Prioritized Region of Interest Coding in JPEG2000

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Abstract

A method is proposed to encode multiple regions of interest in the JPEG2000 image-coding framework. The algorithm is based on the rearrangement of packets in the code-stream to place the regions of interest before the background coefficients. In order to improve the quality of the reconstructed image, partial background information is included with the regions of interest. The method makes use of a Gaussian priority distribution to assign different priority levels to background and region of interest packets. The priority level is in turn used to determine how much background information should be included with the regions of interest. The proposed technique is fully compatible with the current JPEG2000 standard and allows transmission of different regions of interest with different priorities. Experimental results demonstrating the validity of the proposed approach are presented and compared with existing region of interest coding techniques.

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1. Introduction

The new JPEG2000 standard [1] for still images is intended to overcome the shortcomings of the existing JPEG standard. It employs the discrete wavelet transform, and incorporates functionalities such as lossless and lossy compression, spatial and quality scalability, region of interest coding, random code-stream access and error-resilient coding. The applications of the JPEG2000 standard include Internet, printing, digital photography, remote sensing, mobile, digital libraries and E-commerce. Some of the most important features of JPEG2000 are [2]:

1) Lossless and lossy compression: the standard provides lossy compression with performance superior to the JPEG standard at low bit-rates. It also provides lossless compression with progressive decoding. Applications such as digital libraries/databases and medical imagery can benefit from this feature.
2) Protective image security: the open architecture of this standard facilitates the use of protection techniques of digital images such as watermarking, labeling, stamping or encryption [2].
3) Region-of-interest coding: in this mode, regions of interest (ROI) in an image can be defined. The ROI can then be encoded and transmitted with better quality than the rest of the image [1].
4) Robustness to bit errors: the standard incorporates a set of error resilient tools to make the bitstream more robust to transmission errors.

The encoding of ROIs in an image with quality better than the background is one of the new features of the JPEG2000 standard. Reconstructing a specific region of an image before the background is useful in applications such as image databases, telemedicine and web browsing [3,4]. Several techniques have been proposed for ROI-based image coding [5, 6, 7]. JPEG2000 currently supports two methods to encode ROIs: the general scaling based method (GSBM) and the maximum shift (MAXSHIFT) method [1,2].

In the GSBM [8], the coefficients associated with the ROI are scaled-up so that the corresponding bits are placed in higher bit-planes. Given the hierarchical structure of the JPEG2000 code-stream, these scaled-up bit-planes are placed in the final bitstream before any bit-planes associated with the background. Depending on the scaling value, some bits of the ROI coefficients may be encoded along with background coefficients. At the decoder side, the ROI is decoded first before the rest of the image. Therefore, if the image is truncated or the coding process terminated, the ROI will have a higher quality than the background. Prior to the start of the coding process, a mask representing the coefficients associated with the ROI is generated. The main drawback of the GSBM is the need to encode and transmit the shape information of the ROI, resulting in an increase in the computational complexity as well as the bit-rate (due to shape encoding).

The MAXSHIFT method [8] scales-up the coefficients associated with the ROI well above the background coefficients and thus eliminates the need of generating the mask at the encoder. In the MAXSHIFT method, the scaling value s is chosen according to the following criteria:

$$s \geq \max\left\{M_b^i\right\} \qquad 1 \leq i \leq Q$$

where Q is the number of coefficients in the ROI and M_b^i is the number of most significant bit-planes for the ith ROI coefficient. At the decoder, the nonzero ROI and background coefficients are identified by their magnitude. The coefficients with magnitude less than the *s-th* bit-plane belong to the background. Therefore, there is no need to explicitly transmit the shape information of the ROI. Before the inverse wavelet transform is applied, the background coefficients are scaled-up by s bit-planes.

The main disadvantage of the MAXSHIFT method is that it is not possible to define the relative importance of the ROI and background coefficients. Therefore, in every subband where a ROI is created, the background data cannot be received until the ROI is fully decoded. Another limitation of the MAXSHIFT method is that different ROIs cannot have their own scaling value; consequently, different ROIs with different priorities cannot be defined.

A more flexible method to define ROIs is proposed in [9]. This method, termed as Bitplane-by-Bitplane shift (BbBShift), supports arbitrary ROI shapes and scaling values. Here, instead of shifting the bit-planes all at once by the same scaling value as in MAXSHIFT, BbBShift shifts them on a bitplane-by-bitplane basis. The method allows for the decoding of background information once a high enough quality ROI is achieved. However, the major drawback of the BbBShift method is that it is not fully compatible with the current JPEG2000 ROI coding definitions. In order to use the BbBShift method, a new coding mode must be added to the standard. A similar method called Partial Significant Bit-planes Shift (PSBShift) was proposed in [10]. PSBShift combines the advantages of the two standard ROI coding methods defined in JPEG2000. The method supports arbitrarily shaped ROI coding without coding the shape, and enables the flexible adjustment of compression quality in the ROI and the background. However, similar to the BbBShift method, PSBShift is not fully compatible with the current JPEG2000 standard. A method to encode ROIs by rearranging packets is proposed in [11]. This method shifts packets to initial layers to make possible the decoding of ROIs before the background. Even though the method is compatible with the standard, it does not allow decoding any background information before the ROI is fully processed.

In this paper, we propose a ROI coding technique where partial background information is encoded along with the ROI. We use a prioritization strategy to determine how much background information should be included with the ROI packets. Instead of defining two priority levels, namely, high priority for a ROI and low priority for the background, we create several priority levels according to the distance of a region from the ROI. The proposed technique can also encode multiple ROIs (with different priorities) in an image.

The remainder of this paper is organized as follows: Section 2 presents a short overview of a few selected JPEG2000 features. The proposed method is described in Section 3, followed by experimental results in Section 4. Finally, concluding remarks are given in Section 5.

2. Review of ROI coding in JPEG2000

The JPEG2000 standard uses wavelets to decompose the image into high-frequency and low-frequency subbands. After the wavelet decomposition, each subband is divided into rectangular blocks called *precincts*. Each precinct is further divided into smaller blocks called code-blocks. 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 code-stream.

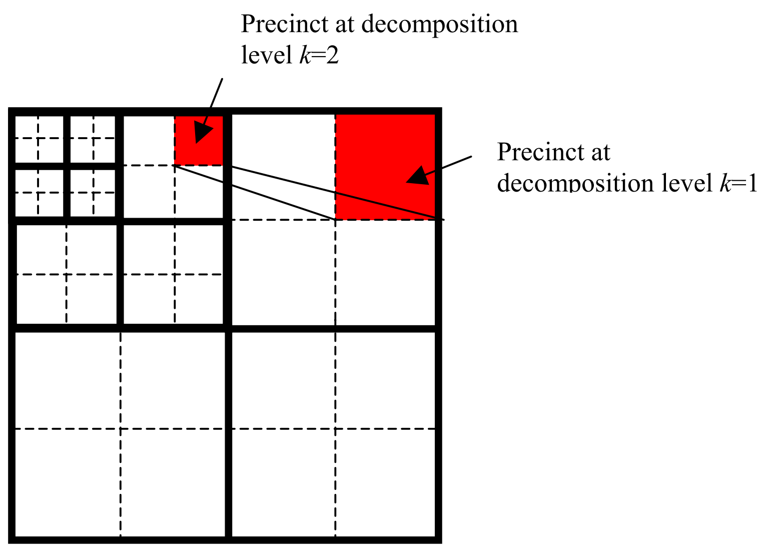

Fig. 1: Image with three levels of decomposition and four precincts per subband. Precincts in gray describe the same spatial region at two different decomposition levels.

A packet describes a specific region of the image at a specific resolution. If the number of precincts is consistent across the different decomposition levels, pyramid decomposition is achieved. In pyramid decomposition, a region of size $m \times n$ and position $\{i, j\}$ at decomposition level k is related to a region of size $2m \times 2n$ and position $\{2i, 2j\}$ at decomposition level k-1, where k=1 is the first decomposition level. Figure 1 shows an example with three levels of decomposition and four precincts per subband.

When an image is compressed with precincts as described in Fig. 1, the resulting packets contain information about a specific region of an image at a given decomposition level. In order to define a ROI, it is only necessary to rearrange the packets in such a way that the initial layers contain only those packets describing the ROI. Figure 2(a) shows an example of an image with two layers, four packets per layer and a single ROI. The second and fourth packet of each layer describes the ROI. We note that two extra layers have been created in Fig. 2(b) and the packets describing the ROI have been placed in the first two layers along with empty packets. The remaining packets are placed in layers three and four.

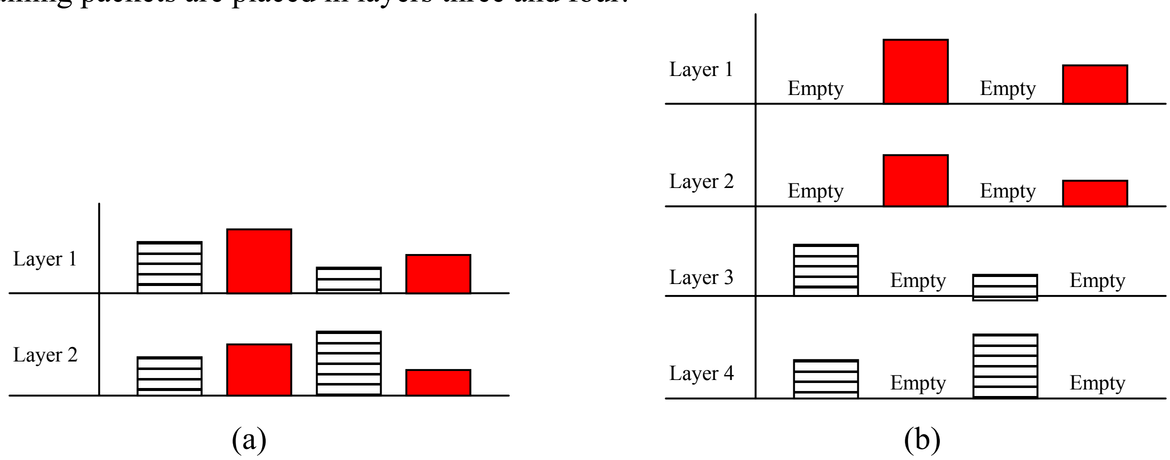

Fig. 2: a) Original code-stream with two layers and four packets per layer. Packets in gray describe a ROI. b) Modified code-stream. The initial two layers describe only the ROI. Background packets have been moved to the latter layers [1,11].

Note that the size of the precincts must be constant across the different decomposition levels so the ROI can be progressively decoded.

3. Proposed algorithm

Section 2 describes the encoding of ROIs in a JPEG2000 compressed image by rearranging packets and inserting additional quality layers. However, when the decoder receives the initial layers, only information about the ROI is obtained and the background remains empty. It is observed in Fig. 2(b) that if the decoding process is terminated before layer three is received; no background information will be available in the decompressed image. In order to improve the quality of the decoded image, we propose to include background packets in the layers containing the ROI. In the following, we explain how the proposed method works for the case of a single ROI and multiple ROIs.

3.1 Single ROI coding

The proposed method prioritizes each packet according to its distance from the ROI. The concept of prioritizing data based on the distance from a ROI was first introduced in [12]. This particular prioritization method employs a foveated image and allows gradual increase in peripheral quality loss during network congestion. Foveation techniques have been used in previous work to improve image and video coding algorithms [13]-[15]. In [13], an image compression scheme based on variable resolution is presented. The method is based on the idea that in many images there often exists an area which is of greater interest (fovea) than then the rest of the picture. Therefore, more detail is required in this area. This work also introduces a prototype teleconferencing system based on variable resolution. In [14] a foveated wavelet image quality measurement in presented. The proposed metric can be used to mediate the compression and enhancement of ROI coded images and videos. A foveation scalable video-coding algorithm is introduced in [15]. This algorithm creates a final bitstream that can be decoded at an arbitrary bit-rate taking into account a foveation model.

Here, we extend the idea of prioritizing data to the JPEG2000 framework to improve the overall visual quality of the decoded image while retaining the ROI coding property. Packets within a ROI receive the highest priority, whereas the surrounding packets receive a priority inversely proportional to their distance measured from the center of the ROI. In this work, the priority level may be any real number in the range [0,1]. In order to assign priorities to the surrounding packets, we use a Gaussian distribution. For an image with *L* quality layers and *M* packets per layer, packet *m* in layer *l* receives a priority level, $p_{m,l}(r)$, according to the following equation:

$$p_{m,l}(r) = \begin{cases} \dfrac{\mathrm{P}_{ROI}}{L} \cdot (L - l + 1) & \textit{if packet} \in ROI \\ \dfrac{\mathrm{P}_{ROI} \cdot 2^{-(r/R)^2}}{L} \cdot (L - l + 1) & \textit{if packet} \notin ROI \end{cases} \tag{1}$$

where P_{ROI} is the priority level assigned to the ROI, *r* is the distance between the centers of the ROI and the region represented by packet *m*, *L* is the number of layers used to compress the image and *R* (the shape parameter) is defined as the radius at which the priority drops to one-half its maximum value.

The shape parameter *R* is used to change the rate at which the priority drops. A large *R* results in a flat distribution, while a small *R* results in a fast decaying distribution. Let the horizontal and vertical size of the image be denoted by *H* and *V*, respectively. The diagonal length of the image (measured in pixels) can be calculated as:

$$S = \sqrt{H^2 + V^2} \tag{2}$$

Figure 3 shows the rate of decay of the Gaussian priority distribution as a function of the distance *r* for different values of *R* for an image of 512×512 pixels. It is observed that for $R > 2S$, the priority level of ROI is not much different from the background packets. Hence, in this paper, we limit the value of R to the range [0,2S].

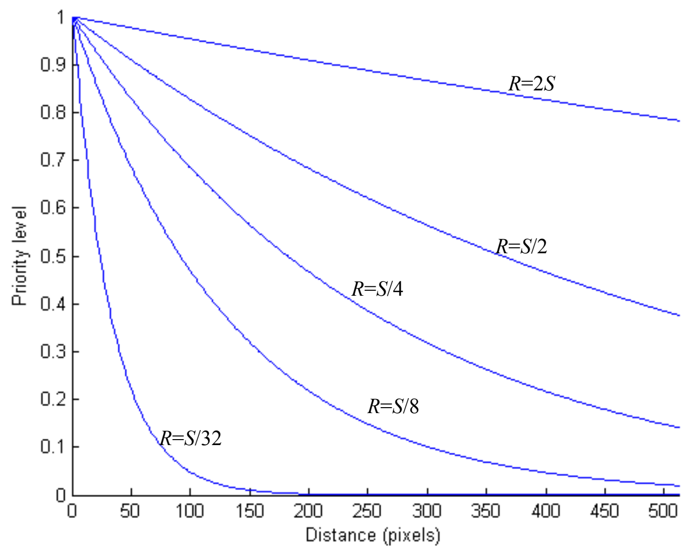

Fig. 3: Rate of decay of the Gaussian priority distribution as a function of the distance r for different values of R for an image of 512×512 pixels.

In order to create the final code-stream*,* the packets are placed in the different layers according to their priorities. The following steps explain how the proposed method works:

1. The image is first encoded using the same number of precincts in every subband. The resulting packets are distributed across L quality layers. The greater the number of quality layers, better is the resolution scalability. The size of the precinct is chosen such that there are identical number of small regions in each subband. For example, for a 512×512 image with four levels of decomposition, a precinct size of 32×32 for the first level of decomposition may be a good choice.
2. The packets describing a ROI across the different levels of decomposition and layers are then identified. A priority level, P_{ROI}, is assigned to the ROI and a priority distribution is computed using Eq. 1, centered at the ROI. The process is applied to every level of decomposition. Note

that it is possible to define a ROI in none, some or all levels of decomposition. Similarly, the priority level and parameter R can be different at each level of decomposition. When no ROI is defined at any decomposition level, all packets in that level are assumed to have the lowest priority level (*e.g.*, zero).

3. The number of layers is increased to L' (where $L' > L$). A large value of L' results in a smooth enhancement of the background and foreground quality.

4. The priority range, g=[0, max($p_{m,l}(r)$)]=[0, P_{ROI}] is sub-divided into L' equal ranges. Each of the L' layers is assigned one of these small priority ranges starting with the initial layer, l=1. The range of priorities for layer l is given by:

$$g^{(l)} = \left[\frac{\max(p_{m,l}(r))}{L'} \cdot (L' - l), \frac{\max(p_{m,l}(r))}{L'} \cdot (L' - l + 1) \right] \quad 1 \leq l \leq L' \qquad (3)$$

5. Packets are then moved to the layer with the range that includes their level of priority. The main header of the final code-stream is modified to account for the extra layers, and empty packets are created as necessary. Note that only non-empty layers will be placed in the final code-stream.

By using a Gaussian priority distribution, the method assigns a higher priority to the ROI packets and decreases this level of priority smoothly as a function of the distance measured from the center of the ROI. Only those background packets with a significant priority level (*e.g.*, the packets close to the ROI) are included in the layers containing the ROI packets. The higher the shape parameter R, the flatter the priority distribution, resulting in more background information being transmitted along with the ROI packets. Finally, it is important to note that the maximum number of layers in the final code-stream is equal to L'.

3.2 Multiple Regions of Interest

This section describes how to encode multiple ROIs using the proposed method. Let us assume that N different ROIs need to be encoded with different priorities. The set of N priorities can be expressed as:

$$H = \{P_{ROI}^{1}, P_{ROI}^{2}, P_{ROI}^{3}, \ldots, P_{ROI}^{N-1}, P_{ROI}^{N}\} \quad (4)$$

where P_{ROI}^{n} is the priority assigned to the nth ROI.

Note that when dealing with multiple ROIs, the priority level P_{ROI}^{n} assigned to the nth ROI determines the relative importance of the region in the entire image. A higher priority level results in the placement of a ROI in the initial layers of the final bitstream.

The proposed method, as described in Section 3.1, may then be separately performed for each priority P_{ROI} in H. As a result, each packet is assigned N different priority levels according to Eq. 1. The set of priority levels assigned to packet m in layer l may be expressed as:

$$h_{m,l} = \{p_{m,l}^{1}(r), p_{m,l}^{2}(r), p_{m,l}^{3}(r), \ldots, p_{m,l}^{N-1}(r), p_{m,l}^{N}(r)\} \quad (5)$$

The final priority level $p_{m,l}^{0}(r)$ of packet m in layer l is then defined as the maximum priority level in $h_{m,l}$:

$$p_{m,l}^{0} = \max\{h_{m,l}\} \quad (6)$$

Similarly, the priority range g^{0} used to compute the L' equal ranges as described in Section 3.1 is now defined as:

$$g^{0} = [0, \max(H)] \quad (7)$$

where H is given in Eq. 4.

Finally, packets are moved to different layers according to their final priority level $p^0_{m,l}(r)$ and the main header is modified to account for additional layers.

The main advantage of the proposed method is that it can encode multiple ROIs and include background information along with them. The ROIs may be encoded even after the image has been compressed, provided an equal number of precincts are used in every subband. It is possible for each ROI to have its own priority level in the final code-stream. According to the value of the parameter *R*, some background information may be included in the layers containing the ROIs. This results in a better visual quality compared to the MAXSHIFT method, where the ROI has to be completely decoded before improving the quality of the background information.

4. Experimental Results

The performance of the proposed technique has been evaluated with the 512×512 gray level Lena image. Figure 4 shows the reconstructed images for the case of a single ROI at different quality layers. The image was compressed using four levels of decomposition and 10 quality layers. A precinct size of 64×64 was used in all cases for the first decomposition level and the number of quality layers was extended to 20 after applying the proposed method. The shape parameter *R* was varied in each case to change the amount of background included in the layers containing the ROIs. The single ROI was defined in every decomposition level with the same priority; therefore, the priority level was set to the maximum value. Table I shows the parameters assigned to the ROIs at each decomposition level.

Table I. Priority levels and shape parameters for the decomposition levels of images in Fig. 4. The first decomposition level corresponds to the highest frequency subbands.

Decomposition level	Priority level P_{ROI}	*R* parameter		
		Fig. 4(A)	Fig. 4(B)	Fig. 4(C)
1	1	*S*/6	*S*	*S*/3

2	1	$S/6$	$0.7S$	$S/3$
3	1	$S/6$	$S/2$	$S/3$
4	1	$S/6$	$S/4$	$1.5S$

Figure 4(A) shows the case when the ROI receives the same shape parameter for all decomposition levels. In this case, no background information is included along with the ROI packets in the initial layers because the shape parameter R is low enough. Note that although the ROI is defined as an oval area encircling the face, it appears to be larger in Fig. 4(A) for the initial layer because the packets are not small enough for the ROI to be accurately defined. A smaller packet size may result in a more precise ROI definition.

Figures 4(B) and 4(C) show how some background information may be included in the initial layers by incrementing the value of R for the lowest frequency subband. Fig. 4(C) also shows that the quality of the background may be progressively updated by gradually increasing the value of the shape parameter at each decomposition level starting from the low frequency subband. Note that in all cases the quality of the image improves from the center of the ROI to the periphery with progressive decoding of the coded bitstream.

Figure 5 shows the result for the case of multiple ROIs. The 256×256 gray level Couple image was compressed using lossless coding with four levels of decomposition, five quality layers and two ROIs. The regions comprise the male face area and the female face area. The final rearranged bitstream consists of twenty-two quality layers. We assigned different parameters to each region according to Table II. The reconstructed Couple images at different quality layers show how our method allows assigning different priorities to multiple ROIs. The female face area receives a lower priority and therefore its quality improves slower than the male face area, but faster than the background.

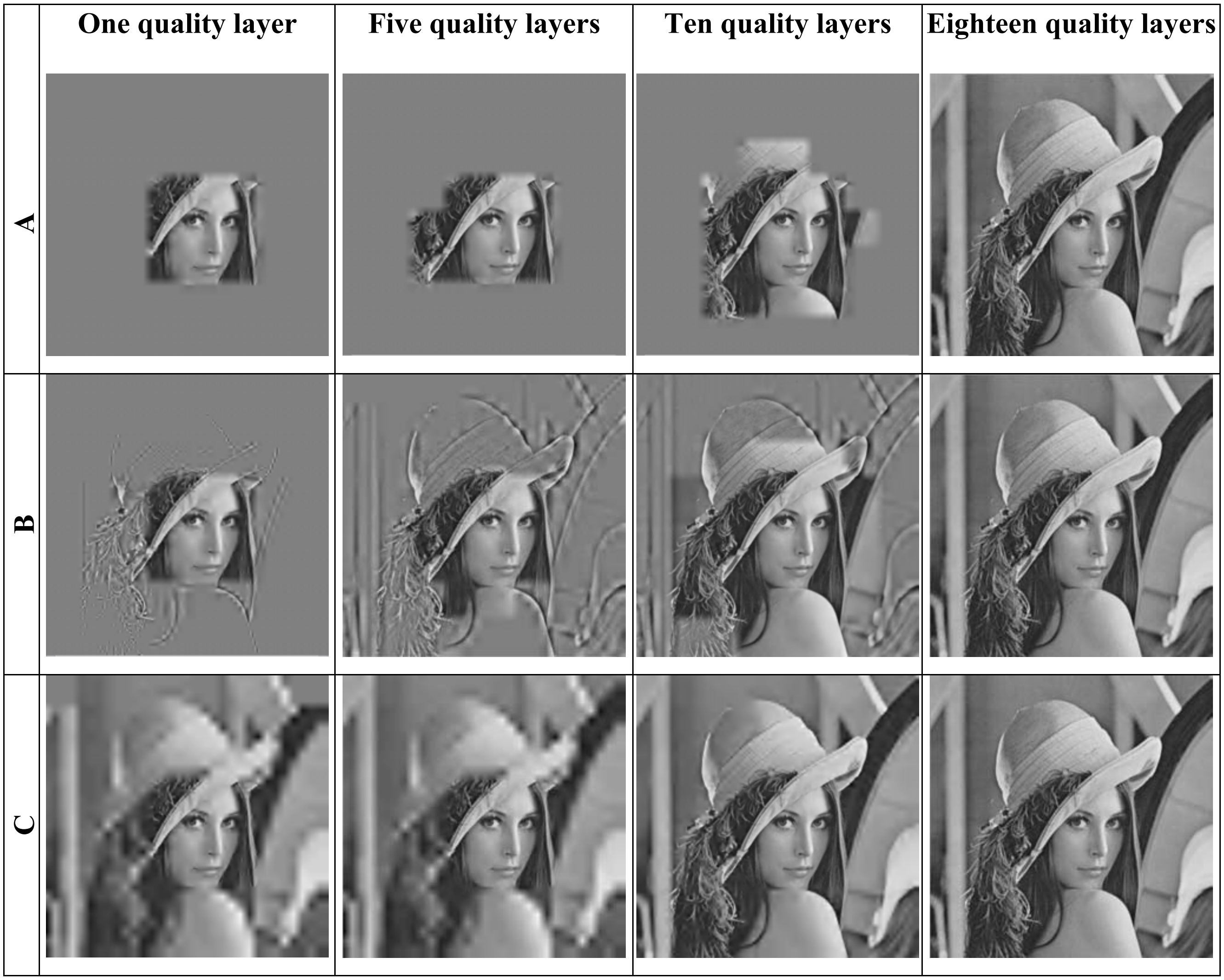

Fig. 4: Lena image reconstructed with a single ROI, representing the face area, using the proposed technique (L=10, L'=20). The initial layers contain A) no background information, B) small amount of background information, and C) more background information. The images in a row show the quality improvement as more layers are decoded.

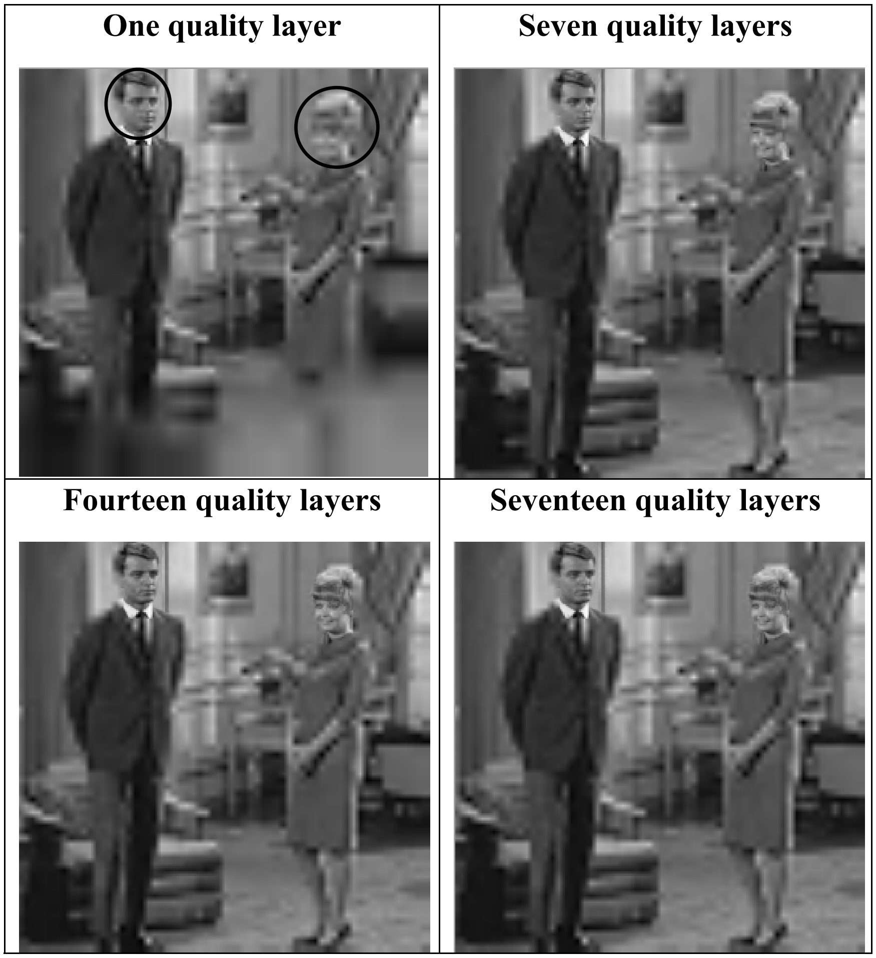

Fig. 5: "Couple" image reconstructed with two ROIs using the proposed technique (*L*=5, *L'*=22). The ROI encircles the male face area and the female face area. The priority and shape parameter *R* are as shown in Table II.

Table II. Priority levels and shape parameters for the four decomposition levels of image in Fig. 5. The first decomposition level corresponds to the highest frequency subbands.

Decomposition level	Priority level P_{ROI}		*R* parameter	
	Male face	Female face	Male face	Female face
1	1	0.8	*S*/16	*S*/16
2	1	0.8	*S*/2	*S*/2
3	1	0.8	1.5*S*	1.5*S*
4	1	0.8	2*S*	2*S*

4.1 Comparisons with related work.

We compared the coding efficiency of the proposed method to the MAXSHIFT method, a packet rearrangement method and compression with no ROI. In all cases, we implemented lossless coding with five decomposition levels and ten quality layers. We used pyramid decomposition (as described in Section 2, with a precinct size of 128×128 for the first decomposition level) in our method and the packet rearrangement method. For the case of MAXSHIFT coding and compression with no ROI, a precinct size of 128×128 was fixed for all decomposition levels. The packet rearrangement method resulted in sixteen quality layers after shifting up the ROI packets. Our method extended the final bit-stream to twenty quality layers (L'=20). The ROI comprises the face area.

Figure 6 shows the results of the compressed images at 0.025, 0.05, 0.0625 and 0.125. We set a shift value of 11 in the MAXSHIFT method and the lowest resolution subband was included in the ROI. In our method, all five decomposition levels received the same priority value. However, the lowest frequency resolution subbands were assigned larger shape parameters while the remaining decomposition levels were assigned the same lower shape parameter. Details about the priority values for the different decomposition level are summarized in Table III.

Table III. Priority levels and *R* parameters for the five decomposition levels of image in Fig. 6(D). The first decomposition level corresponds to the highest frequency subbands.

Decomposition level	Priority level P_{ROI}	*R* parameter
1	1	$S/4$
2	1	$S/4$
3	1	$S/4$
4	1	$1.5S$
5	1	$2S$

A	B	C	D

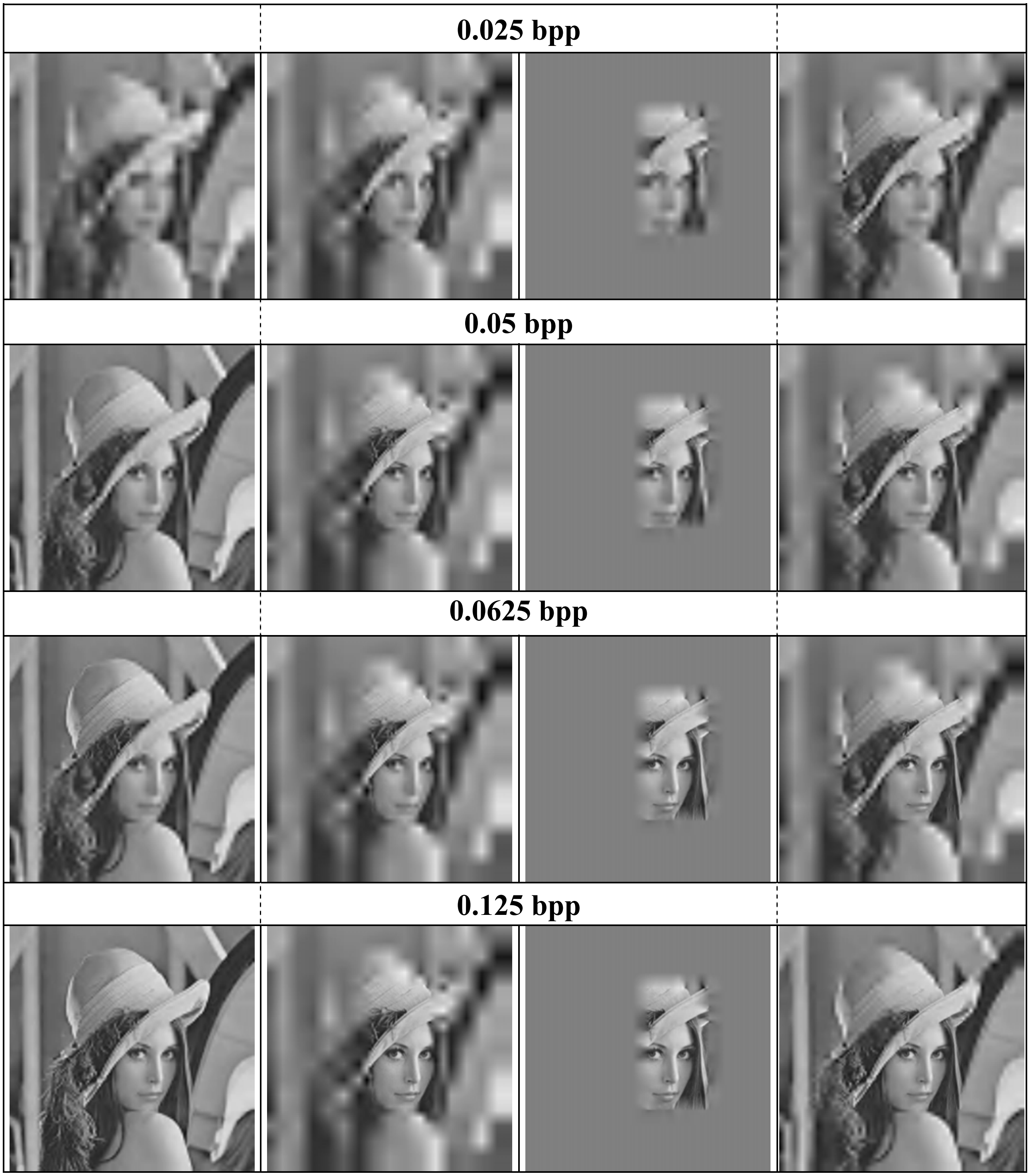

Fig. 6: Lena image encoded by different ROI coding techniques where the ROI comprises the face area. A) no ROI coding, B) MAXSHIFT method [1], C) a packet rearrangement method [11] and D) the proposed method (L=10, L'=20). The image was compressed using lossless coding with five levels of decomposition and ten quality layers.

Simulation results show an improvement on the visual quality of the reconstructed images. Although the MAXSHIFT method allows the inclusion of subbands with the ROI information, the ROI must still be first decoded before the background quality starts improving. On the other hand, the proposed method is able to decode some background information along with the ROI. Similarly, the packet rearrangement method decodes the packets describing the ROI first before any packet containing background coefficients.

At low bit rates (e.g. 0.0625 bpp), our method results in a better visual quality compared to the case of compression with no ROI. In applications with bandwidth constraints, the proposed method may be used in lieu of regular compression with no ROI.

It has been reported [8] that for the case of lossless compression, the MAXSHIFT method increases the bit-rate by 1-8%, compared to lossless coding without ROI. The simulation results presented in Fig. 6 increase the bit-rate by 5.2% using the MAXSHIFT method, and 6.8% using the method in [11] and using our method, compared to lossless compression without ROI. In other words, the increase in bitrate in the proposed technique is similar to that of the MAXSHIFT method. But the proposed method provides the flexibility of multiple priority ROI encoding even after the image has been compressed as well as the inclusion of partial background information. This may be useful in database and low bandwidth applications.

5. Conclusions

In this paper we proposed a technique to encode multiple regions of interest for JPEG2000 and vary the details smoothly in peripheral regions following a prioritization method. Experimental results and comparison with the current MAXSHIFT method and some related work demonstrate the advantage of smoothly varying quality within an image. The proposed method allows specifying the relative importance of the background and ROI data in each decomposition level. Moreover, when there are multiple regions of interest in the same image, a region can have its own priority level and therefore importance during the encoding process. This is useful when the background needs to be updated differently in various applications.

Acknowledgement

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