency ν) and spatial orientations o. It is described as

$$\mathcal{I} = \sum_{s=1}^{n} \sum_{o=v,h,dgl} \omega_{s,o} + c_n \ , \tag{2}$$

where n is the number of wavelet planes, c_n is the residual plane and o is the spatial orientation either *v*ertical, *h*orizontal or *d*iagona*l*. The perceptual image $\mathcal{I}_\rho$ is recovered by weighting these $\omega_{s,o}$ wavelet coefficients using the *extended Contrast Sensitivity Function* (e-CSF), which considers spatial surround information (denoted by r), visual frequency (ν related to spatial frequency by observation distance) and observation distance (d). Perceptual image $\mathcal{I}_\rho$ can be obtained by

$$\mathcal{I}_\rho = \sum_{s=1}^{n} \sum_{o=v,h,dgl} \alpha(\nu,r)\,\omega_{s,o} + c_n \ , \tag{3}$$

where $\alpha(\nu,r)$ is the e-CSF weighting function that tries to reproduce some perceptual properties of the HVS. The term $\alpha(\nu,r)\ \omega_{s,o} \equiv \omega_{s,o;\rho,d}$ can be considered the *perceptual wavelet coefficients* of image $\mathcal{I}$ when observed at distance d. For details on the CIWaM and the $\alpha(\nu,r)$ function, see [5].

1.2.2 Quantization

We employ the perceptual quantizer (ρSQ) either forward (F-ρSQ) and inverse (I-ρSQ), defined by Moreno and Otazu in [6]. Quantization is the only cause that introduces distortion into a compression process. Each transform sample at the perceptual image $\mathcal{I}_\rho$ (from Eq. 3) is mapped independently to a corresponding step size either Δ_s or Δ_n, thus $\mathcal{I}_\rho$ is associated with a specific interval on the real line. Then, the perceptually quantized coefficients $\mathcal{Q}$ (F-ρSQ), from a known viewing distance d, are calculated as follows:

$$\mathcal{Q} = \sum_{s=1}^{n} \sum_{o=v,h,d} sign(\omega_{s,o}) \left\lfloor \frac{|\alpha(\nu,r)\cdot\omega_{s,o}|}{\Delta_s} \right\rfloor + \left\lfloor \frac{c_n}{\Delta_n} \right\rfloor \tag{4}$$

The perceptual inverse quantizer (I-ρSQ) or the recovered $\widehat{\alpha}(\nu,r)$ introduces perceptual criteria to the classical Inverse

Scalar Quantizer and is given by:

$$\widehat{\mathcal{I}} = \begin{cases} \sum_{s=1}^{n} \sum_{o=v,h,d} sign(\widehat{\omega_{s,o}}) \, \frac{\Delta_s \cdot (|\widehat{\omega_s^o}| + \delta)}{\widehat{\alpha}(\nu, r)} & \\ + \, (|\widehat{c_n}| + \delta) \cdot \Delta_n \ , & |\widehat{\omega_{s,o}}| > 0 \\ 0, & \widehat{\omega_{s,o}} = 0 \end{cases} \qquad (5)$$

2. Related Work

2.1 BbBShift

Wang and Bovik proposed the bitplane-by-bitplane shift (BbBShift) method in [7]. BbBShift shifts bitplanes on a bitplane-by-bitplane strategy. Figure 3(a) shows an illustration of the BbBShift method. BbBShift uses two parameters, φ_1 and φ_2, whose sum is equal to the number of bitplanes for representing any coefficient inside the image, indexing the top bitplane as bitplane 1. Summarizing, the BbBShift method encodes the first φ_1 bitplanes with ROI coefficients, then, BG and ROI bitplanes are alternately shifted, refining gradually both ROI and BG of the image (Fig. 3(a)). The encoding process of the BbBShift method is defined as:

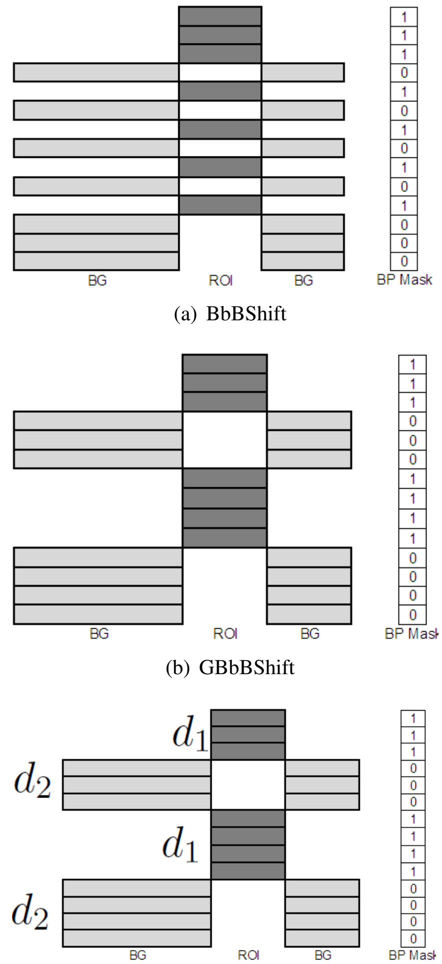
1) For a given bitplane *bpl* with at least one ROI coefficient:
   - If $bpl \leq \varphi_1$, *bpl* is not shifted.
   - If $\varphi_1 < bpl \leq \varphi_1 + \varphi_2$, *bpl* is shifted down to $\varphi_1 + 2\,(bpl - \varphi_1)$
2) For a given bitplane *bpl* with at least one BG coefficient:
   - If $bpl \leq \varphi_2$, *bpl* is shifted down to $\varphi_1 + 2bpl - 1$
   - If $bpl > \varphi_2$, *bpl* is shifted down to $\varphi_1 + \varphi_2 + bpl$

2.2 GBbBShift

In practice, the quality refinement pattern of the ROI and BG used by BbBShift method is similar to the general scaling based method. Thus, when the image is encoded and this process is truncated in a specific point the quality of the ROI is high while there is no information of BG.

Hence, Wang and Bovik [8] modified BbBShift method and proposed the generalized bitplane-by-bitplane shift (GBbBShift) method, which introduces the option to improve visual quality either of ROI or BG or both. Figure 3(b) shows that with GBbBShift method it is posible to decode some bitplanes of BG after the decoding of same ROI bitplanes. It allows to improve the overall quality of the recovered image. This is posible gathering BG bitplanes. Thus, when the encoding process achieves the lowest bitplanes of ROI, the quality of BG could be good enough in order to portray an approximation of BG.

Therefore, the main feature of GBbBShift is to give the opportunity to arbitrary chose the order of bitplane decoding, grouping them in ROI bitplanes and BG bitplanes. This is posible using a binary bitplane mask or BP_{mask}, which contains one bit per each bitplane, that is, twice the amount of bitplanes of the original image. A ROI bitplane is represented by 1, while a BG bitplane by 0. For example, the BP_{mask} for MaxShift method in Figure 1(c) is 11111110000000, while for BbBShift in Figure 3(a) and GBbBShift in Figure 3(b) are 11101010101000 and 11100011110000, respectively.



(a) BbBShift

(b) GBbBShift

(c) ρGBbBShift

Fig. 3

ROI CODING METHODS. (A) BBBSHIFT, $\varphi_1 = 3$ AND $\varphi_2 = 4$, (B) GBBBSHIFT AND (C)ρGBbBShift. BACKGROUND IS DENOTED AS BG (FOR ρGBbBShift METHOD IS PERCEPTUALLY QUANTIZED BY ρSQ AT d_2), REGION OF INTEREST AS ROI (FOR ρGBbBShift METHOD IS PERCEPTUALLY QUANTIZED AT d_1 BY ρSQ) AND BITPLANE MASK AS BP_{mask}.

At the encoder side, the BP_{mask} has the order of shifting both the ROI and BG bitplanes. Furthermore, BP_{mask} is encoded in the bitstream, while the scaling values φ or φ_1 and φ_2 from the MaxShift and BbBShift methods, respectively, have to be transmitted.

3. ρGBbBShift Method

In order to have several kinds of options for bitplane scaling techniques, a perceptual generalized bitplane-by-bitplane shift(ρGBbBShift) method is proposed. The ρGBbBShift method introduces to the GBbBShift method perceptual criteria when bitplanes of ROI and BG areas are shifted. This additional feature is intended for balancing perceptual importance of some coefficients regardless their numerical importance and for not observing visual difference at ROI regarding $\mathrm{MaxShift}$ method, improving perceptual quality of the entire image.

Thus, ρGBbBShift uses a binary bitplane mask or BP_{mask} in the same way that GBbBShift (Figure 3(c)). At the encoder, shifting scheme is as follows:

1) Calculate φ using Equation 1.
2) Verify that the length of BP_{mask} is equal to 2φ.
3)
   - For all ROI Coefficients, forward perceptual quantize them using Equation 4 (F-ρSQ) with viewing distance d_1.
   - For all BG Coefficients, forward perceptual quantize them using Equation 4 (F-ρSQ) with viewing distance d_2, being $d_2 \gg d_1$.
4) Let τ and η be equal to 0.
5) For every element i of BP_{mask}, starting with the least significant bit:
   - If $BP_{mask}(i) = 1$, Shift up all ROI perceptual quantized coefficients of the $(\varphi - \eta)$-th bitplane by τ bitplanes and increment η.
   - Else: Shift up all BG perceptual quantized coefficients of the $(\varphi - \tau)$-th bitplane by η bitplanes and increment τ.

At the decoder, shifting scheme is as follows:

1) Let $\varphi = \frac{length\ of\ BP_{mask}}{2}$ be calculated.
2) Let τ and η be equal to 0.
3) For every element i of BP_{mask}, starting with the least significant bit:
   - If $BP_{mask}(i) = 1$, Shift down all perceptual quantized coefficients by τ bitplanes, which pertain to the $(2\varphi - (\tau + \eta))$-th bitplane of the recovered image and increment η.
   - Else: Shift down all perceptual quantized coefficients by η bitplanes, which pertain to the $(2\varphi - (\tau + \eta))$-th bitplane of the recovered image and increment τ.
4) Let us denote as $c_{i,j}$ a given non-zero wavelet coefficient of the recovered image with 2φ bitplanes and $\overline{c}_{i,j}$ as a shifted down c obtained in the previous step, with φ bitplanes.
   - If $(c_{i,j}\ \&\ BP_{mask}) > 0$, inverse perceptual quantize $\overline{c}_{i,j}$ using Equation 5 (I-ρSQ) with d_1 as viewing distance.
   - If $(c_{i,j}\ \&\ BP_{mask}) = 0$, inverse perceptual quantize $\overline{c}_{i,j}$ using Equation 5 (I-ρSQ) with d_2 as viewing distance.

4. Experimental Results

The ρGBbBShift method, as the other methods presented here, can be applied to many image compression algorithms such as JPEG2000 or H*i*-SET[9]. We test our method applying it to H*i*-SET and the results are contrasted with $\mathrm{MaxShift}$ method in JPEG2000 and H*i*-SET. The setup parameters are $\varphi = 8$ for $\mathrm{MaxShift}$ and $BP_{mask} = 1111000110110000$, $d_1 = 5H$ and $d_2 = 50H$, where H is picture height (512 pixels) in a 19-inch LCD monitor, for ρGBbBShift. Also, we use the *JJ2000* implementation when an image is compressed by JPEG2000 standard[10].

4.1 H*i*-SET: Brief description of the coding algorithm

H*i*-SET considers three coding passes: Initialization, Sorting and Refinement[11].

1) **Initialization:**
   - Divide the original Image $\mathcal{I}_{org}(i,j)$ into four sets according to Hilbert Rules described in [9], i.e. from $(level)\,\mathcal{U}$ to $(level-1)\,\mathcal{LUUR}$.
   - Output $thr = \left\lfloor \log_2 \left(\max_{(i,j)} \{|\mathcal{I}_{org}(i,j)|\} \right) \right\rfloor$
   - Set the List of Significant Pixels (LSP) to empty.
2) **Sorting:**
   - Replace with the production rules only curves, which contain significant coefficients until reaching the fractal $level = 1$. If there is a significant coefficient, output the sign, 0 for positives and 0 for negatives.
3) **Refinement**
   - For each (i,j) at LSP, output the thr-th most significant bit of $|\mathcal{I}_{org}(i,j)|$.
   - Decrement thr and if $thr \neq 1$ go to step 2, otherwise a lossless compression would be reached.

4.2 Application in well-known Test Images

Figure 4 shows a comparison among methods $\mathrm{MaxShift}$ and GBbBShift applied to JPEG2000, in addition to, ρGBbBShift applied to H*i*-SET. The 24-bpp image *Barbara* is compressed at 0.5 bpp. It can be observed that without visual difference at ROI, the ρGBbBShift method provide better image quality at the BG than the general based methods defined in JPEG2000 Part II[1].In order to better qualify the performance of $\mathrm{MaxShift}$, GBbBShift and ρGBbBShift methods, first, we compared these methods applied to the H*i*-SET coder and then, we compare $\mathrm{MaxShift}$ and ρGBbBShift methods applied to the JPEG2000 standard and H*i*-SET, respectively. We compress two different grayscale and color images of *Lenna* at different bit-rates. ROI area is a patch at the center of these images, whose size is 1/16 of the image. We employ the perceptual quality assessment proposed by Moreno and Otazu in [12], which weights the mainstream PSNR by means of a chromatic induction model ($\mathcal{C}_w\mathrm{PSNR}$).

Figs. 5(a) and 5(b) show the comparison among $\mathrm{MaxShift}$(Blue Function), GBbBShift(Green Function) and $\rho\mathrm{GBbBShift}$(Red Function) methods applied to $\mathrm{H}i\text{-}\mathrm{SET}$ coder. 512×512 pixel Image *Lenna* for gray-scale is employ for this experiment. These Figures also show that the $\rho\mathrm{GBbBShift}$ method gets the better results both in PSNR(objective image quality, Fig. 5(a)) and $\mathcal{C}_w\mathrm{PSNR}$(subjective image quality, Fig. 5(b)) in contrast to $\mathrm{MaxShift}$ and GBbBShift methods. In addition, when $\mathrm{MaxShift}$ method applied to JPEG2000 coder and $\rho\mathrm{GBbBShift}$ applied to $\mathrm{H}i\text{-}\mathrm{SET}$ coder are compared, $\rho\mathrm{GBbBShift}$ obtains less objective quality (Fig. 5(c)), but better subjective quality for gray-scale images (Fig. 5(d)).

Figure 6 shows a visual example, when image *Lenna* is compressed at 0.34 bpp by JPEG2000 and $\mathrm{H}i\text{-}\mathrm{SET}$. Thus, it can be observed that $\rho\mathrm{GBbBShift}$ provides an important perceptual difference regarding the $\mathrm{MaxShift}$ method(Fig. 6(d)). Furthermore, Figs. 6(b) and 6(c) show the examples when $\mathrm{MaxShift}$ and GBbBShift methods, respectively, are applied to the $\mathrm{H}i\text{-}\mathrm{SET}$ coder.

4.3 Application in other image compression fields

The usage of ROI coded images depends on an specific application, but in some fields such as manipulation and transmission of images is important to enhance the image quality of some areas and to reduce it in others[13], [14]. In Telemedicine or in Remote Sensing (RS) it is desirable to maintain the best quality of the ROI area, preserving relevant information of BG, namely the most perceptual frequencies. Figure 7 shows an example of the application of ROI in Remote Sensing. Image *2.1.05*, from *Volumen 2: aerials* of USC-SIPI image database 8 bits per pixel[15], is compressed at 0.42 bpp. $\mathrm{MaxShift}$ method spends all the bit-ratio for coding ROI, located at [159 260 384 460], while $\rho\mathrm{GBbBShift}$ balances a perceptually lossless ROI area with an acceptable representation of the BG. Hence, the overall image quality measured by PSNR in Figure 7(a) is 16.06 dB, while in Figure 7(b) is 24.28 dB. When perceptual metrics assess the image quality of the $\rho\mathrm{GBbBShift}$ coded image, for example, VIFP=0.4982, WSNR=24.8469 and $\mathcal{C}_w\mathrm{PSNR}$=27.07, while for $\mathrm{MaxShift}$ coded image VIFP=0.2368, WSNR=11.33 and $\mathcal{C}_w\mathrm{PSNR}$=16.72. Thus, for this example, both PSNR and these subjective metrics reflect important perceptual differences between ROI methods, being $\rho\mathrm{GBbBShift}$ method better than $\mathrm{MaxShift}$ method.

5. Conclusions

A perceptual implementation of the Region of Interest, $\rho\mathrm{GBbBShift}()$, is proposed, which is a generalized method that can be applied to any wavelet-based compressor. We introduced $\rho\mathrm{GBbBShift}$ method to the $\mathrm{H}i\text{-}\mathrm{SET}$ coder and it visually improves the results obtained by previous methods like $\mathrm{MaxShift}$ and GBbBShift. Our experiments show that $\rho\mathrm{GBbBShift}$ into $\mathrm{H}i\text{-}\mathrm{SET}$ provides an important perceptual difference regarding the $\mathrm{MaxShift}$ method into JPEG2000, when it is applied to conventional images like *Lenna* or *Barbara*.

Acknowledgment

This work is supported by The National Polytechnic Institute of Mexico by means of a granted fund by the Committee of Operation and Promotion of Academic Activities (COFAA).

References

[1] M. Boliek, E. Majani, J. S. Houchin, J. Kasner, and M. Carlander, *Information Technology: JPEG2000 Image Coding System (Extensions)*, JPEG 2000 Part II final committee draft ed., ISO/IEC JTC 1/SC 29/WG 1, Dec. 2000.

[2] M. Boliek, C. Christopoulos, and E. Majani, *Information Technology: JPEG2000 Image Coding System*, JPEG 2000 Part I final committee draft version 1.0 ed., ISO/IEC JTC1/SC29 WG1, JPEG 2000, April 2000.

[3] D. S. Taubman and M. W. Marcellin, *JPEG2000: Image Compression Fundamentals, Standards and Practice*, ser. ISBN: 0-7923-7519-X. Kluwer Academic Publishers, 2002.

[4] E. Atsumi and N. Farvardin, "Lossy/lossless region-of-interest image coding based on set partitioning in hierarchical trees," in *International Conference on Image Processing*, vol. 1, oct 1998, pp. 87 –91 vol.1.

[5] X. Otazu, C. Párraga, and M. Vanrell, "Toward a unified chromatic induction model," *Journal of Vision*, vol. 10(12), no. 6, 2010.

[6] J. Moreno and X. Otazu, "Perceptual quantization using a chromatic induction model," July 2011, under review in IEEE Transactions on Image Processing.

[7] Z. Wang and A. C.Bovik, "Bitplane-by-bitplane shift (Bb BShift) - a suggestion for JPEG2000 region of interest image coding," *IEEE Signal Processing Letters*, vol. 9, no. 5, pp. 160 – 162, May 2002.

[8] Z. Wang, S. Banerjee, B. L. Evans, and A. C. Bovik, "Generalized bitplane-by-bitplane shift method for JPEG2000 ROI coding," *IEEE International Conference on Image Processing*, vol. 3, pp. 81–84, September 22-25 2002.

[9] J. Moreno and X. Otazu, "Image coder based on H*i*lbert Scaning of Embedded quadTrees: An introduction of H*i*-SET coder," *IEEE International Conference on Multimedia and Expo*, July 2011.

[10] C. Research, École Polytechnique Fédérale de Lausanne, and Ericsson. (2001) JJ2000 implementation in Java. Cannon Research, École Polytechnique Fédérale de Lausanne and Ericsson. [Online]. Available: http://jj2000.epfl.ch/

[11] J. Moreno and X. Otazu, "Image coder based on H*i*lbert Scaning of Embedded quadTrees," *IEEE Data Compression Conference*, p. 470, March 2011.

[12] ——, "Full-reference quality assessment using a chromatic induction model: Jpeg and jpeg2000," July 2011, under review in Journal of the Optical Society of America A.

[13] J. Bartrina-Rapesta, F. Auli-Llinas, J. Serra-Sagrista, A. Zabala-Torres, X. Pons-Fernandez, and J. Maso-Pau, "Region of interest coding applied to map overlapping in geographic information systems," in *IEEE International Geoscience and Remote Sensing Symposium*, 23-28 2007, pp. 5001 –5004.

[14] J. Gonzalez-Conejero, J. Serra-Sagrista, C. Rubies-Feijoo, and L. Donoso-Bach, "Encoding of images containing no-data regions within JPEG2000 framework," in *15th IEEE International Conference on Image Processing*, 12-15 2008, pp. 1057 –1060.

[15] S. I. P. I. of the University of Southern California. (1997) The USC-SIPI image database. Signal and Image Processing Institute of the University of Southern California. [Online]. Available: http://sipi.usc.edu/database/

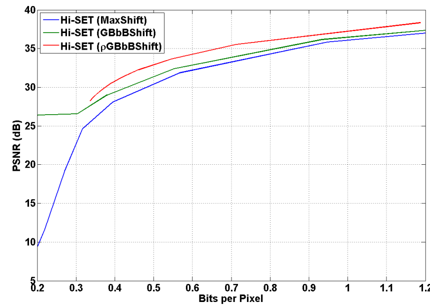
(a) MaxShift in JPEG2000 coder, 0.5 bpp

(b) GBbBShift in JPEG2000 coder, 0.5 bpp

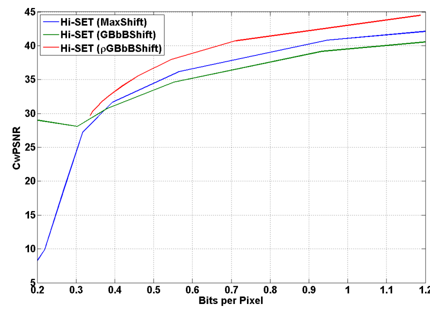
(c) ρGBbBShift in Hi-SET coder, 0.5 bpp

Fig. 4

512 × 640 pixel Image *Barbara* with 24 bits per pixel. ROI is a patch of the image located at [341 280 442 442], whose size is 1/16 of the image. Decoded images at 0.5 bpp using MaxShift method in JPEG2000 coder((a) $\varphi = 8$), GBbBShift method in JPEG2000 coder ((b)$BP_{mask} = 1111000110110000$) and ρGBbBShift method in Hi-SET coder ((c)$BP_{mask} = 1111000110110000$).



(a)



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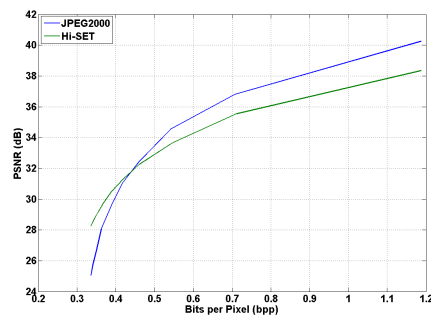
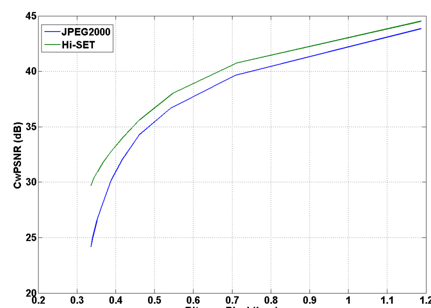


(c)



(d)

Fig. 5

(a-b) Comparison among MaxShift(Blue Function), GBbBShift(Green Function) and ρGBbBShift(Red Function) methods applied to Hi-SET coder. (c-d) Comparison between MaxShift method applied to JPEG2000 coder and ρGBbBShift applied to Hi-SET coder. 512 × 512 pixel Image *Lenna* with 8 bits per pixel is employed for this experiment. ROI is a patch at the center of the image, whose size is 1/16 of the image. The overall image quality of decoded images at different bits per pixel are contrasted both (a and c) objectively and (b and d)subjectively.

(a) MaxShift method in JPEG2000 coder, 0.34 bpp.

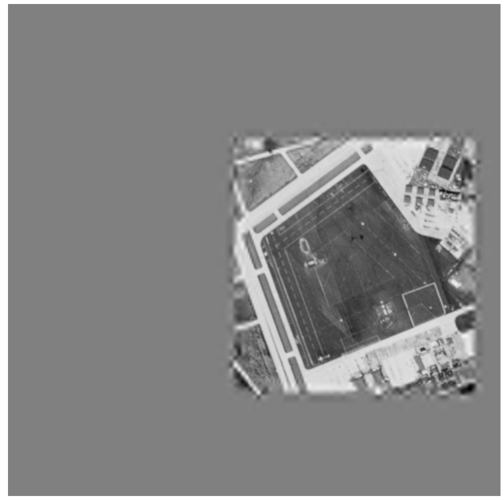
(b) MaxShift method in H*i*-SET coder, 0.34 bpp.

(c) GBbBShift method in H*i*-SET coder, 0.34 bpp.

(d) ρGBbBShift method in H*i*-SET coder, 0.34 bpp.

Fig. 6

512×512 pixel Image *Lenna* from CMU image database with 8 bits per pixel. ROI is a patch at the center of the image, whose size is 1/16 of the image. Decoded images at 0.34 bpp using $\varphi = 8$ for MaxShift method (a) in JPEG2000 coder and (b) in H*i*-SET coder, and $BP_{mask} = 1111000110110000$ for (c) GBbBShift and (d) ρGBbBShift methods in H*i*-SET coder.



(a) MaxShift in JPEG2000 coder, 0.42 bpp

(b) ρGBbBShift method in H*i*-SET coder, 0.42 bpp

Fig. 7

Example of a remote sensing application. 512×512 pixel Image *2.1.05* from *Volumen 2: aerials* of USC-SIPI image database at 8 bits per pixel. ROI is a patch with coordinates [159 260 384 460], whose size is 225×200 pixels. Decoded images at 0.42 bpp using MaxShift method ((a) $\varphi = 8$) in JPEG2000 coder and ρGBbBShift method ((b)$BP_{mask} = 1111000110110000$) in H*i*-SET coder.