PROGRESSIVE MEDICAL IMAGE COMPRESSION USING A DIAGNOSTIC QUALITY MEASURE ON REGIONS-OF-INTEREST

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ABSTRACT

Dealing with lossy compression of medical images requires particular attention whether for still images, video or volumetric slice-sets. In this work we propose an approach based on a selective allocation of coding resources that is directly related to the diagnostic task. We introduce the concepts of Region of Diagnostic Interest (RODI) and Diagnostic Quality as key links between the radiological activities and responsibilities and the functioning of a selective coding algorithm. The coding engine is a modified version of Shapiro's EZW algorithm and the coded bit-stream is fully progressive. The RODI selectivity corresponds to the choice of a set of subband weighting masks that depends on a small set of parameters handled and validated by the radiologist in a very natural manner. In conclusion, we present some experimental results that give interesting insights in favor of using lossy compression in a controlled fashion by a competent physician.

1 INTRODUCTION

We propose here a novel methodology to compress diagnostic pictures which can be integrated into the diagnostic activity of a digitized Radiology department supplied with a PACS (Picture Archive and Communication System). In this context, where all images are stored in digital format and all supporting information for patients is digital, it is a requirement to limit as much as possible the memory needs [1, 2]. This requirement comes for reducing storage costs and transmission delays in any telemedicine perspective. Nevertheless, "high" compression ratios can be obtained only if lossy coding algorithms are taken into account. It must be however clarified whether this is possible in the field of diagnostic practice for PACS applications. In fact medical and legal matters, time spent in compression procedures and needs of training, are costs to be avoided, or eventually minimized, in order to obtain a technique that can be proposed for a professional usage. The ultimate scope of our work is to give the radiologist the total control of the compression result without impairing his normal diagnostic activity. The proposed scheme should clearly be linked to man–machine interaction issues to allow for high level perceptual tasks, that cannot be carried out in an automated fashion (except possibly in some application specific contexts). The final validation of the compression procedure lies therefore essentially at a semantic level, in the sense that it will be based at the level where semantics comes into place to reach the diagnosis. Accordingly, a diagnostic measure of quality will be proposed to face this difficult objective.

1.1 An interactive human–computer compression

The overall compression method (see the essential scheme in Fig.1) is multi–resolution (wavelet–based), provides for an embedded generation of the bit–stream and guarantees for a good rate–distortion trade–off, at various bit–rates, with spatially varying (region dependent) reconstruction quality. The allocation of bandwidth for the compression algorithm is made selective by using some form of weighting masks, which emphasize image characteristics within the RODI.
We note (Fig.1) that the first block is semantic, because the diagnosis is reached by the physician, so that we deal with a paradigm of compression that can be called "semantically–lossless" [3]. The second unit identifies a reduced number of coefficients related to the diagnostic task. These are set by the physician (according to his/her knowledge of the artifact introduced on the coded material); they are then automatically translated into the set of weighting mask parameters [4]. As a result a set of masks exist for each subband in the wavelet domain, which rescale each individual wavelet coefficient that can then be passed to Shapiro's EZW algorithm [5, 4].
In section 2 we concentrate on the structure of the masks; in section 3 we present some related experimental results. Finally (par. 3.3) we give some hints for the use of color to enhance the coding effects in the reconstructed image.

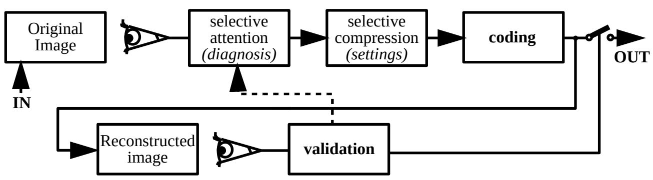

Figure 2: *The validation process, based on semantic selective attention.*

2 THE MASKING STRUCTURE

2.1 Meaning of masks

In our context, masking means creating a hierarchy into the data in some domain of representation. This is strictly connected to some criterion of visual attention [6]. We consider high–level (task–oriented) diagnostic attention. With respect to Fig.2 we can see that this "semantic hierarchy" can be subdivided in two steps:

1. At the time of diagnosis the doctor simply defines the RODIs and the relative importance between these regions and the remaining image context.

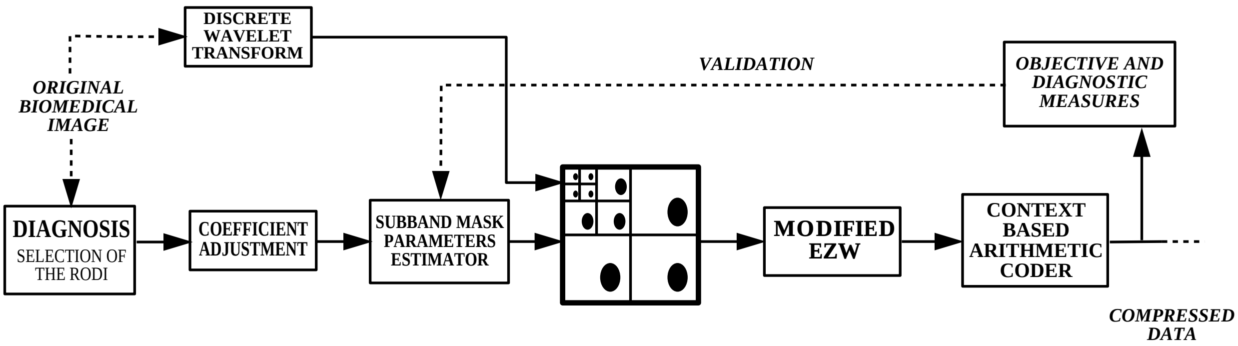

Figure 1: *Diagnostic image coding scheme.*

2. The coding algorithm enables a selective allocation of resources in order to match these coefficients set by the physician.

In other words, during the diagnostic task, the physician selects one or more Regions of Diagnostic Interest and sets the coefficients using a graphical interface. In fact, to simplify the planning of a proper RODI morphology by a non compression expert, three "diagnostic" coefficients appear to be well adapted to the normal practice of the doctor. These represent: i) the relative weight Ir between RODI and $\overline{\text{RODI}}$ (the main parameter which regulates the mask amplitude); ii) the absolute quality level Ia of the RODI (which is directly related to bit-rate) and iii) a selectivity factor S (which regulates, visually and in an energy related fashion, the RODI-$\overline{\text{RODI}}$ transition on the resulting coded image). In our experiments we have noticed how the correct usage of these coefficients does not require substantial training of the physicians. The reason lies in the fact that they intuitive but precise significance and can be set during the diagnostic task. At this stage of the coding procedure we have introduced a set of relationships which translates the "diagnostic" coefficients in weighting mask characteristics [4]. This allows the physician to control and validate the compression at will, and the technique evolves naturally in its diagnostic responsibilities.
The RODI is constructed according to this procedure and the radiologist works directly in the image domain. Yet, for coding purpose, an image domain masking strategy is not adequate.

2.2 Subband masking

We do not perform the weighting in the image domain rather in the Wavelet Transform domain using a set of subband–windows; this first avoids the introduction of high energy detail coefficients (due to the presence of the weighting window in the image domain) which would cause a drop in coding gain. It also makes the mask framework more versatile. The subband masking exploits the co-spatiality trees of information in the wavelet coefficient domain. The masking functions are mirrored-sigmoidal shaped with elliptical symmetry, so as to form a set of bell shaped windows which are maximally flat within the RODI and within the out-of-RODI ($\overline{\text{RODI}}$), with a smooth transition region, the decaying speed of which can be easily modulated. In fact a too sharp transition between RODI and $\overline{\text{RODI}}$ should be considered a potentially objectionable artifact to be avoided in the biomedical field. Moreover, the elliptical shape match well the anatomical and pathological morphology (it does not reflect, for example, polygonal contours). Mask informations can be coded using very few bits, and the analytical formula of the subband set of masks is the following:

$$m(x,y) = (t^{(ij)} - b^{(ij)}) + b^{(ij)} \cdot \left[\frac{1}{1 + \exp\left(\sqrt{(x - x_c^{(ij)})^2 \cdot e^2 + (y - y_c^{(ij)})^2} - r/s_i \right) \cdot d} \right] \qquad (1)$$

where:

- (x_c, y_c) is the center of the mask,
- e is the ellipticity $\in (0, \infty)$; $e = 1$ for the circle,
- s denotes the scaling factor,
- r denotes principal ray,
- d denotes smoothing of the decay,
- t sets the RODI amplitude (top),
- b sets the $\overline{\text{RODI}}$ amplitude (bottom).

$i = 1 \dots p$ represents the decomposition level, while p corresponds to the decomposition depth; $j = 1 \dots 3$ identifies the considered subband (h,v,d) which is equal to 0 only for $x_c^{(p0)}, y_c^{(p0)}$, the coarse resolution subband.
The above set of parameters makes the subband masking a flexible and versatile tool for the selective coding in a variety of contexts (e.g. the subbands weighting coefficients were adjusted according to perceptual criterions), they also take into account the length of the wavelet filters as well as diagnostic experimental considerations about the absolute extension of the RODI with respect to the related scaled versions into the subband-set.
Examples of masking are shown in Fig.3; the decision of which set of masks is appropriate cannot be taken rigorously but it has some fuzziness that depends on medical issues (shape and "diagnostic" coefficients) and from the adequate translation of the "diagnostic" coefficients in weighting parameters [4].

2.3 Properties of the coded bit-stream

Masking will not disturb the progressivity property of the compression scheme; on the contrary we demonstrate that the above property evolves in a hierarchical "multi-progressivity" through the use of the weighting parameters. The progressivity property is not only important for teleradiology applications, but also for storing images with a certain truncation policy in order to achieve a target compression ratio in a time-delayed fashion. This insight is particularly

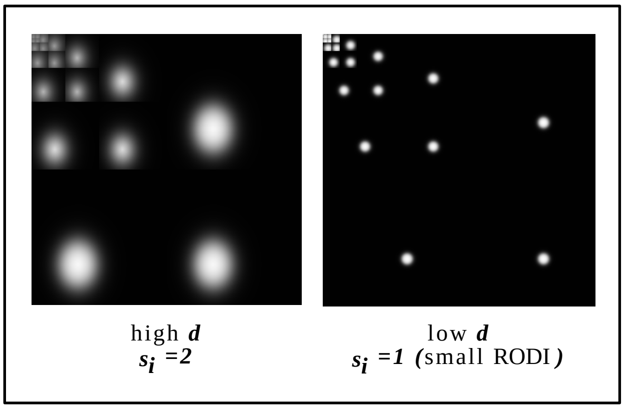

Figure 3: *Two different types of masking parameters: (a) scale-invariant, $s_i \simeq 2$; (b) subband-invariant, $s_i \simeq 1$ (more adequate for small RODIs).*

attractive to deal with medical and legal issues that occurs with the lossy approach. It is important to note that lossless, *visually lossless* [7] and *regionally lossless* [2] coding, can be considered as particular cases of our general scheme.

3 EXPERIMENTAL SIMULATIONS

To demonstrate the validity of the methodology, a series of objective and subjective experiments have been carried out with the support and critical contribution of the medical counterpart. These experiments aimed at describing the coding system and its performance, as well at testing the possibility of a professional usage of the guided compression methodology.

3.1 Objective control

We have obtained plots of the operational R–D curve and estimated the relationships that may exist between objective distortion measures and the weighting mask features (size, shape, diagnostic parameter dependencies,...). This gave a good characterization of the algorithm performance and specifically a set of quantitative considerations about the use and the validation of weighting masks.
An example of R–D curve (for a single elliptical mask representing 5% of image area) is shown in Figure 4. The repetitive slope relapse of the curves is a characteristics of the EZW algorithm, which matches the sequence of dominant and subordinate quantization passes [5].

3.2 User-defined subjective validation

The subjective experimentations were carried out on a set of significant pathological cases so as to test the system in the context of critical diagnosis; for example single wide critical lesion or multiple small centers. Tests were essentially carried out on MR images 512x512 and 8bpp of resolution (after 12 bit gray–level windowing and/or contrast selection). Experiments were performed to establish:

- the benefit of the use of the weighting masks;
- the relationship between diagnostic quality and presence of visible artifacts;
- the inhomogeneous distribution of quality due to the selectivity of the used mask;

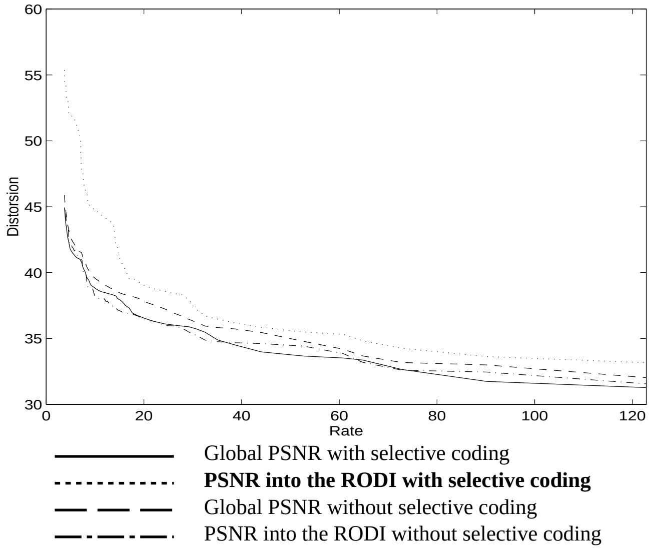

Figure 4: *Rate–Distortion plot for a coding instance, with and without application of the weighting mask.*

Overall goodness		*Impairment*	
		Not noticeable	(1)
Excellent	5	Just noticeable	(2)
Good	4	Noticeable but not substantial	(3)
Fair	3	Impairment not objectionable	(4)
Poor	2	Somewhat objectionable	(5)
Unsatisfactory	1	Definitely objectionable	(6)
		Extremely objectionable	(7)

Table 1: *Goodness scale to evaluate subjective quality. Impairment scale to evaluate reconstructed image fidelity.*

- the optimal strategy to define perceptual weighting options.

Here we cite some results relative to the first two items.

3.2.1 Subjective Quality vs Image Fidelity

It is important not to confuse both terminologies [8]. The first is related to the largest tolerable distortion (here in a diagnostic sense), while the second identifies the just noticeable difference between the original and the reconstructed image. A measure of *Diagnostic Quality* can be introduced. It determines the ability (for a same physician) to perform the same diagnosis on the coded image with respect to the original one. Subjective scales can be defined as in Jain [9] (see Tab.1). For the experimental procedure, we consider one image at a time and 12 coded version of it (3 Ir times 4 compression ratios C.R.), we randomize the order of presentation. Tab.2 indicates an example of the subjective results with the associated PSNR outcomes. There exists a correlation between quality and fidelity, but good diagnostic quality can be achieved in presence of visible fidelity impairment. In this case the best results have been achieved with Ir=6, which is close to the effective choice of the neuroradiologist. This choice however does not appear to be critical in terms of rate–distortion and subjective performance for reasonable RODI dimensions (up to 10% of image area).

Ir	C.R.	**Q**	**F**	PSNR Global	RODI	$\overline{RODI}$
3	8	5	2	40.40	45.35	40.18
3	18	5	3	37.63	39.05	37.54
3	32	4	4	35.59	36.02	35.56
3	50	2	6	34.61	34.50	34.62
6	8	5	1	39.59	47.89	39.32
6	18	5	3	36.95	40.93	36.75
6	32	4	3	35.13	37.07	35.01
6	50	3	5	33.82	36.17	33.68
9	8	5	2	39.91	50.32	39.61
9	18	5	3	36.45	41.97	36.21
9	32	4	4	34.92	37.69	34.77
9	50	3	6	33.14	36.68	32.96

Table 2: *Diagnostic Quality (Q) vs Image Fidelity (F) test: subjective evaluations and quantitative measures of PSNR.*

3.2.2 Utility of the masks

This experiment demonstrates the utility of the masking strategy for all the considered cases. In Tab.3, images coded with and without masking are compared with respect to their Diagnostic Quality judgment. A substantial growth of Q can be achieved using the masking proposed by the physician.

3.3 Enhancement of RODI

The use of the weighting mask introduces also additional information which is semantically very relevant (with a marginal increase of coding cost), to specify the RODI shape and weighting parameters. This information suggests the diagnostic result and can help for subsequent archive consultations and for teleradiology as well. For these reasons, a color highlighting of the $\overline{RODI}$ is proposed to identify the RODI. The physician is able to adjust the relative chromatic and intensity scale of the mask so as to perceive the data either in the original form (apart from the compression artifact) or with an implicit diagnostic coding information.
In the context of validation of the compression result, the physician can also use color to identify those areas of the images that exhibit compression errors beyond an adjustable threshold. According to the relevance of these artifacts from a diagnostic quality point of view, the diagnostic parameters can be dynamically readjusted by the physician till a satisfactory result has been reached.

Image	Ir	S	C.R.	**Q**	PSNR Global	RODI	$\overline{RODI}$
Les-1	1		10	5	40.21	39.16	40.31
	4	6	10	5	39.51	43.69	39.29
Foc-1	1		20	2	38.92	36.90	38.93
	6	3	20	4	38.35	41.84	38.34
Les-2	1		30	5	39.26	37.18	39.49
	5	4	30	5	38.85	38.92	38.85
Foc-2	1		40	3	40.71	38.39	40.72
	6	3	40	5	40.63	41.83	40.63
Les-3	1		50	3	40.63	41.83	40.63
	7	2	50	4	33.93	35.14	33.89
	10	3	50	4	33.36	35.85	33.29

Table 3: *With and without mask test: Diagnostic Quality (Q) and PSNR on 5 different images at the same compression ratio (C.R.); "Les" corresponds to tumoral or bruise lesion images, "Foc" corresponds to multiple sclerosis images.*

4 CONCLUSIONS

This work has proposed a semantic guided methodology, based on Regions of Diagnostic Interest, to selectively allocate compression resources, allowing to reach various quality degrees in selected image regions in the reconstructed image. Such quality can clearly range from perfect (lossless) to visually lossless or even lossy. A fundamental rule was played by the **Diagnostic Quality** measure in order to define the limitations of our weighting strategy. This quality measure has been extensively used during subjective experimentations. The selection of the compression parameters can be carried out in a "natural" fashion within the normal diagnostic practice. This kind of man–machine interaction is needed as the high level diagnostic task cannot be reached with an automatic compression algorithm.
The compression degree and the resource allocation can fully reflect the medical and legal responsibilities of the physician that perform the diagnosis and validate the quality of the compressed image. Furthermore, thanks to the progressivity of the bit–stream, higher compression can be reached at a later stage, depending on the memory needs within the PACS. At high compression ratio (around 50, starting from 8bpp image representation) no experimental simulations have lead to a false lesion.

5 Acknowledgments

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6 References

[1] S. Wong, L. Zaremba, D. Gooden, and H. Huang. Radiologic image compression – a review. *Proc.of the IEEE*, 83(2):194–219, Feb. 1995.

[2] J. Ström and P.C. Cosman. Medical image compression with loss-less regions of interest. *Signal Proc.*, 59(2):155–172, Jun. 1997.

[3] A. Signoroni and R. Leonardi. Progressive ROI coding and diagnostic quality for medical image compression. In *Proc. SPIE Visual Communications and Image Processing '98*, volume SPIE-3309, pages 674–685, Jan. 1998.

[4] A. Signoroni. *Codifica basata su Regioni di Interesse mediante Trasformata Wavelet: applicazioni alle Immagini Biomediche.* Thesis of Laurea, University of Brescia (Italy), Jun. 1997.

[5] J.M. Shapiro. Embedded image coding using zerotrees of wavelet coefficients. *IEEE Trans. on Signal Proc.*, SP-41(12):3445–3462, Dec. 1993.

[6] E. Nguyen Phuc. *Compression sélective et focalisation visuelle: application au codage hybride de séquences d'images.* Ph.D. thesis, Université de Rennes 1 (F), 1995.

[7] N. Jayant, J. Johnston, and B. Safranek. Signal compression based on models of human perception. *Proc. IEEE*, 81(10):1385–1422, Oct. 1993.

[8] J.E. Farrell D.A. Silverstein. The relationship between image fidelity and image quality. In *Int. Conf. on Image Processing*, pages 13–16 (Vol.II), Washington. DC, Oct. 1995.

[9] A. Jain. *Fundamentals of Digital Image Processing*, pages 57–60. Englewood Cliffs, NJ: Prentice-Hall, 1989.