

On Region of Interest Coding for Wireless Imaging

Muhammad Imran Iqbal and Hans-Jürgen Zepernick

Blekinge Institute of Technology

PO Box 520, SE-372 25 Ronneby, Sweden

E-mail: {muhammad.imran.iqbal, hans-jurgen.zepernick}@bth.se

Abstract—Numerous studies in the fields of human vision and electronic imaging have revealed that the human visual system (HVS) tends to focus on a few preferred areas for given typical images/scenes. Subjective experiments have also shown a strong correlation for these preferred areas among the involved test subjects provided that the same context is viewed. In light of the limited available and expensive resources in technical systems such as mobile multimedia systems, it would therefore be favorable to explore findings about the operation of the HVS in the design of technical communication systems. This paper aims at stimulating such HVS driven approaches in the context of preferential image coding; the region of interest (ROI) coding and its potential application in wireless imaging. In particular, we will elaborate on the general concepts of ROI coding, propose a framework for ROI coding for wireless imaging, review ROI identification mechanisms, and discuss ROI support by non-standardized techniques and ROI support in the JPEG2000 standard. As this paper is of conceptual nature, the work will be consolidated in a classification of contemporary ROI coding techniques including a discussion of their advantages and disadvantages. As a consequence, a number of application areas of ROI coding are identified with the major focus given to the field of wireless imaging.

I. INTRODUCTION

The rapid growth of the third and development of future generation radio communication technologies has led to a significant increase in the demand for multimedia communications involving image and video services. However, the hostile nature of the radio channel, which is time-varying and susceptible to multipath fading, makes the deployment of such multimedia services much more challenging as would be the case in a wired system. Limitations are also imposed on these services due to the constraints on the available spectrum resources. Especially, image and video services require a substantial amount of bandwidth compared to speech services, which in turn results in increased terminal power consumption and potentially reduced range. Radio resource management (RRM) has therefore gained particular attention in the design of modern mobile radio systems where high bandwidth demanding services and mixed traffic characteristics pose key challenges on the resource management. Efficient utilization of bandwidth in digital imaging and video services is achieved by the use of various compression techniques. In this paper, we are interested in preferential image coding; the region of interest (ROI) coding and its potential application in wireless imaging.

The concept of ROI coding is motivated by studies in the fields of human vision and electronic imaging, which have revealed that the human visual system (HVS) tends to

focus on a few preferred areas when viewing an image [1]. Factors that have been identified to influence visual attention include contrast [2], shape of objects [3], size of objects [4], color [5], location [6], and context of a given image. It has also been shown that people in an image attract immediate attention by the human observer [7]. Furthermore, it has been observed that objects in the foreground of an image are given preferable attention over objects in the background of an image. As such, it is natural to exploit characteristics of the HVS, especially ROI coding, in the design of technical systems. So far, applications of ROI coding have mainly been focusing on source compression techniques, image quality evaluation, image databases, and strategies for advertising. However, the use of ROI coding for wireless imaging in mobile radio systems or wireless local area networks (WLAN) appears to mainly concentrate in combination with approaches that deploy unequal error protection [8]–[12]. On the other hand, more general approaches of using ROI coding with RRM can be expected to perform favorable in terms of overall system capacity over traditional RRM techniques.

Moreover, ROI coding potentially allows specified regions of interest to receive preferential treatment at compression-time whereby these regions can be compressed at a higher quality than the rest of the image. This allows further gains in compression efficiency to be achieved at the expense of the quality of the less important background image information while preserving the quality of the more important ROI image information. Thus, ROI coding is applicable in a radio environment where the aim is to efficiently utilize and manage the scarce radio resources whilst at the same time guarantee a satisfactory end-user quality of service (QoS). As a consequence of the high compression efficiency of ROI coding, the resulting data streams are highly susceptible to the effects of transmission errors. Even though a number of error resilience tools have been incorporated with certain standards, these do not guarantee that the received data is free of errors. Thus, it is recommended to use advanced error control coding along with ROI coded multimedia services in mobile radio applications to minimize the effect of transmission errors.

In view of the above, this paper aims at stimulating HVS driven signal processing approaches in terms of preferential image coding; the ROI coding and its potential application in wireless imaging. In particular, we elaborate on the general concepts of ROI coding, present ROI definitions and identification mechanisms, and discuss ROI support by non-standard techniques and as suggested in the JPEG2000 standard. This

will be consolidated in a classification of contemporary ROI coding techniques including a discussion about their advantages and disadvantages.

This paper is organized as follows. Section II describes general concepts of ROI coding. In Section III, a framework for use of ROI coding in wireless imaging is presented. Subsequently, Section IV elaborates on approaches that support ROI identification as this would be a crucial function in exploiting ROI coding in applications such as RRM in mobile multimedia systems. In Section V, we provide a survey of realizations of ROI coding techniques ranging from non-standardized approaches to JPEG2000 and research focusing on improving JPEG2000. In Section VI, advantages of ROI coding in different applications are presented. Section VII concludes the paper.

II. GENERAL CONCEPTS OF ROI CODING

The sizes of digital images and videos have been increasing continuously in recent years, which in turn has increased storage demands as well as bandwidth requirements for their transmission. Source compression is the most common technique used to cope with these resource problems. These techniques may take advantage of different features of the HVS. For example, the HVS has been shown to be more sensitive to the luminance (brightness) of an image/scene and less sensitive to its chrominance (color) information. This has led to preferential treatment of luminance over chrominance during compression, i.e. more compression is imposed on chrominance while less compression is applied to the luminance. As far as imaging is concerned, the Joint Photographic Experts Group (JPEG) and JPEG2000 standards have used these types of HVS characteristics.

A. Region of Interest

While luminance and other features are commonly applied to whole images, additional compression gains can be obtained by exploring spacial sensitivity of the HVS. Studies have shown that the HVS is more sensitive to certain areas than the rest of an image. For example, for the image shown in Fig. 1, the majority of human observers will give preferential attention to the two helicopters while the remainder of the image will hardly attract the observers interest. In general, the areas or regions of the image which attract the HVS attention more are called ROIs while the rest of the image is called background. In literature, different terms are used for ROI such as “preferential area”, “zone of interest”, “focus of attention”, “object of interest” [13] and “targets” [14]. Keeping terminology with the majority of publications, we will use the term ROI. In this sense, ROI coding refers to image and video coding that gives preferential treatment to ROIs.

Apparently, ROIs can have arbitrary shapes and sizes and can be different for different observers and for different image classes. Furthermore, ROIs can be static or dynamic. The static or fixed ROIs are those defined at encoding time and cannot be changed later on while the dynamic ROIs are those defined and/or changed interactively by the users during the



Fig. 1. Image with helicopters as ROIs [58].

progressive transmission of images. In view of defining an ROI in a technical system, different shapes may be considered for segmentation the image/scene content into ROI and background such as circle, rectangle, elliptical segmentation, or even arbitrary shapes.

B. Image Classes and Region of Interest

As far as implementation of ROI concepts in technical systems is concerned, a classification of image types with reference to their source of origin and/or application may be useful. In the sequel, some of the prominent image classes along with the related notion of ROI that is typically associated with these classes are identified and explained.

1) *Digital photographs*: This class of images is produced using a digital camera such as a pocket camera, professional camera or a mobile handheld equipped with a digital camera. Accordingly, the range of content may vary from portraits of people, photos of groups of people, architectural buildings and landmarks, and landscapes. As such, an ROI is naturally related to the type of content, for example, faces of people in a group.

2) *Satellite images and aerial photographs*: Satellite images include images of the Earth or other planets taken from satellites. Aerial photographs are images of the ground taken from the air, for example, using a helicopter or aircraft. These images can have a variety of ROIs depending on the application. Typical examples include buildings, tanks, and planes on military bases.

3) *Medical images*: This class refers to images of the human body or parts of it, taken for either diagnostic and examination purposes for different diseases or for study purposes. Endoscopic images, thermographic images, and retina fundus images are examples of medical images. ROI in this class of images can vary depending upon many factors including the disease under consideration.

4) *Document images*: These are images of different documents generated by scanning the printed documents. These documents can be of any type used in residential homes and offices. The ROIs in this class of images may be printed text, handwritten text, and stamps etc.

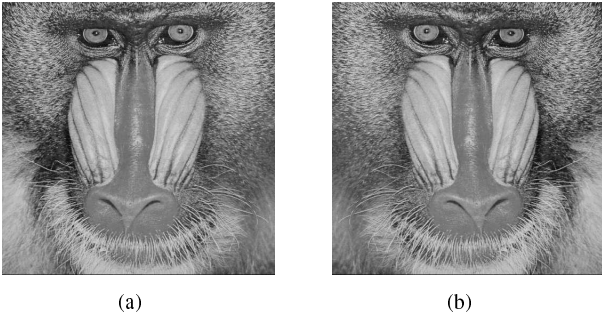


Fig. 2. Sample image “Mandrill”: (a) Original image giving PSNR= 58.48 dB and HIQM= 24.2, (b) Mirrored image giving PSNR= 14.59 dB and HIQM= 24.2 [16].

C. Quality assessment of ROI coding schemes

Quality assessment of particular source compression or ROI coding schemes are often based on using measures such as peak signal-to-noise ratio (PSNR) and mean squared error (MSE). However, both measures are fidelity metrics that relate to pixel-by-pixel comparisons, they not necessarily correlate well with human perception [17], [18]. In order to better correlate the performance of image or video processing approaches to the actual quality as perceived by humans, it is suggested to deploy measures that incorporate aspects of the HVS. We will refer to these measures as objective perceptual image quality measures when they are based on algorithms that mimic characteristics of the HVS and subjective perceptual image quality measures when they are deduced from subjective experiments. In particular with ROI coding, which itself is based on characteristics of the HVS, it would be natural to replace fidelity metrics with objective perceptual quality metrics.

To further motivate this perceptual-based image quality assessment, Fig. 2 presents the example of sample image “Mandrill” showing (a) the original image and (b) the same image but mirrored with respect to a vertical axis placed at the center of the horizontal axis. Clearly, PSNR cannot cope with this type of operation as pixels would not line up between unprocessed and mirrored image. In this example, it would suggest a significant reduction in image quality indicated by the decrease of PSNR from 58.48 dB to 14.59 dB. In contrast, perceptual-based quality metrics such as the hybrid image quality metric (HIQM) [15], [16] can be expected to better align with quality as perceived by humans. For the example shown in Fig. 2, HIQM actual gives the same value of 24.2 for both the original image and the mirrored image as the viewing experience is the same.

In recent years, a number of metrics that are based on image features rather than image fidelity have been proposed such as the following measures:

1) *Reduced-reference image quality assessment*: The reduced-reference image quality assessment (RRIQA) technique has been proposed in [19]. It is based on the natural image statistic model in the wavelet domain. In particular, it calculates the distortion between received and transmitted image using the Kullback-Leibler distance between the

probability density functions with respect to each subband in the transmitted and received image. The attribute of being reduced-reference relates to the fact that this metric does not rely on the availability of the original image but requires only information of some image properties.

2) *Measure of structural similarity*: A full-reference metric has been reported in [20] requiring availability of the original image for its operation as is the case with PSNR. Although the applicability of this metric for wireless imaging is limited due to its full-reference nature, it may serve as a benchmark test for the reduced-reference metrics. This metric is based on the degradation of structural information. Its outcome is a measure of structural similarity (SSIM) between the reference and the distorted image.

3) *Hybrid image quality metric*: The reduced-reference hybrid image quality metric (HIQM) as proposed in [15] focuses on extracting different features of an image. Namely, it considers blocking, blur, image activity, and intensity masking each described by its own metric. The contribution of each feature to the overall image quality is calculated as weighted sum of the involved feature metrics. It is noted that these weights were extracted by statistical analysis of subjective experiments. The HIQM value is calculated for both the original image and distorted image, thus, quality degradation is indicated simply by their difference. Due to the limited bandwidth of the radio channel, HIQM seems to be well suited as the overall perceptual quality measure can be represented by a single number. This number can be concatenated with the data stream of each transmitted image without creating too much overhead.

4) *Normalized hybrid image quality metric*: Although HIQM uses feature value normalization, namely relevance normalization, an extreme value normalization would be more convenient in view of comparisons with other distance measures such as the L_p -norm. The related NHIQM approach has been presented in [21], [22]. The normalization ensures that the weights of the different feature measures fall into the same range. It is also suggested in this work to optionally clip the normalized feature values that are actually calculated in a real-time wireless imaging application to fall in the interval $[0, 1]$. For example, severe signal fading due to multipath propagation could result in significant image impairments at certain times such that the user-perceived quality is in a region where the HVS cannot differentiate anymore among quality degradation levels.

III. FRAMEWORK OF ROI CODING FOR WIRELESS IMAGING

Having motivated a HVS driven system design paradigm, key functionalities with respect to wireless imaging are identified in this section. Fig. 3 illustrates the associated conceptual framework of ROI coding for wireless imaging.

At the transmitting end, source encoding and channel encoding represent the unique processing blocks in this framework that explore characteristics of the HVS for efficient image compression and enable reliable transmission of the

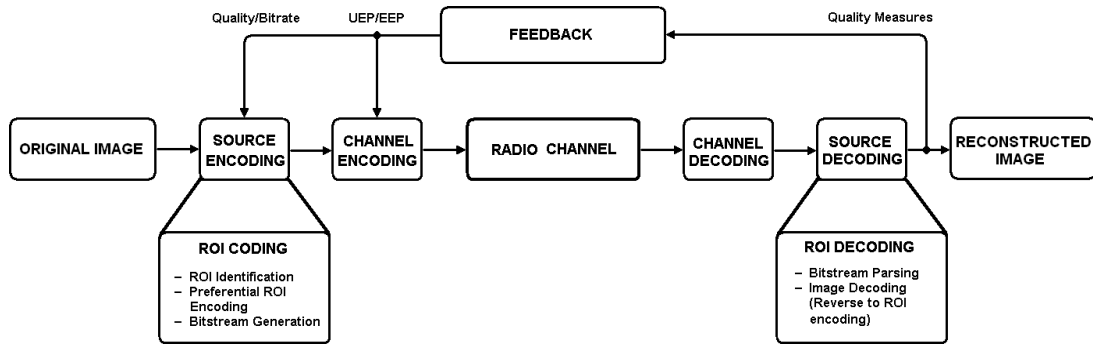


Fig. 3. A framework for ROI coded image transmission over error prone radio channel.

compressed image data over the radio channel, respectively. In contrast to the conventional image compression approaches of using spatial redundancy and psychovisual redundancy for lossy compression, we suggest to also deploy ROI coding for the preferential areas. This allows for another degree of freedom in the design of an efficient overall system supporting the following mechanisms among others:

- High quality source encoding of ROIs over background to reduce bandwidth and storage requirements.
- Controlling of ROI and background compression rates subject to given QoS constraints. In other words, bit rate may be traded off with QoS and vice versa.
- Increasing the tool set for producing a desired bit rate budget other than by the conventional bits per pixel (bpp) considerations.
- Offering additional source significant information that can be used to advice more efficient channel coding schemes for source compressed image data other than preferential treatment of headers over payload.
- Increasing the options for explicit link adaptation in terms of ROI versus background compression to accompany power control, adaptive modulation, and adaptive channel coding.
- Enabling to produce HVS based key performance indicators that may be explored for charging models.

The conceptual components of ROI coding include automatic ROI identification as a first processing step and the subsequent encoding of the ROI area or shape. Owing the fact that the contemporary image coding techniques use some form of linear block transform, ROI representation may include a transform of the ROI shape into an ROI mask with respect to the transform coefficients. The subsequent preferential ROI encoding may then be combined with the usual image compression steps such as quantization, linear block transform, encoding, and bitstream generation.

The bitstream released by the ROI encoder constitutes the input to the channel encoder. In addition to conventional bitstream compositions such as headers, markers, and payload, the additional source significant information given by the ROIs calls for replacing equal error protection (EEP) by unequal error protection (UEP) or incremental redundancy concepts. This increases the flexibility in adaptation of channel coding

depending on the source compressed image data and the progression of the transmission conditions on the radio channel over time including the following options:

- Preferential channel encoding of header and ROI information over other components of the bitstream.
- Adaptation between EEP and UEP depending on the channel conditions.
- Support of explicit link adaption by providing a range of UEP codes.
- Implicit link adaption with focus on the ROIs using error detection along with automatic repeat request (ARQ) and soft-combining techniques.

At the receiving end, the reverse operations to the ROI encoding and channel encoding need to be performed, given by the related channel decoding and ROI decoding algorithms. The major challenges at the receiver, however, may be imposed by the calculation of suitable quality measures. As far as mobile multimedia systems in general and wireless imaging in particular is concerned, approaches that support objective perceptual quality assessment have gained increased attention just recently. Hence, especially no-reference or reduced-reference objective perceptual quality metrics are still needed as the original image content would not be available at the receiver. These metrics may then be fed back to the transmitter to be used for link adaptation purposes.

It shall be noted that the proposed framework of ROI coding for wireless imaging may scale towards wireless video services. However, spatial-temporal redundancy would need to be considered in this case requiring to process visual information across a sequence of frames.

IV. ROI IDENTIFICATION

Given the important role of ROI identification within the framework of ROI coding in wireless imaging as shown in Fig. 3, some of the related identification methods are described in this section.

The importance of image content to viewers varies largely with the content itself and the class of image under consideration. This variation makes the task of automatic identification of ROIs more difficult and it becomes challenging for an algorithm to identify ROIs such that they correlate well with the ones identified by the human observer. To increase this

correlation, human perception and visual attention (VA) should be taken into account when developing algorithms to identify ROIs. Different approaches and algorithms for automatic ROIs identification and extraction can be found in literature [13], [23]–[29], some of which are discussed in the sequel. It may be concluded from this overview that the area of ROI identification constitutes a field which needs further work on algorithms supporting efficient wireless imaging. For example, although two methods for ROI coding are defined in JPEG2000 [30]–[32], no procedures are given for automatic ROI identification.

A. Visual Attention Based ROI Identification

An image coding scheme in conjunction with automatic ROI identification is presented in [33]. In this work, first ROIs are identified using an algorithm [23], [24] that simulates VA. After refining these ROIs [34], the image is finally encoded following JPEG2000 Part 1.

The VA simulation algorithm is based on the hypothesis that visual attention is, to a certain extent, dependent upon the disparities between neighborhoods in the image. Although, the results described in [23], [24] lend some support to the conjecture, more experiments are needed to further clarify this hypothesis and the performance of the algorithm.

B. Knowledge Based ROI Identification

A knowledge based hierarchical ROI detection method is proposed in [26]. This method comprises of three steps as will be explained in the following paragraphs.

In the first step, object grouping is performed based on their optical characteristics and then within each group proper resolutions are assigned to objects of similar sizes.

In the next step, ROIs are detected for a given resolution commencing with extracting different image features based on color, intensity, edges, and others. Then, some morphological operations are performed to split overlapping objects and to merge different regions to form a complete description of one object in one region. Finally, the detected ROIs are verified on bases of supervisory information.

In the last step, redundancy that may have been introduced in the preceding ROI detection step due to downsampled versions of the input image is removed by pixel grouping. The small candidate ROIs are then connected to form bigger ROI bases on the existing knowledge of ROI sizes. A probability based voting method is used for proper integration.

The advantages of the method include its ability to detect ROIs of arbitrary shapes, applicability to images containing connected or broken objects, insensitivity to contrast levels, and robustness to noise. This approach is useful in the situations where some of the information about the ROIs is available.

C. ROI Identification for Document Images

An approach for ROI detection for the financial document images is presented in [25]. In this method, the ROIs are defined and classified into three types; filled information (FI), stamps and seals (SS), and handwritings (HW). All three

types of ROIs are detected differently. For FI ROIs, first, the document classification is done based on matching the input document with a library of predefined document models to find the best match. After the input document is classified, the exact locations of FI ROIs are known based on the document model of that category. The class of SS ROIs are detected using connected component analysis based on color and shape information and the HW ROIs are located by handwriting identification using an incremental fisher linear discriminant classifier. After merging of all the three types of ROIs, a final ROI mask is constructed and finally the document is encoded with the JPEG2000 encoder using the generated ROI mask.

The method works well in the detection of ROIs for financial documents. After some modifications, the method may be used for ROI detection in other types of document images but it cannot be used for other image classes.

V. ROI CODING TECHNIQUES

In this section, we consider some typical non-standard ROI coding techniques that have been proposed as well as ROI coding in the JPEG2000 standard along with amendments to this standard. This will reveal the tool set and existing approaches that may be deployed in wireless imaging applications.

A. Non-Standard Techniques

Many different schemes for preferential image coding have been proposed in the literature of which a representative selection shall be presented in the following.

1) *ROI coding scheme for digital photography*: A progressive ROI image coding technique based on improved zerotree wavelet (IEZW) algorithm [36] has been proposed in [37]. After applying a wavelet transform, the algorithm encodes the wavelet coefficients in three stages as follows. Firstly, only the ROI coefficients for N successive approximation quantization (SAQ) iterations are encoded. Then, the coefficients related to the background region are encoded for the next N iterations. Finally, encoding is performed on all wavelet coefficients of the image until the desired bit rate is achieved. The quality of the ROI increases with the number N of SAQ iterations. The location information of the ROI is encoded using the coordinate data compression (CDC) method [38] in the lowest frequency band. The simulation results presented in [37] indicate that, for low bit rates, this algorithm performs better for the ROI compared to conventional progressive coding in terms of PSNR. For high bit rates, it gives the same PSNR for the whole image as the conventional approaches.

Regarding applications for wireless imaging, progressive ROI image coding is attractive, for example, in database searches. It allows to quickly identify the content of an image using a small area that is given by the ROI and proceed to the next image if the viewed image is not of interest. In this way, transmission capacity and service costs can be conserved as only a small amount of bits need to be transmitted over the radio link. Progressive ROI image coding can also be used to adopt to a given bit rate budget by trading off the quality of ROI and background such that a given quality measure is fulfilled.

2) ROI coding scheme for satellite and aerial images:

Another example of ROI coding can be found in [14] aiming at very low bit rates. This scheme advocates an object-based wavelet technique for encoding the ROI. In the first step, contour masks are generated for all ROIs indicating the shapes of the targets. For this purpose, the automatic target recognition (ATR) system described in [39] is used. To reduce the size of information, these contour masks are downsampled and then coded using a differential chain code (DCC). The significant mask in the wavelet domain is constructed by using the upsampled versions of the downsampled masks. In this step, the image is decomposed into 22 subbands using a 5-3 biorthogonal 2-D discrete wavelet transform (DWT). Then, two normalized sequences are produced for each subband; one consisting of wavelet coefficients related to the ROI and the other to the coefficients of the background. In the next step, these normalized subband coefficients are encoded using a fixed rate trellis code quantizer (TCQ) [14]. Finally, the bits are allocated optimally in the MSE sense as suggested in [40].

In view of wireless imaging, one advantage of the above algorithm and similar schemes is its ability to scale the quality of the regions of interest. In addition, the potential of operating with very low bit rates, such as related to compression ratios of 320:1, would be a beneficial feature for wireless applications.

3) ROI coding scheme for medical images: A detailed survey on ROI coding for the class of medical images can be found in [41]. In the sequel, we will discuss the method presented in [42] as an example of this class.

In particular, the image compression algorithm proposed in [42] aims at reducing storage data with lossless ROI but lossy background compression. The algorithm is based on the hierarchical subband decomposition called S+P transform (Sequential transform + Prediction) [43], which is an integer wavelet transform. The algorithm is organized in the following steps. Firstly, normalization of coefficients is done after taking S+P transform. Then, the ROI mask is calculated following the same steps as the forward S+P transform. Subsequently, a progressive quantization of the calculated coefficients is performed using a modified version of the set partitioning in hierarchical trees (SPIHT) algorithm [44]. The results are kept in order of importance. Finally, the symbol stream is encoded using entropy encoder.

B. ROI Coding in the JPEG2000 Standard

As far as imaging is concerned, JPEG2000 is the latest version of a series of standards for image compression developed by the Joint Photographic Experts Group (JPEG). JPEG2000 is thought to provide superior performance and overcome limitations of the existing JPEG image compression standard, which suffers from blocking and ringing artifacts, especially at high compression rates. The rich feature set of JPEG2000 include superior compression performance, multiple resolution representation, bitstream organization mechanisms to facilitate progressive decoding by quality and/or by spatial resolution, single architecture for both lossless and lossy compression, ROI coding and error resilience tools. Conceptually,

JPEG2000 is a wavelet-based coding system drawing mainly on ideas of embedded block-based coding with optimized truncation (EBCOT). In brief, wavelet coefficients are calculated to reveal the redundancy contained in the image content, the resulting coefficients are quantized and subsequently entropy encoded. The information in the wavelet domain is organized within bitplanes with each bitplane relating to a particular compression rate and image quality with respect to the reconstruction. While the lower bitplanes relate to large compression rates and lowest quality, the higher bitplanes relate to small compression rates and highest quality. The bitstream released by the encoder is organized accordingly, commencing with the highest bitplane followed by the underlying bitplanes.

Preferential encoding of the ROI is one of the unique features of JPEG2000 [30], [45] that makes it suitable for applications such as imaging over error prone channels. In the sequel, the two methods for ROI coding defined in the standard, general scaling based (GSB) and maximum shift (MAXShift) method [30]–[32], are presented.

1) *General scaling based method*: In GSB [30], [32] the quantized wavelet coefficients associated with the ROI are scaled up by a given value, so that the corresponding bits are placed in higher bitplanes compared to the background as shown in Fig. 4. For this purpose, the ROI shape needs to be defined, encoded, and included in the bitstream. This shape is represented by the so-called ROI mask, a bitplane indicating those quantized transform coefficients that are sufficient for the decoder to reconstruct the ROI. In order to reduce processing complexity and overhead, only rectangular and elliptical ROI shapes are allowed.

Advantages of GSB include simple means of adjusting the preferential treatment of ROI compared to background by choosing the scaling value and the potential of defining multiple ROIs with different priorities.

2) *Maximum shift method*: In MAXShift, the quantized wavelet coefficients associated with the ROI are scaled up by an amount such that ROI and background coefficient bitplanes do not overlap. In this way, the ROI coefficients are elevated to bitplanes above those for the background coefficients as shown in Fig. 4. As a consequence, ROI information is placed first in the bitstream and hence no background can be processed before the whole ROI is decoded. Clearly, all coefficients above a distinct bitplane belonging to the ROI while those coefficients below that bitplane relate to the background. As a result, neither overhead nor complexity has to be spent for ROI mask features.

The advantages of MAXShift include the fact that no ROI shape needs to be encoded and transmitted, which reduces bit rate and processing complexity at encoder and decoder. Also, arbitrary ROI shapes are supported and different subbands can be treated differently [32].

C. Amendments to ROI coding in JPEG2000

Despite all benefits, JPEG2000 has certain limitations. MAXShift has limitations including those listed below:

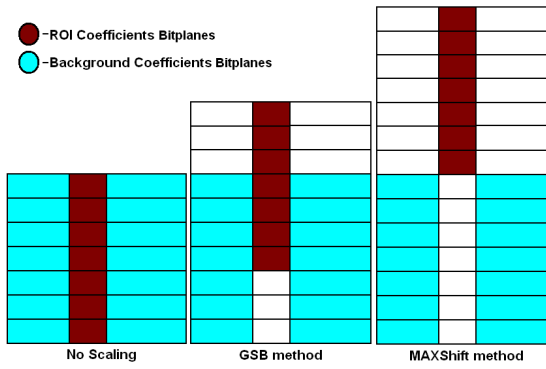


Fig. 4. ROI coding in JPEG2000 [47], [51].

- Relative importance between ROIs and background cannot be controlled.
- No more than one ROI out of several ROIs can be encoded with different priority.
- No background information can be processed until all ROI coefficients are fully decoded.
- Large bit shifts for ROI coding may cause bit overflows.

GSB overcomes some of the above listed limitations but has its own shortcomings, such as those listed below:

- ROI shape information needs to be encoded, which increases overhead and complexity.
- Arbitrary shaped ROIs other than rectangular and elliptical cannot be encoded with GSB.

Suggestions have been given to overcome these limitations and to improve ROI coding in the existing JPEG2000 standard. These approaches fall into two main categories i.e. coefficient scaling based methods and packet rearrangement based methods. Some of the approaches covering above mentioned categories are demonstrated below and a comparison is made at the end of this section.

1) *MAXShift-like method*: An improvement for MAXShift and GSB is proposed in [46]. Suggestions are given on how to choose the optimal scaling value for MAXShift and the padding of the extra bits appearing during the shift operation. Also a new ROI coding algorithm called MAXShift-like algorithm is presented. The MAXShift-like algorithm uses a smaller scaling value compared to MAXShift.

The MAXShift-like algorithm reduces the bit rate compared to MAXShift at the cost of a slightly decrease in ROI and background qualities. MAXShift-like improves over GSB by removing the need for encoding and transmitting ROI shape information. The generated codestreams can be handled by any JPEG2000 decoder.

2) *Bitplane-by-bitplane shift/Generalized bitplane-by-bitplane shift method*: A bitplane-by-bitplane shift (BbBShift) based ROI coding method is presented in [47]. Instead of scaling all the bitplanes of ROI coefficients with the same amount as in JPEG2000, the scaling is done differently for different bitplanes. The resulting bitplanes after scaling can be divided into three categories; the first and most significant category contains s_1 most significant bits (MSBs)

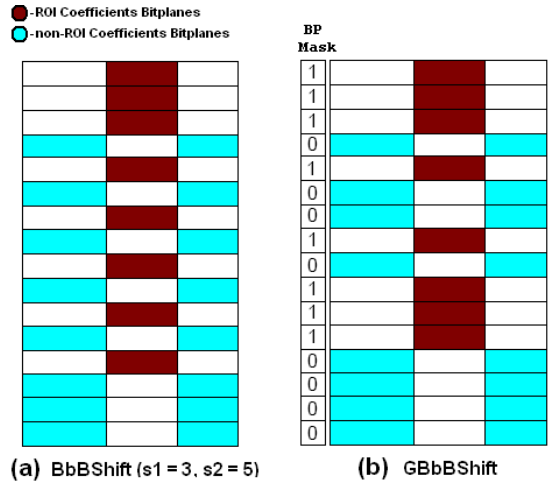


Fig. 5. ROI coding using BbBShift and GBbBShift as in [47] [48].

of ROI coefficients, the second category comprises of the subsequent $2s_2$ bitplanes containing s_2 MSBs of background and unassigned s_2 bits of ROI coefficients alternately, while the third category contains the remaining least significant bitplanes of the background. Here the sum $s_1 + s_2$ is equal to the largest number of bitplanes for ROI coefficients. This bit assignment scheme is illustrated in Fig. 5a.

The so-called generalized bitplane-by-bitplane shift (GBbBShift) method proposed in [48] expands on BbBShift. Specifically, after arbitrary non-overlapping ROI and background bitplane shifting, a binary bitplane (BP) mask is created that locates the shifted ROI and background bitplanes. Each bit of the BP mask represents one bitplane as shown in Fig. 5b. The BP mask is encoded and transmitted which assists the decoder in shifting the bitplanes back to their original order.

The BbBShift/GBbBShift methods allow early decoding of significant bitplanes of the background once sufficient ROI quality is achieved. Clearly, more flexible control of ROI and background is supported by BbBShift/GBbBShift which would operate favorable within the considered framework for wireless imaging. Moreover, the ROI shape does not to be encoded while arbitrary scaling values are allowed.

3) *Most/partial significant bitplane shift method*: In the most significant bitplane shift (MSBShift) method [49], also known as partial significant bitplane shift (PSBShift) [50], only the s most significant ROI bitplanes are shifted keeping the other bitplanes at their original places (Fig. 6).

The advantages of the method include that relative importance of ROI and background can be adjusted, multiple ROIs can be handled using different priorities, and arbitrary shaped ROIs can be handled without shape encoding.

4) *Hybrid bitplane shift method*: Another ROI coding method called hybrid bitplane shift (HBShift) method is presented in [51], which is actually a combination of the BbBShift and MSBShift methods. Here, the coefficient bitplanes are divided into three parts; the most significant bitplanes of ROI (MSR), the general significant bitplanes of ROI and BG (GSRB), and the least significant bitplanes of ROI and BG

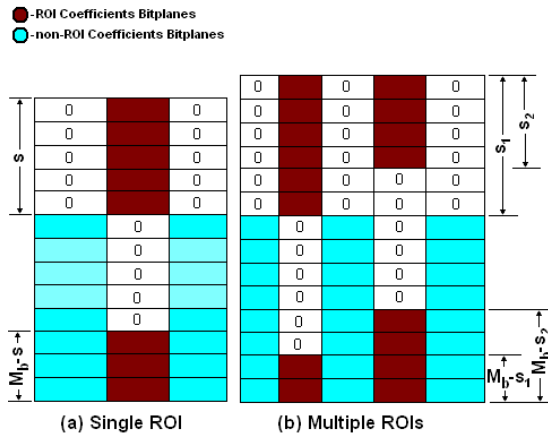


Fig. 6. ROI coding using MSBShift/PSBShift.

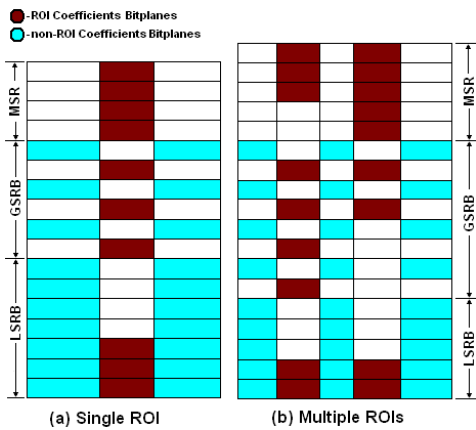


Fig. 7. ROI coding using HBShift.

(LSRB). The MSR and GSRB bitplanes are shifted in a way similar to the BbBShift method while the encoding of LSRB bitplanes is done without any shift like in MSBShift method (see Fig. 7).

The advantages of the method include; arbitrary ROI shapes can be encoded and for this purpose no ROI shape information is needed to be encoded and transmitted, the relative importance of ROI and background can be controlled and multiple ROIs can be encoded with different priorities.

5) *Demand driven packet rearrangement method*: A dynamic ROI coding scheme based on the rearrangement of the packets in the encoded JPEG2000 data stream is proposed in [52]. The main idea is to place packets associated with ROI first and those belonging to background afterwards in the data stream so that the ROI can be received and decoded before the background. The packets linked to the user-defined ROIs are selected after the computation of associated precincts. The remaining packets in the data stream are rearranged in such a way that these selected packets are sent prior to the non-demanded packets, now considered as background for the rest of the transmission or until a change in the user demands occurs.

The demand driven packet rearrangement method allows for

dynamic ROI encoding and supports regular polygonal-shaped ROIs.

6) *Multi-level-priority based packet rearrangement method*: This method allows for gradual priority change between ROIs and background [10], [11]. Instead of defining two priority levels, one for ROIs and the other for background, multiple priority levels are introduced between ROIs and the background. The highest priority level is assigned to ROI packets while for the background packets, the priority drops following a Gaussian distribution. After priority assignment, the packets are rearranged among the layers regarding their level of priorities. The main header of the final codestream is modified to accommodate the new generated layers and empty packets are created where necessary.

Controlling relative importance between ROIs and background in each decomposition level and handling multiple ROIs with different priorities are among the benefits of this method.

7) *Low priority packet supersession based packet rearrangement method*: Another approach of ROI coding based on packet rearrangement is proposed in [53], which is similar to the demand driven method discussed above. The only difference is that no new layers are created and the packets with priorities lower than certain values are suppressed instead and therefore there is no need to update the main header.

As such, this method is simple and fast. Also, re-encoding of the image, i.e. updating the main header, is not needed.

D. Comparison of ROI Coding Methods

A comparison among different approaches of scaling based ROI coding is given here and summarized in Table I. The features used for classification of these methods are:

- Support of multiple ROIs with different priorities.
- Relative preference control for ROI and background.
- Support of arbitrary shaped ROIs without need for shape encoding and transmission.
- Compatibility with JPEG2000 standard.

A more comprehensive comparison may be given if some more features/parameters such as complexity and memory requirements for all the methods could be measured accurately. However, this is outside the scope of this conceptual paper as the presented methods serve only as indication for potential amendments in contemporary image compression techniques towards wireless imaging.

VI. ADVANTAGES OF ROI CODING IN DIFFERENT APPLICATIONS

It is important to understand the effects of preferential ROI image coding on perceptual quality in order to eventually benefit over non-ROI coding. As JPEG2000 is the only standard that supports ROI coding, preliminary research has been focusing on this standard and its ROI coding approach.

A. General Performance Characteristics of ROI Coding

1) *Subjective experiment*: The work presented in [33] investigates on perceptual quality of ROI coding versus non-ROI

TABLE I
COMPARISON BETWEEN DIFFERENT ROI CODING METHODS.

Name	Support of multiple ROIs encoding with different priorities	ROIs and background relative preference control	Arbitrary shaped ROIs without shape encoding	Compatibility with JPEG2000 standard
MAXShift	-	-	✓	Included in the standard
GSB	✓	✓	-	Included in the standard
MAXShift-Like	-	✓	✓	✓
BbBShift/GBbBShift	-	✓	✓	-
MSBShift/PSBShift	✓	✓	✓	-
HBSHift	✓	✓	✓	-

coding. Detection of the primary ROIs was done using a VA algorithm [23], [24], [54]. Images were ROI encoded using the MAXShift method of JPEG2000. A subjective experiment was conducted involving ten subjects (8 male and 2 female viewers) to reveal the relationship between encoding/decoding mechanisms and perceptual quality. It was concluded that ROI coding performs well for image content that comprises of a distinguished ROI over background of little relevance. The favorable operation of ROI coding seems to decrease with an increase of contextual detail in the background. It was also concluded that the benefits of ROI coding over non-ROI coding increases with the decrease of bit rate in terms of bits per pixel. Specifically, it was suggested that coefficient scaling based ROI coding is best in situations where arbitrary shaped ROI needs to be encoded in the bitstream and where ROI size is less than 25% of the image size.

Although this experimental work indicates benefits of ROI coding in certain scenarios over non-ROI coding, larger subjective test campaigns would need to be conducted. In order to produce statistically more relevant results, a methodology following ITU-R Rec. BT.500-11 [55] is recommended. This would involve a group of at least 20 test subjects and the experiment to be conducted in two independent visual laboratories. In view of applications in wireless imaging, it would also be interesting to investigate whether the benefits of ROI coding are more pronounced once impairments to the JPEG2000 compressed image are imposed by the error prone radio channel as an ultimate test of its applicability. Furthermore, ROI coefficient scaling methods other than MAXShift may perform differently and should be analyzed for comparison.

2) *Mechanisms of processing spatial detail*: In [54], an investigation about the impact of the three different mechanisms provided in JPEG2000 for encoding/decoding of spatial detail on the perceptual image quality is provided. In particular, tiling of ROI and background, code block size selection, and scaling of ROI coefficients are considered. Performance assessment was done using the fidelity metric PSNR and was not linked to a perceptual metric or a subjective experiment. The numerical results produced in this work support the following conclusions. ROI coding using tiling was not found to be efficient. This is thought to be due to the primary purpose of tiling being a mechanism to reduce memory requirements

rather than advancing ROI coding. As for the ROI coding using different code block sizes, it was observed that the selection highly depends on bit rate, ROI size and priority of ROI compared to the background. For high bit rates, large ROI or nearly equal important ROI and background, a block size of 32×32 was suggested while a 16×16 block size should be used when ROI size is small compared to image size, bit rate is low or when ROI has high priority over background. In addition, it is also suggested to use code block selection where arbitrarily shaped ROI is expected to be extracted from the coded bitstream. Finally, the coefficient scaling based ROI coding seems to perform best in scenarios where arbitrary shaped ROIs are needed and ROI accounts for less than 25% of the image.

B. Exploring ROI Coding for Wireless Imaging

Combining ROI coding with channel coding, in particular using UEP over EEP, is a natural choice for exploring spatial detail. Three UEP schemes for ROI coding are reported in the sequel. They all support the favorable operation of ROI coding in conjunction with UEP for wireless imaging.

1) *UEP and ROI Coding*: The scheme proposed in [56] takes advantage of the hierarchical nature of the ROI coding of JPEG2000. It uses MAXShift for ROI coefficient scaling and applies two levels of error protection. Strong protection is given to the ROI packets using the (24,12) extended Golay code and relatively weak protection is given to the background packets using the (8,4) extended Hamming code. Conventional EEP was considered for comparison. The average PSNR of the ROI and the background information over 100 transmissions of the image under test and number of openable images (openable with the *Kakadu* software [57]) were compared for both schemes. The results show that the images protected by UEP offer higher PSNR compared to those protected by EEP. For the scenario considered in this work, it has also been observed that none of the received images was decodable at a signal-to-noise ratio of 6dB when EEP was used whereas 42% of the received images were decoded when UEP was utilized.

2) *Adaptive UEP and ROI Coding*: In [12], the prioritized adaptive unequal channel protection (PAUCP) scheme is presented. It assigns protection to each JPEG2000 packet by making use of adaptive unequal channel protection (AUCP)

[8], [9] and the priority of the packet based on its distance from the center of the ROI as presented in [10]. Simulation results for Rayleigh fading channel showed an improvement in the visual quality of the reconstructed images compared to different channel protection techniques at different channel conditions and bit rates.

3) *JPEG2000 Wireless*: In April 2007, the JPEG2000 image coding system Part 11: Wireless, also referred to as JPWL, has become a published standard [59]. JPWL employs error detection and error correction techniques to the codestream in order to facilitate transmission of JPEG2000 encoded image data over error prone wireless channels and networks. It basically addresses the fact that the error protection technique advised in the JPEG2000 core standard operates on the premise of error-free headers, which in many applications such as wireless imaging over radio channels may not be fulfilled. In particular, JPWL specifies two cyclic redundancy check (CRC) codes, the 16-bit CRC-CCITT (X25) and 32-bit Ethernet CRC to be used in the common way for error detection. Alternatively, a set of Reed-Solomon (RS) codes for a variety of block lengths and error correction capabilities are specified. The set of RS codes is used for forward error correction and enables to perform UEP for different parts of the codestream depending on their importance for the reconstruction of the image at the receiver. In particular, more error protection may be given to the main header and tile headers in the codestream.

VII. CONCLUSIONS

In this conceptual paper, we have focused on stimulating HVS driven signal processing approaches in terms of preferential image coding; the ROI coding and its potential application in wireless imaging. For this purpose, the general concepts behind ROI coding have been presented including the notion of ROI, image classes, and the important field of quality assessment of ROI coding and related perceptual metrics. On this basis, a framework for ROI coding for wireless imaging has been proposed and its key functions have been discussed. In particular, the areas of ROI identification, ROI coding and quality measures may be seen as unique features of such a framework allowing for a number of advanced system design options. Especially, UEP can accompany or replace EEP while suitable quality measures would drive link adaptation techniques and allow for trading off quality with bitrate and vice versa. Regarding the building blocks for the suggested framework, it can be concluded that both ROI identification and perceptual-based image quality needs further research efforts in order to provide the complete tool set for the wireless imaging scenario to function efficiently. On the other hand, ROI coding techniques itself are available as non-standard algorithms and the JPEG2000 standard. Both classes have been surveyed and discussed in this paper revealing many options for preference scaling between ROI and background in the JPEG2000 standard. It has also been noted that JPEG2000 has recently advised a wireless part that includes some conventional channel coding schemes to account for the error prone wireless channel and support

UEP of headers and ROI over background information in the codestream. Eventually, advantages of ROI coding and some related work that explores ROI coding is reported and discussed. Although ROI coding has been shown to operate favorable over non-ROI coding, the related work appears to be inconclusive. It may be recommended to perform larger scale subjective experiments as well as expanding towards studying the effects of the error prone channel on the perceptual quality and not solely concentrate on the ROI coding algorithms in isolation. Similar scope appears to exist when it comes to exploiting the ROI feature as only a few UEP coding approaches have been suggested so far while efficient link adaptation schemes could further strengthen the benefits of ROI coding in wireless imaging. The work presented in this paper can support the understanding of the relationship between the fundamental components of ROI coding for wireless imaging and stimulate the consolidation of those fields that may still be considered as underdeveloped. It can also be seen as a platform to expand HVS based methodologies towards cross-layer design techniques for wireless multimedia systems and general RRM strategies other than explicit and implicit link adaptation.

REFERENCES

- [1] L. Stelmach, W. J. Tam, and P. J. Hearty, "Static and Dynamic Spatial Resolution in Image Coding: An Investigation of Eye Movements", in *Proc. SPIE Human Vision, Visual Processing and Digital Display II* San Jose, USA, vol. 1453, pp. 147-152, June 1991.
- [2] L. Stark, I. Yamashita, G. Tharp, and H. X. Ngo, "Search Patterns and Search Paths in Human Visual Search", in D. Brogan, A. Gale, and K. Carr (eds), *Visual Search 2*, pp. 37-58, Taylor and Francis, London, 1993.
- [3] N. H. Mackworth and A. J. Morandi, "The Gaze Selects Informative Details Within Pictures", *Perception and Psychophysics*, vol. 2, no. 11, pp. 547-552, 1967.
- [4] J. M. Findlay, "The Visual Stimulus for Saccadic Eye Movements in Human Observers", *Perception*, vol. 9, pp. 7-21, 1980.
- [5] M. D'Zmura, "Color in Visual Search", *Vision Research*, vol. 31, no. 6, pp. 951-966, 1991.
- [6] J. Wise, "Eye Movements While Viewing Commercial NTSC Format Television", White Paper, *SMPTE Psychophysics Committee*, 1984.
- [7] A. L. Yarbus, "Eye Movements and Vision", *Plenum Press*, New York, 1967.
- [8] V. Sanchez and M. K. Mandal, "Adaptive Unequal Channel Protection for JPEG2000 Images", in *Proc. Indian Conf. on Computer Vision, Graphics and Image Processing*, Ahmedabad, India, Dec. 2002.
- [9] V. Sanchez, M. K. Mandal, and A. Basu, "Efficient Channel Protection for JPEG2000 Bitstream", *IEEE Trans. on Circuits and Systems for Video Technology*, vol. 14 no. 14, pp. 554-558, Apr. 2004.
- [10] V. Sanchez, A. Basu, and M. K. Mandal, "Prioritized Region of Interest Coding in JPEG2000", in *Proc. Int. Conf. on Pattern Recognition*, Cambridge, UK, vol. 2, pp. 799-802, Aug. 2004.
- [11] V. Sanchez, A. Basu, and M. K. Mandal, "Prioritized Region of Interest Coding in JPEG2000", *IEEE Trans. on Circuits and Systems for Video Technology*, vol. 14, pp. 1149-1155, Sept. 2004.
- [12] V. Sanchez, M. Mandal, and A. Basu, "Robust Wireless Transmission of Regions of Interest in JPEG2000", in *Proc. Int. Conf. on Image Processing*, Singapore, vol. 4, pp. 2491-2494, Oct. 2004.
- [13] T. M. Stough and C. E. Brodley, "Focusing Attention on Objects of Interest Using Multiple Matched Filters", *IEEE Trans. on Image Processing*, vol. 10, no. 3, pp. 419-426, March 2001.
- [14] D. Giguet, L. J. Karam, and G. P. Abousleman, "Very Low Bit-Rate Target-Based Image Coding", in *Proc. Asilomar Conf. on Signals, Systems and Computers*, Pacific Grove, USA, pp. 778-782, Nov. 2001.
- [15] T. M. Kusuma and H.-J. Zepernick, "A Reduced-Reference Perceptual Quality Metric for In-Service Image Quality Assessment", in *Proc. IEEE Symp. on Trends in Commun.*, Bratislava, Slovakia, pp. 71-74., Oct. 2003.

- [16] T. M. Kusuma, "A Perceptual-Based Objective Quality Metric for Wireless Imaging", *Ph.D. thesis*, Curtin University of Technology, Perth, Australia, 2005.
- [17] S. Winkler, E. D. Gelasca, and T. Ebrahimi, "Perceptual Quality Assessment for Video Watermarking", in *Proc. IEEE Int. Conf. on Inf. Technology: Coding and Compression*, Las Vegas, USA, pp. 9094, Apr. 2002.
- [18] A. W. Rix, A. Bourret, and M. P. Hollier, "Models of Human Perception", *Journal of BT Technology*, vol. 17, no. 1, pp. 2434, Jan. 1999.
- [19] Z. Wang and E. P. Simoncelli, "Reduced-Reference Image Quality Assessment Using a Wavelet-Domain Natural Image Statistic Model", in *Proc. SPIE Human Vision and Electronic Imaging* vol. 5666, pp. 149-159, Mar. 2005.
- [20] Z. Wang, A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli, "Image Quality Assessment: From Error Visibility to Structural Similarity", *IEEE Trans. on Image Processing*, vol. 13, no. 4, pp. 600-612, Apr. 2004.
- [21] U. Engelke and H.-J. Zepernick, "Quality Evaluation in Wireless Imaging Using Feature-Based Objective Metrics", in *Proc. IEEE Int. Symp. on Wireless Pervasive Computing*, San Juan, Puerto Rico, pp. 367-372, Feb. 2007.
- [22] U. Engelke and H.-J. Zepernick, "An Artificial Neural Network for Quality Assessment in Wireless Imaging Based on Extraction of Structural Information", in *Proc. IEEE Int. Conf. on Acoustics, Speech, and Signal Processing*, Honolulu, USA, pp. 1249-1252, Apr. 2007.
- [23] F. W. M. Stentiford, "An Evolutionary Programming Approach to Simulation of Visual Attention", in *Proc. Congress on Evolutionary Computation*, Seoul, Korea, vol. 2, pp. 851-858, May 2001.
- [24] F. W. M. Stentiford, "An Estimator for Visual Attention Through Competitive Novelty with Application to Image Compression", in *Proc. Picture Coding Symp.*, Seoul, Korea, pp. 101-104, April 2001.
- [25] X. C. Yin, C. P. Liu, and Z. Han, "Financial Document Image Coding With Regions of Interest Using JPEG2000", in *Proc. Int. Conf. on Document Analysis and Recognition*, Seoul, Korea, vol. 1, pp. 96-100, Aug/Sept. 2005.
- [26] H. Lin, J. Si, and G. P. Abousleman, "Knowledge-Based Hierarchical Region-of-Interest Detection", in *Proc. IEEE Int. Conf. on Acoustics, Speech and Signal Processing*, Orlando, USA, vol. 4, pp. IV-3628-IV-3631, May 2002.
- [27] C. M. Privitera and L. W. Stark, "Algorithms for Defining Visual Regions-of-Interest: Comparison with Eye Fixations", *IEEE Trans. on Pattern Analysis and Machine Intelligence*, vol. 22, no. 9, pp. 970-982, Sept. 2000.
- [28] A. Wong and W. Bishop, "Expert Knowledge Based Automatic Regions-of-Interest (ROI) Selection in Scanned Documents for Digital Image Encryption", in *Proc. Canadian Conf. on Computer and Robot Vision*, Quebec City, Canada, pp. 51-51, June 2006.
- [29] S. L. Stoev and W. StraBer, "Extracting Regions of Interest Applying a Local Watershed Transformation", in *Proc. IEEE Visualization 2000 Conf.*, Salt Lake City, USA, pp. 21-28, Oct. 2000.
- [30] D. S. Taubman and M. W. Marcellin, "JPEG2000: Image Compression Fundamentals, Standards and Practice", *Kluwer Academic Publishers*, Boston/Dordrecht/London, 2002.
- [31] A. N. Skodras and T. Ebrahimi, "JPEG2000 Image Coding System Theory and Applications", in *Proc. IEEE Int. Symp. on Circuits and Systems*, Kos, Greece, pp. 4, May 2006.
- [32] C. Christopoulos, J. Askelf and M. Larsson, "Efficient Methods for Encoding Regions of Interest in the Upcoming JPEG2000 Still Image Coding Standard", *IEEE Signal Processing Letters*, vol. 7, no. 9, pp. 247-249, Sept. 2000.
- [33] A. P. Bradley, "Can Region of Interest Coding Improve Overall Perceived Image Quality?", in *Proc. APRS Workshop on Digital Image Computing*, Brisbane, Australia, pp. 41-44, Feb. 2003.
- [34] A. P. Bradley and F. W. M. Stentiford, "Visual Attention for Region of Interest Coding In JPEG 2000", *Journal of Visual Communication and Image Representation*, vol. 14, pp. 232-250, 2003.
- [35] A. Signoroni, "Exploitation and Extension of the Region-of-Interest Coding Functionalities in JPEG2000", *IEEE Trans. on Consumer Electronics*, vol. 49, no. 4, pp. 818-823, Nov. 2003.
- [36] E. S. Kang, T. Tanaka, and S. J. Ko, "Improved Embedded Zerotree Wavelet Coder", *Electronics Letters*, vol. 35, no. 9, pp. 705-706, April 1999.
- [37] E. S. Kang, H. J. Choi, and S. J. Ko, "Progressive Region of Interest Coding Using an Improved Embedded Zerotree Wavelet Coding", in *Proc. IEEE Region 10 Conf.*, Cheju Island, Korea, vol. 1, pp. 609-612, Sept. 1999.
- [38] S. A. Mohamed and M. M. Faymy, "Binary Image Compression Using Efficient Partitioning Into Rectangular Regions", *IEEE Trans. on Commun.*, vol. 43, no. 5, pp. 1888-1893, May 1995.
- [39] L. Ma, J. Si and G.P. Abousleman, "Image Segmentation Using Watershed Guided By Edge Tracing", in *Proc. Int. Conf. on Info-tech and Info-net*, Beijing, China, vol. 3, pp. 372-377, Oct./Nov. 2001.
- [40] Y. Shoham and A. Gersho, "Efficient Bit Allocation for an Arbitrary Set of Quantizers", *IEEE Trans. on Acoustics, Speech and Signal Processing*, vol. 36, no. 9, pp. 1445-1453, Sept. 1988.
- [41] J. Strom and P. C. Cosman, "Medical Image Compression with Lossless Regions of Interest", *Signal Processing*, vol. 59, no. 2, pp. 155-171, June 1997.
- [42] D. Nister and C. Christopoulos, "Lossless Region of Interest with a Naturally Progressive Still Image Coding Algorithm", in *Proc. IEEE Int. Conf. on Image Processing*, Chicago, USA, vol.3, pp. 856-860, Oct. 1998.
- [43] A. Said and W. A. Pearlman, "An Image Multiresolution Representation for Lossless and Lossy Compression", *IEEE Trans. On Image Processing*, vol. 5, no. 9, Sept. 1996.
- [44] A. Said and W. A. Pearlman, "A New, Fast and Efficient Image Codec Based On Set Partitioning In Hierarchical Trees", *IEEE Trans. on Circuits and Systems for Video Technology*, vol. 6, no. 3, pp. 243-250, June 1996.
- [45] A. N. Skodras, C. Christopoulos, and T. Ebrahimi, "The JPEG2000 Still Image Compression Standard", *IEEE Signal Processing Mag.*, pp. 3658, Sept. 2001.
- [46] R. Grosbois, D. S. Cruz and T. Ebrahimi, "New Approach to JPEG2000 Compliant Region of Interest Coding", in *Proc. SPICE*, San Diego, California, USA, vol. 4472, pp. 267-275, Aug. 2001.
- [47] Z. Wang and A. C. Bovik, "Bitplane-by-Bitplane Shift (BbShift) - A Suggestion for JPEG2000 Region of Interest Coding", *IEEE Signal Processing Letters*, vol. 9, pp. 160-162, May 2002.
- [48] Z. Wang, S. Banerjee, B. L. Evans, and A. C. Bovik, "Generalized Bitplane-by-Bitplane Shift Method for JPEG2000 ROI Coding", in *Proc. Int. Conf. on Image Processing*, Rochester, USA, vol. 3, pp. III-81-III-84, Sept. 2002.
- [49] L. Liu and G. Fan, "A New Method for JPEG2000 Region-of-Interest Image Coding: Most Significant Bitplanes Shift", in *Proc. Midwest Symp. on Circuits and Systems*, Oklahoma State University, Oklahoma, USA, vol. 2, pp. II-176-II-179, Aug. 2002.
- [50] L. Liu and G. Fan, "A New JPEG2000 Region-of-Interest Image Coding Method: Partial Significant Bitplanes Shift", *IEEE Signal Processing Letters*, vol. 10, no. 2, pp. 35-38, Feb. 2003.
- [51] L. B. Zhang and K. Wang, "New Approach for JPEG2000 Region of Interest Image Coding: Hybrid Bitplane Shift", in *Proc. Int. Conf. on Machine Learning and Cybernetics*, Shanghai, China, vol. 6, pp. 3955-3960, Aug. 2004.
- [52] R. Rosenbaum and H. Schumann, "Flexible, Dynamic and Compliant Region of Interest Coding in JPEG2000", in *Proc. Int. Conf. on Image Processing*, Rochester, USA, vol. 3, pp. III-101 - III-104, Sept. 2002.
- [53] H. S. Kong, A. Vetro, T. Hata, and N. Kuwahara, "Fast Region-of-Interest Transcoding for JPEG2000 Images", in *Proc. IEEE Int. Symp. on Circuits and Systems*, Kobe, Japan, vol. 2, pp. 952-955, May 2005.
- [54] A. P. Bradley and F. W. M. Stentiford, "JPEG2000 and Region of Interest Coding", in *Proc. Digital Image Computing Techniques and Applications*, Melbourne, Australia, pp. 303-308, Jan. 2002.
- [55] ITU, "Methodology for the Subjective Assessment of the Quality of Television Pictures," ITU-R, Rec. BT.500-11, 2002.
- [56] Y. Yatawara, M. Caldera, T. M. Kusuma, and H. J. Zepernick, "Unequal Error Protection for ROI Coded Images Over Fading Channels", in *Proc. Systems Commun.*, Montreal, Canada, pp. 111-115, Aug. 2005.
- [57] D. Taubman, "Kakadu Software", [Online], Available <http://www.kakadusoftware.com>, July 2007.
- [58] Sample Image, [Online], Available, <http://www.navy.gov.au/gallery/>, July 2007.
- [59] International Organization for Standardization, "JPEG2000 Image Coding System: Wireless", ISO/IEC 15444-11:2007, May 2007.