Generalized region of interest coding applied to SPIHT

Roger Fredy Larico Chavez, Yuzo Iano, Rogério Seiji Higa, Rangel Arthur and Osamu Saotome

***Abstract*—The present work provides a method to use the ROI in conjunction with the SPIHT algorithm, the method apply various schemes that can be used by other encoders. The proposal uses a flexible method to determine the ROI into the DWT and accepts multiple regions. The ROI is defined by a mask applied on the LL region which reduces the amount of bits needed for the mask. Moreover, this proposal keeps the properties of SPIHT that has low complexity, is progressive and has good performance with respect to PSNR. The results show that some vectors configurations have a better performance than others for a given set of specific test images. A module was developed to generate these configurations.**

***Index Terms*—Image processing, image compression, region of interest, based scaling, SPIHT.**

I. Introduction

The coding of an image using a region of interest (ROI) allows that a region within an image be encoded with better quality or more importance than the others regions, like the background of the image. For storage and communication applications it is desirable that the image is considerably compressed. The compression explores the correlation between pixels and errors that can occur as noise. This noise could occur in the capture, transmission or processing of the image, and it can be independent or dependent of the content [18]. The noise problem can be overcome by the image hierarchization. The ROI coding is important for compression and it influences directly in transmission with priority or degrees of interest [31]. The most important information (ROI) is sent first and if necessary the rest (BG) is sent later.

The ROI coding can be applied in high performance compression schemes like the JPEG2000, where the use of ROI is widely studied. It can also be highlighted the high complexity of the JPEG2000 [16, 13] given its structure with many encoders. This makes the SPIHT better for low power consumption while maintains a good quality performance. This makes the SPIHT a good candidate for the use of ROI.

The H.264/AVC video compression standard has a better performance in static images (intra frame) in the order of 0.25 to 0.50 dB higher than the JPEG2000 in PSNR [8, 7], however it is not considered in this work because of the high complexity compared to the JPEG2000.

Manuscript received July 10, 2012.

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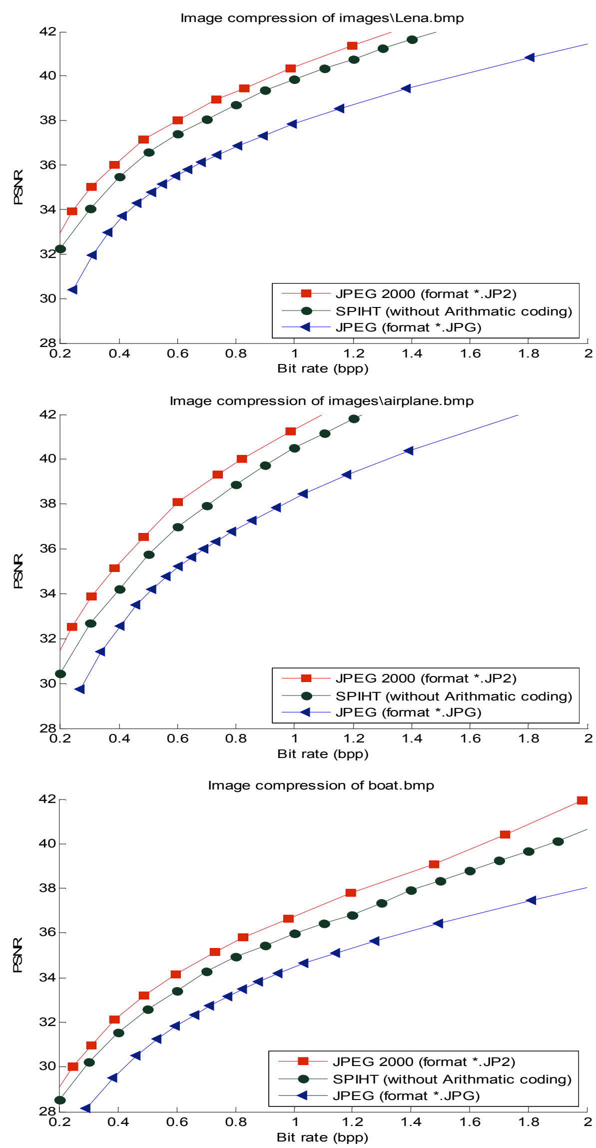

Fig. 1. Performance of JPEG 2000, SPIHT and JPG (images Airplane, Lena and Boat).

In this work the SPIHT algorithm is used due to its low complexity, therefore low power consumption, and a PSNR performance close to the JPEG2000. It has a higher performance than the traditional JPEG as showed in Fig. 1.

In earlier works the ROI coding performance is compared using objective metrics like PSNR and also using subjective methods. The ROI coding can greatly improve the subjective quality of the image; however there are some known disadvantages in existing methods of the ROI coding [30]. It is not made any subjective comparison in this work, instead it is used the traditional PSNR image metric.

The way of coding the region of interest ROI and the background BG is based on the usual method of acquire the regions of coefficients on the wavelet transform that corresponds to the desired ROI. These methods based on DWT are presented in [22, 20]. These coefficients are scaled according to the proposals and established standards like the JPEG2000. The DWT has properties that are explored statistically by the encoders, such as:

* Localization in spatial-frequency. Each wavelet coefficient describes information on a certain frequency band in a specified spatial location.

* Energy compaction. The pyramidal construction of the DWT results that the low pass (*LL*) subband compacts effectively the energy in a few coefficients. This occurs because of the behavior of the energy in homogeneous regions, typical in natural images, in which the energy is focused in one of thesubbands (*LL*).

* Similarity between subbands in different scales. This similarity between the insignificant coefficients (zeros) can be represented by a zerotree.

* Decay of the wavelet coefficients between subbands. It can be statically proved that the coefficient magnitude decays from father to son.

* Clustering of significant coefficients in a subband.

In this work the ROI coding based on wavelet is tackled. The ROI has applications beyond the image compression, for example, in the transmission of images like telemedicine, security, search engines, social networks; error protection like channel coding [12]; and object detection. For larger systems the images can be used along other purposes like watermarking [1], wireless transmission [9], and medical area [3].

Nowadays, the JPEG2000 is the image compression standard that uses ROIthat has various academic proposals for it, compatibles and non-compatibles with the standard. Others less complex schemes and with performance near the JPEG2000 like EZW [21], SPIHT and variants exists in the literature for the ROI coding [13, 5, 4, 23, 29, 33, 6, 10].

Besides the single ROI coding, it also exists the multiple region of interest, multi-ROI like the *HBShift*[32], but there are methods focused on efficiency [11, 14, 15], using the inverse wavelet transform,[14], and other schemes like the *PSBshift*[15]. The idea is to generate priorities in the same image.

One of the challenges faced to apply the ROI in the basic SPIHT algorithm without modifications is the small quantity of research in this area if compared to the JPEG2000. The proposals presented to the JPEG2000 can, with an adaptation and sufficient study, be applied with some advantage in the SPIHT algorithm.

The objective here is to apply the ROI coding in the SPIHT in a transparent way, that means, the input of the SPIHT will be the DWT modified by the proposed ROI coding.

The advantage of an algorithm like the SPITH with ROI is to diminish the processing costs or energy consumption compared to other schemes. Another advantage is that the quality performance does not fall, since it stays close to the JPEG2000. The SPIHT algorithm uses the following strategy to organize the wavelet coefficient data: a structure of set partitioned in a tree to bring together the insignificant fields through the descendants' bands. It uses and explores the statistical properties of the DWT in a way that if a zero father coefficient is found, the probability that its descendants are zero is very high (zerotree), mainly from its grandchildren [17, 19].

The SPIHT algorithm uses the wavelet characteristics, excepting the clusterization, through all bitplanes. If it finds a significant coefficient, it will enter in a subset that will be sent bit by bit, without compression. If some kind of scaling/shifting on the coefficients exists, then the coefficient will be longer as it will be represented by more bits. And as a result more inexistent zeros will be sent.

Tools and research for analysis and comparison of the various possible configurations are needed to balance all the advantages and disadvantages in the ROI application.

This work is organized as follow: first a general overview of the ROI coding in JPEG2000 is presented, showing the main proposals in this subject. Next we write about the ROI coding in SPIHT algorithm, where a generalized scaling proposal is presented as a tool for researchers. Finally the conclusions and future works recommendations are presented.

II. ROI CODING

A. ROI coding in JPEG2000

The JPEG2000 [7, 22, 24] is considered by many people the state of art standard for image compression.

The most used methods for ROI coding are the MaxShift and the ScaleShift, which are used in the JPEG2000 standard. They use rectangular or elliptic regions [22, 24, 25]. There are flexible ROI coding proposals like the *HBShift*[32] and some ROI scaling methods like the *BbBShift*[28] and the *GBbBShift*[27] seen in Fig.2.

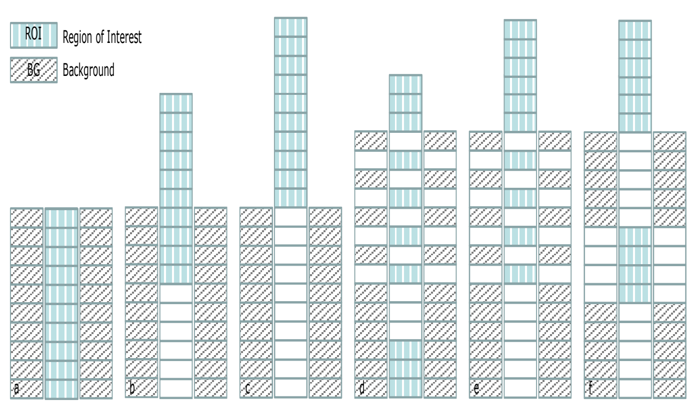

Fig.2. ROI scaling methods a) not ROI; b) ScaleShift method of general scaling $s=6$; c) MaxShift method $s=10$; d) HBShift hybrid method $s_1=3$ and $s_2=4$; e) BbBShiftmethod $s_1=6$ and $s_2=4$; f) GBbBShift method.

Disadvantages of ROI coding in JPEG 2000.

The MaxShift method is a simple and efficient approach to encode a region of interest. However it presents the disadvantages reported in [27, 32]. The first is that method does not have the flexibility to define the importance of the ROI and BG, because it lacks of arbitrary scaling. This can lead to the prioritization of the last ROI bitplanes, where the noise and the unnoticeable details information are located.

The second disadvantage is that the method decodes all the ROI to only then access the BG. This fact generates long shifts that increases the total number of bitplanes. This effect is not desired in the encoder because it increases the memory consumption.

The third disadvantage is the lack of flexibility on browsers and interactive applications. If the download is slow, only the ROI will be sent until the user changes the page. And the last disadvantage occurs when there are multiple regions inside the same image. In this case, the priority of each region cannot be different through the encoding and transmission.

In ROI coding, a region is dynamic or statically chosen. The static regions of interest are defined at the encoding process, while the dynamic regions are interactively defined, semi-automatically or manually, by the user through a progressive transmission. In the JPEG2000, if different priorities are needed, it is possible to apply the scaling-based method, but these regions are limited to rectangular and elliptic shapes. This shows the lack of flexibility, as it is not possible to choose other shapes.

B. ROI coding in SPIHT

The research of ROI coding on SPIHT is not as advanced compared to the JPEG2000. That is why it is needed a generalized format for the tests. Many application methods of ROI are found in the works of this area, but in the most of them the algorithm is modified to reach the results [10, 6]. In general, this make hard to reuse the modules and it increases the dynamic memory consumption [10].

Many applications in the telemedicine field uses the ROI coding because of the high volume data transmitted. The SPIHT was used as a way to preserve the ROI, using lossless compression, with greater fidelity [33]. It was also applied in the text analysis and using scaling methods [2] similar to the scaling-based standard of the JPEG2000, see Fig.2.b. In previous works about the SPIHT, the algorithm was always modified. In this work, the ROI coding will only initialize the DWT module to make the method transparent. A mask that corresponds to the chosen region is generated, the ROI is coded and the modified coefficients are sent to the traditional SPIHT algorithm. The behavior of this configuration will be observed for various schemes.

III. Generalized ROI coding

In this section it is presented an overview of the methods for coding the region of interest (ROI) and the background (BG) seen previously at the state of the art. The methods studied were the ones that used the wavelet decomposition like the JPEG2000, EBCOT, LZW, EZW, SPIHT, SPECK. Therefore, the advantages of the wavelet transform can be used to prioritize the region of interest in compression, transmission, object and shape detection and some others purposes.

In this work a generalized ROI coding scheme is implemented using a mask for the ROI shape, *roi_mask*[27]. And two parameters are used to define the ROI and BG bitplane scaling method. These parameters are the scaling vector masks *vsROI* and *vsBG*. This implementation allows generalizing with two vectors any ROI coding that uses binary vectors. This includes the general scaling-based, MaxShift, and others variations of codifications with and without overlaps. An example is shown inFig.3, where it is observed the codification method of the ROI and the flexibility to prioritize the bitplanes with binary vectors. This is important as the methods can be adapted according to the behavior of the bitplanes. This behavior is influenced by various sources like the image content, wavelet filter or the bitplane coder. Since the *vsROI* and *vsBG* vectors are flexible, they can be adapted to produce a better performance in PSNR.The developers and researchers have a great variety of types and choices for the bitplane strategy in certain regions of interest.

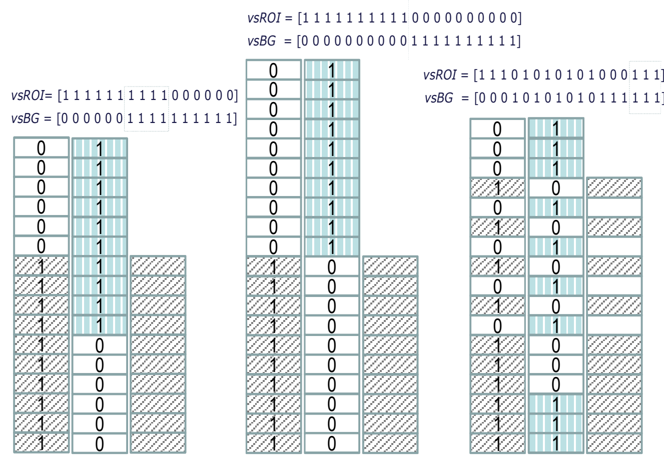

Fig.3. Parameter 'scaling vector' of the region of interest: *vsROI*; and of the background: *vsBG*.

The coding method starts with the definition of a matrix *mDWT(i, j)*that contains the coefficients coming from some wavelet decomposition. Each coefficient of row i and column j has an associated quantity of bits *b*. In this way it can be represented in the form $mDWT_b(i, j)$ where the information needed from the bitplane and position can be obtained.

The ROI and BG coding are processed using shifts according to the 1's and 0's from the vectors *vsROI* and *vsBG*. These last two are processed independently. The 1's means that the bitplane has valid data, but the vector bit order and the bitplane order may differ. The 0's mean that a shift was made and this position has no information. In this case, the codec understands as 0. This definition applies to both scaling vectors *vsROI* and *vsBG.*

It is defined a suitable *b* that depends on the number of bits per coefficient *c* used, for example, b_{max}=15. The less significant bitplane (LSB) is the first bitplane$b$=1 and the most significant bitplane (MSB) is $b=b_{max}$.

The example in Fig.3.a shows that the vector *vsROI*=[1111111111000000] and the vector *vsBG*=[0000001111111111] are equivalent to scaling-based with *s=6*. TheFig.3.b is the same as the *MaxShift*with*s=10* and Fig.3.c is equivalent to an arbitrary method with overlap in the less significant bitplanes$mDWT_{b=1,2,3}$.

Therefore, in the bitplane compression scheme, the transmission is made by priorities. In the decoder, the bitplanes of some coefficient *c* are scaled so that it returns to the original coefficient without scaling. This generalized method allows the use of any variation of ROI coding and multi-ROI. It is necessary the use of a mask to classify the ROI and the BG. This part can use any configuration of *vsROI*or*vsBG*, and although there are many configurations the desired result is not always found. In the Metaheuristic Tool section it is presented a method to select the best results.

IV. Generation the ROI mask

To appoint the region of interest ROI and BG it is necessary to define the limits of this region manually or automatically. Normally, the shape of this region is rectangular or elliptic as they are used as a standard in JPEG2000 [22, 24]. A mask that determine which coefficients belongs to the region of interest and which belongs to BG can also be used. As observed in Fig.4, it is necessary a matrix of coefficients as a data input to apply the ROI coding. To delineate any shape it is needed the shape parameters of ROI and create a mask. Finally, we must scale these coefficients with some method and then compress the image.

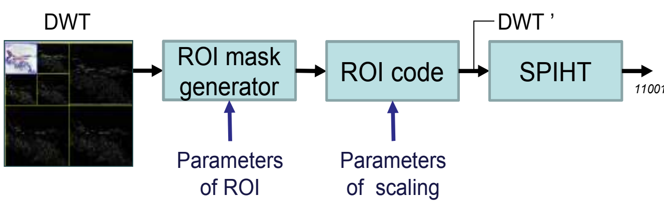

Fig.4. Compression coding scheme using ROI from a DWT.

There are many ways to tell the encoder and decoder the region of interest. The most used are: send the mask coordinates, in the case of rectangular and elliptic shapes; send the mask matrix to delineate the regions; and included inside the specification of the scaling rules (ROI scaling coding). Each one of these methods has its advantages and disadvantages in flexibility or in the quantity of information sent to the decoder.

In this work it is tacked and emphasized the ROI coding applied to the SPIHT algorithm with multiple regions of interest (multi-ROI). The representation of the region of interest can have many forms. Since it will be applied to a generalized ROI coding, the method to send the mask information will be through the matrix *roi_mask*, without modifying the rules of the compression algorithm, which means that it will be an independent module.

The DWT always have *n* levels of decomposition. The higher level is the *LL* region, where the visual information (lowest resolution) is found, and where we make the selection of the region of interest. This information will be sufficient if the size relation between the *LL*(resolution) is objectively or subjectively acceptable by the user (see Fig 5.).

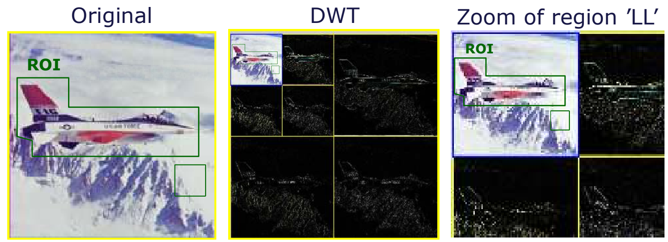

Fig.5. Region of interest viewed in the original image and in the *LL* region of the DWT.

Before the definition of the algorithm, it is necessary to know what information must be sent to generate the header or the format of the transmitted data. The information bits of the defined matrix *mDWT*will be sent along with other information such as: size of the wavelet matrix; number of decomposition levels; number of bits used to represent each coefficient; scaling parameters; and the ROI mask matrix. The proposed mask *roi_mask* is a binary matrix with the same size of the *LL*, 8 bytes for a 6 decomposition levels DWT.

A. Proposed algorithm

The algorithm is composed by the following steps:

The DWT is applied to the image with *nlevels* levels and the result is stored in the *mDWT* matrix. The *LL* region is located in the *mDWT* matrix and copied in the *m_LL* matrix.

The ROI is chosen directly in the *m_LL*, based in the original image ROI or an approximation of it. A binary matrix *m_ROI_LL* is created, this is the ROI mask that corresponds to the *LL*. Where the 1's values correspond to the ROI and the 0's to the background.

The next step is to find the position of all elements of the decomposition tree of each wavelet coefficient that belongs to the ROI (children, grandchildren), using *m_ROI_LL*. A new binary matrix *m_ROI* is generated, which contains the total ROI mask of the *mDWT* matrix, as seen in Fig.6.

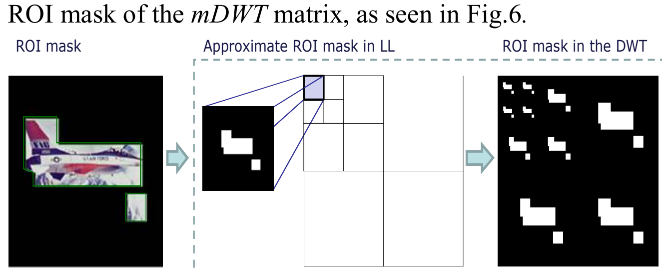

Fig.6. How to apply the desired ROI in the *LL*, and then expanding to the other decomposition levels.

Before the start of the algorithm, the user must choose the ROI directly in the image. This selection can be made manually or automatically. In the second step, it can be used tools that transform a typical ROI chosen in the image into an equivalent in the *LL* (bilinear interpolation). In the proposed implementation the encoder and decoder initializes from the *m_ROI_LL*mask only. The *m_ROI* matrix is generated from it. The *m_ROI_LL*mask is the same *roi_mask*.

The advantage of the ROI coding using only the *LL* is the smaller quantity of bits used to represent the same region compared to a mask of the entire image. The more levels the DWT have, then the smaller will be the size of the mask generated in the encoder and decoder. The use of a mask enables the definition of multiples regions of interest (multi-ROI) and the presented scheme can be utilized in any compression or analysis module based in wavelet decomposition.

The main disadvantage is that if the region or regions of interest are not square based shapes, then the precision defined initially will decreases as the levels of the DWT increases. The size of the *LL* decreases $(1/2)^n$, where n is the wavelet level. This compromise between precision and size is not critical as the selection of the region of interest is not necessarily an object segmentation, where only the object must be selected. So the selection of a region of interest can have an object or target with some of the background showing the context of the image.

V. METAHEURISTIC TOOL

To better explore the ROI coding in this conditions, a method to generate binary vectors was created. The heuristic of neighborhood search like the local search is applied. The process starts necessarily from a viable initial solution that are the known vectors originating from JPEG2000 research. The best response is stored (depends on a threshold), and then all variables are reset and a new generation of solutions are generated from the found ones (elitism). As a diversity factor, it is applied a bit exchange between the *vsROI*and the*vsBG* (crossover points). When the same desired bit quantity per vector is not achieved, an isolated trade is applied in a same vector (mutation) that produces overlays between vector and diversity similar to the predecessor.

The diagram and steps of the algorithm are illustrated in Fig.7 and Fig.8. First, the vectors contain a constant numbers of 1's, the *vsROI* vector has to be larger and after the bits crossover has to be checked, otherwise restart the step. Second, the random variability will be made, exchanging bits for the first step to be achieved, if necessary. Finally the metric will be calculated, in this case PSNR, and only the ones with an acceptable performance will be stored (~20dB and up to 1.5 bpp). The process is repeated until a defined number of iterations. Since the search is local, the initial vectors must be known for each iteration set.

VI. SIMULATIONS AND RESULTS

The simulation of the proposed algorithm was programmed in MATLAB. A tool for bits treatment for ROI coding over a DWT module was created. The traditional SPIHT encoder [20] was loaded too. Both modules were inserted in the developed generic simulation proceeding, as shown in Fig.9.

The images set used were: *airplane*, *baboon*, *Lenna*, *Barbara*, *Goldhill*, *peppers*, *sailboat* and *satellite*. The size of the images is 512×512 *pixels.* The DWT used was the biortho-

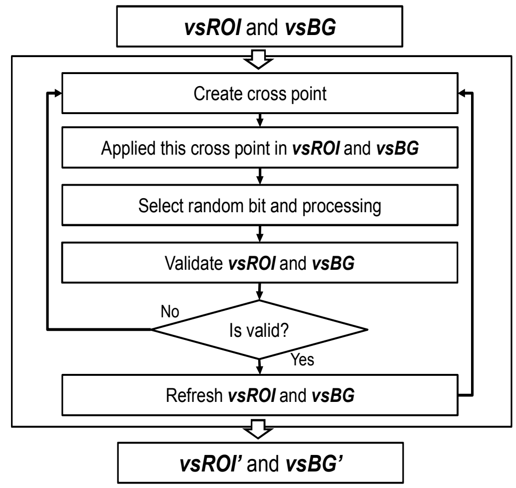

Fig.7. Flowchart of the binary vector generator algorithm.

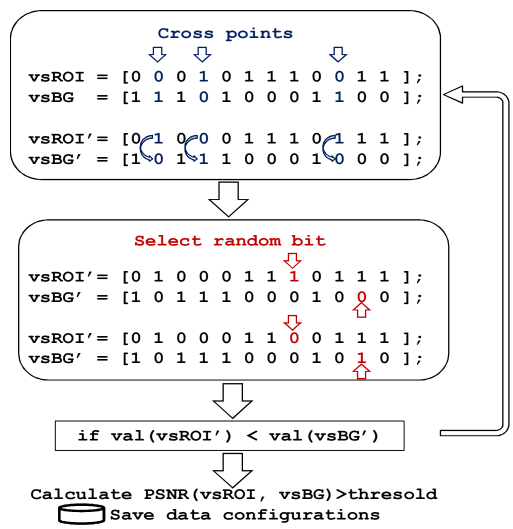

Fig.8. Example of how to apply an iteration of the binary vector generator on *vsROI*and *vsBG*.

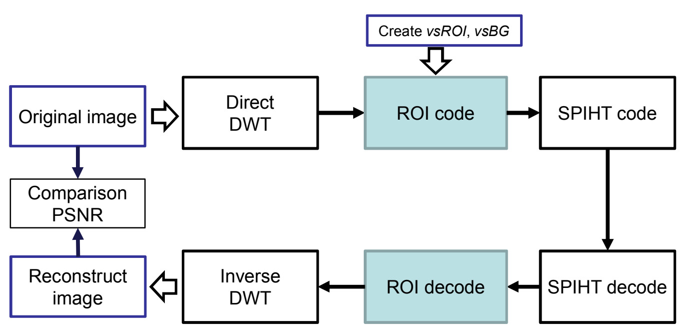

Fig.9. Proceeding to execute the image compression with ROI.

gonal (bior4.4), and the integer part of the coefficients were used, 15bits for each coefficient. The number of levels for this implementation is an important parameter, so the behavior observed for this configuration was tested to validate this parameter, see Fig. 10. The configuration without the proposal used 6 levels of decomposition.

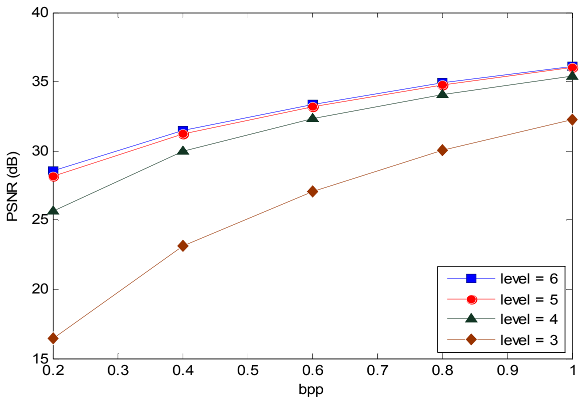

Fig. 10. Performance of the traditional SPIHT algorithm customized in the DWT. (DWT bior4.4, only the integer part and 15 bits to represent each coefficient).

The ROI represents 18.75% of the total image in a centralized format without any special behavior, as seen in Fig. 11.

```
m_ROI_LL =

[  0,0,0,0,0,0,0,0;
   0,0,0,0,0,0,0,0;
   0,0,1,1,1,1,0,0;
   0,0,1,1,1,1,0,0;
   0,0,0,0,1,1,0,0;
   0,0,0,0,1,1,0,0;
   0,0,0,0,0,0,0,0;
   0,0,0,0,0,0,0,0; ];
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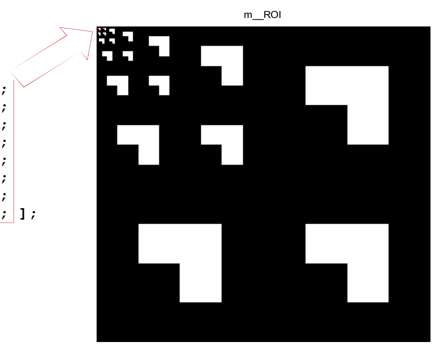


Fig. 11. ROI mask on the *LLm_ROI_LL* of size 8×8*px*; Mask generated from the matrix of all coefficients *m_ROI* 512×512*px*.

Into the ROI theparameterspresented previously are fixed for comparing the number of levels and the quantity of bits per coefficient. It is necessary to double the quantity of bits per coefficient to avoid overflow if the scaling is maximum. The vectors *vsROI* and *vsBG* will be chosen using the methods from the state of the art research and adapted into these vectors. The methods used were *MaxShift*method*,* the hybrid method *HBShift,BbBShift*, *GBbBShift*and methods with overlay. Due to the high quantity of possible combinations only the most desirable results are shown. On the top of the Fig.12 to Fig.16 are the binary vectors *vsROI* and vsBG used in each test. Only results with PSNR larger that 20dB are shown, that is, the desirable results.

The scaled-based methods already had some research related to SPIHT, but with modifications inside the SPIHT algorithm. In this implementation, the method is totally transparent and it can reach reasonable results for a coding of this type, see Fig.14.

As a result, the majority of the methods increases quite a lot the value of the coefficients and decreases the efficiency of the compression. So, too many zeros are added, with the exception of the scaled-based and the hybrid methods with overlay, see Fig.12andFig.16.

Better results were achieved using configurations of hybrid methods with overlay, but these configurations were initialized with configurations of the scaled-based methods as a seed, see Fig.12 and Fig.16. Other hybrid combinations doesn´t have acceptable results, see Fig.18.

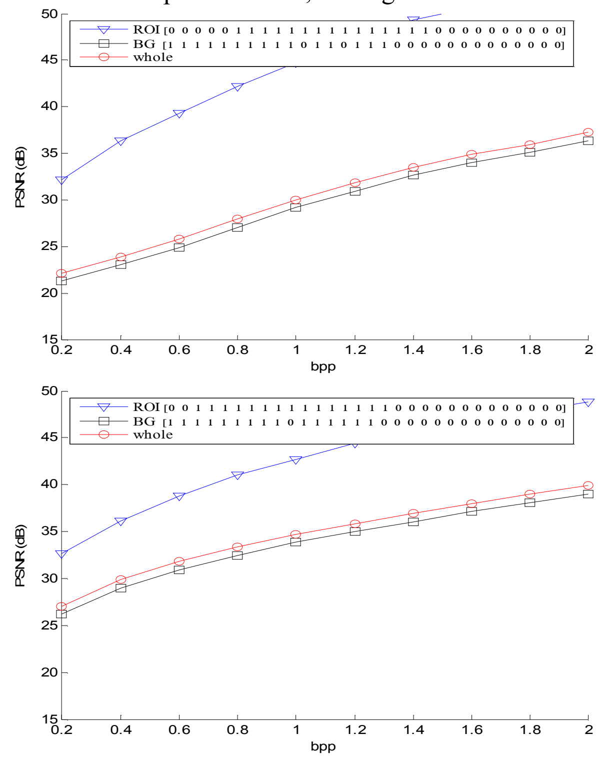
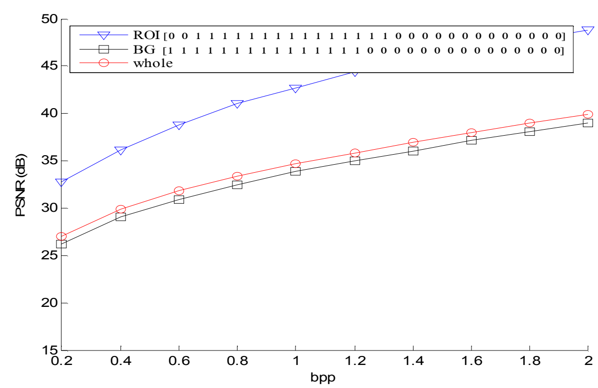


Fig.12. Found desired result using hybrid configuration seeded with *scaling-based.*

On Fig.13 both curves shows that the combination of the priorization of some plane of bits with the scaling-based method provides a better result than using only the scaling-based method.



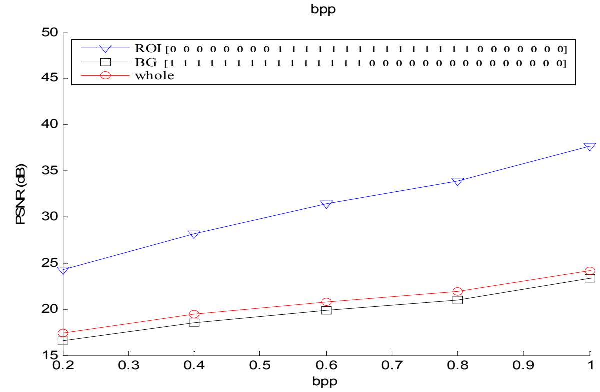


Fig.14. Results using a *scaling-based* equivalent configuration.

It can observedin Fig.15 that the SPITH does not have a good performance using only the scaled-based equivalent. It only gives a good PSNR when scaling between the binary vectors is short.

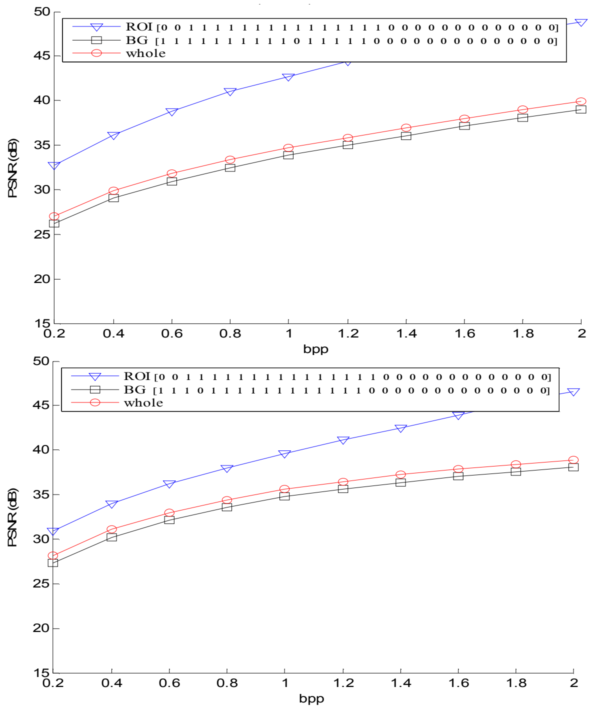


Fig.16. Results using the hybrid configuration seeded with *scaling-based*method.

On Fig. 14 the ROI-BG compromise ratio can be seen, if theROI quality improves the BG diminishes. The quality of BG can be increased at the cost of the quality of the ROI. This is undesirable if the ROI is well defined, but for applications where the ROI is not well defined this could be done to equalize the quality, for example, in surveillance applications.

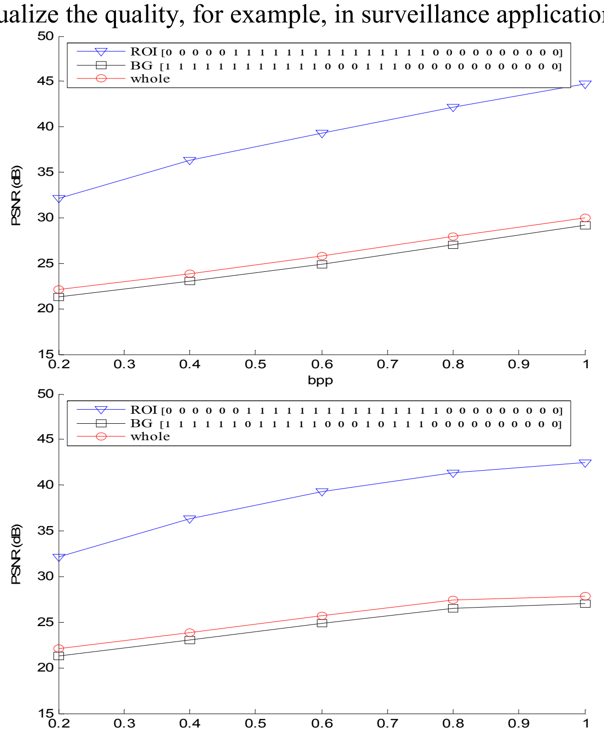


Fig.17. Some results using hybrid configuration that had the seed with cited methods with the exception of *scaling-based* method.

The Fig.17 shows some results using hybrid methods using known configurations [27, 28, 32], the scaling-based method was not used. The results for Fig. 15 were better than the ones in Fig. 16.

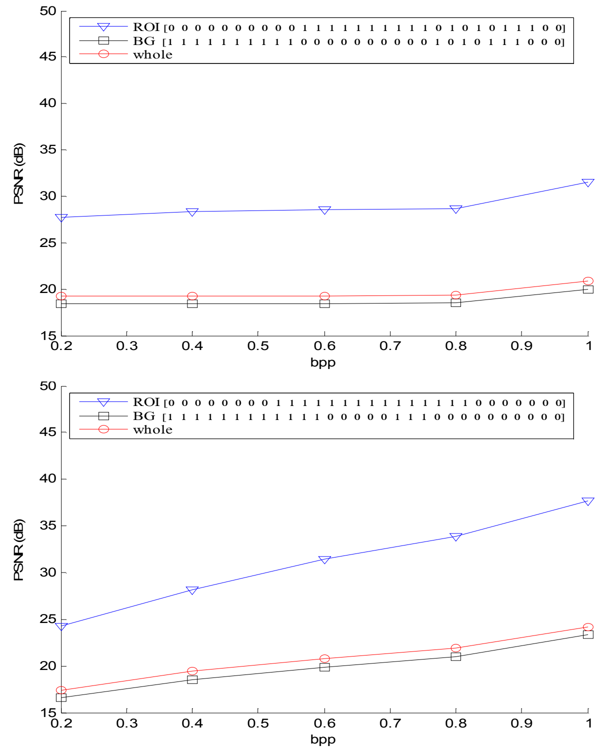


Fig.18. Non desirable results using hybrid configuration that had the seed with mentioned method with the exception of *scaling-based.*

On Fig. 16 it can be seen that the result is non desirable when the hybrid method does not use the scaling-based method seed.However, the scaling information is subjective and depends on many factors, among them the original image that will be decomposed by the wavelet. So, for each image set it is necessary to make this type of test and customize the coding. To accomplish that, it was implemented a fast convergence metaheuristic tool. This tool generates the*vsROI* and the*vsBG* automatically and it avoids testing all possible combinations to find a suitable configuration.

One of the SPIHT characteristics is that it explores the non-significant coefficients in a zeros tree. If a scaling is applied and it is chosen as a significant one in the following steps of the algorithm, especially in the refining step, then the 0's generated will be sent without any compression criteria. This will decrease the total compression performance. Therefore not any form will be viable, because it will be dependent on the information of the coefficients and how they behave in the chosen ROI.

In general the proposed method can be used to customize content dependentapplications, like medical images and surveillance.

The proposed algorithm can be improved with an interactive selection method of ROI [26] and it is possible to use the works like [9].

The proposed algorithm can be used with wavelets with levels greater or equal to three, but as observed for a better performance it is necessary more than 4 levels of decomposition, and the recommended is 6levels. The balance between the performance and the effort in selection has to be made for each specific objective.

To overcome the zero generation problem it is possible to use an arithmetic coder after the SPIHT. This makes the zero sequences shorter and gives the compression a better performance.

The mask information can be defined in the section that corresponds to the *LL* signal (bitplane segment of the signal). On a DWT of a positive image, the approximation(*LL*) must be positive.

It is not recommended to use less than 5 levels for the DWT as shown in Fig. 10. Besides, for each image set it is advised that the test be made again.

In the steps 2 and 4 a binary mask can be used or a priority mask if combined with scaling-based.

CONCLUSIONS

As a conclusion it is observed that proposed method cannot be applied directly like in the JPEG2000. The best scheme to encode the ROI is the scaling-based method with a scaling '*s*' short (*s*=2). The hybrid version similar to this scaling based has a similar performance. But if the binary vectors are close to the scaling based configuration there is a small improvement in ROI or in the BG, but not in both simultaneously. Other forms are also acceptable, however the image set is too general. If the type of the images were restricted, then the results could be improved. Each acceptable configuration can provide a good performance, it only depends on the characteristics of the application.

The proposed tool demonstrates that it is possible to represent many coding forms studied in this area in a modular way, as it was necessary for further advancements.

The mask generation presents an appropriate size because the *LL* region is small and accepts multi-ROI. However, a shorter *LL* region decreases the mask data, and makes the segmentation of a ROI harder and more imprecise.

The tool can be adapted to the scaling coding forms of the JPEG2000. In this research the SPIHT is not specialized or enhanced, but it is expected that it can be used in future researches, using objective and subjective analysis.

ACKNOWLEDGMENT

The authors would like to thank the following institutions, ItasatProject, Fapesp, CTIC-RNP, CNPq, Capes, Capes-RHTVD, Faepex.

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