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Coding of Echocardiographic Image by Selection of the Normalization Matrix Using Fuzzy Logic

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Abstract—**This article presents an algorithm for compression of echocardiographic images. The algorithm is based on the JPEG algorithm and uses a fuzzy inference system to adapt the normalization process of the transformed coefficients through the analysis of the local characteristics of echocardiographic images. The images considered in this paper were acquired in actual echocardiography exams. The proposed encoder guarantees a maximum local signal-to-noise ratio, which is adapted to the characteristics of each sub-block of the image.**

I. INTRODUCTION

THE use of digital medical images is growing worldwide. Thus, the development of techniques that make the storage and the transmission of these images possible is becoming crucial.

Image compression is a signal processing technique that allows the reduction of the amount of data necessary to characterize a certain amount of information. Such reduction is reached by the elimination of redundant and/or irrelevant information. One should always keep in mind that, despite the compression of data is sometimes necessary in order to reduce costs in storage media or in transmission resources, this process should not corrupt the information, especially when the process is used for compression of medical images, in which the quality of the image should be retained in order to allow for accurate medical diagnosis.

This paper presents an algorithm based on the standard defined by the Joint Photographic Experts Group, popularly known as JPEG. In the algorithm, the JPEG is modified in order to allow the achievement, in a certain sense, of a better quality for the compressed image. The objective is to maximize the compression rate, while guaranteeing the subjective quality of the image, in a sense that will be specified later.

We used echocardiographic images in this work in a typical work day. Typically, a physician acquires from four to ten images. Each image has 640x476 pixels and it is stored in the bitmap format with 256 gray levels. Thus, each image has approximately 298 kB and 3 MB of data can be generated in just one examination. If 10 examinations were carried out daily, this would result in the generation of 30 MB of data per day and 1 GB each month. Thus, it is clear that effective compression techniques would reduce the cost in equipment. Another useful application is related to telemedicine, since compression methods usually reduce the amount of date to be transmitted.

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II. THE JPEG STANDARD

The JPEG compression technique can be divided in three sequential steps [1]:

a. Segmentation of the image in sub-blocks of 8x8 pixels and computation of the DCT (Discrete Cosine Transform)
b. Normalization (quantization and threshold)
c. Entropy coding

The standard algorithm uses, in step (b), only one matrix in the normalization of all the sub-blocks of the image. Equation 1 represents the normalization matrix recommended by the JPEG standard:

$$Z_{50} = \begin{bmatrix} 16 & 11 & 10 & 16 & 24 & 49 & 51 & 61 \\ 12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\ 14 & 13 & 16 & 24 & 40 & 57 & 69 & 56 \\ 14 & 17 & 22 & 29 & 51 & 87 & 80 & 62 \\ 18 & 22 & 37 & 56 & 68 & 109 & 103 & 77 \\ 24 & 35 & 55 & 64 & 81 & 104 & 113 & 92 \\ 49 & 64 & 78 & 87 & 103 & 121 & 120 & 101 \\ 72 & 92 & 95 & 98 & 112 & 100 & 103 & 99 \end{bmatrix} \quad (1)$$

The fact that variable compression rates can be reached through the scaling of the normalization matrix Z_{50}, suggested by the JPEG standard, is well-known [2]. The algorithm that adjusts the normalization matrix for quality factors Q between 1 and 100 can be summarized as follows.

If the Q factor is less than 50, then

$$Scal = \frac{5000}{Q}, \quad (2)$$

otherwise,

$$Scal = 200 - 2Q. \qquad (3)$$

Thus, the new normalization matrix is show in Equation 4,

$$Z(u,v) = \frac{Z_{50} \cdot Scal + 50}{100}. \qquad (4)$$

III. Fuzzy Logic

The theory of fuzzy sets was proposed by Lotfi Zadeh in 1965 [3]. In the 70's, Ebrahim Mamdani used the theory to design fuzzy controllers [4].

The fuzzy logic uses a relative treatment for the concept of precision. In this approach, instead of trying to solve a problem in the most accurate way, one tries to use approximated reasoning to obtain an approximated solution. The logic fuzzy can be a convenient way to relate input variables with output variables.

We have decided to use fuzzy logic in this work because of the following reasons [5]:

- it is flexible;
- it is tolerant to inexact data;
- it is capable of shaping nonlinear functions of arbitrary complexity;
- it can be used with specialist systems;
- it is based on natural languages.

IV. Modified JPEG

The proposed algorithm, which we have named "modified JPEG" works as follows. Given a codebook with some normalization matrices, we want to choose, by means of a fuzzy inference system, a matrix for each sub-block that is best for its local characteristics.

The goal is not only to reach high compression rates but also to obtain visually satisfactory results.

Suppose that after we obtain the transform of a sub-block, we want to apply the inverse transform in order to obtain the sub-block in the original representation. It is well-known that after the normalization of the transformed coefficients, some of them are either discarded or modified. Hence, the inverse transform may result in a sequence $\dot{V}[y,x]$ that it is not exactly equal the original representation, $V[y,x]$. It is desirable to measure the difference between the two representations by means of an objective technique. The technique used in the proposed algorithm is the well-known signal-to-noise ratio (SNR), shown in Equations 5,

$$RSR = 10\log\left(\frac{\sigma_V^{\,2}}{\sigma_e^{\,2}}\right) = 10\log\left(\frac{\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}(V[y,x]-\mu_V)^2}{\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}(\dot{V}[y,x]-V[y,x]-\mu_e)^2}\right)\text{dB}, \qquad (5)$$

where σ_V^2 is the variance of the original representation, σ_e^2 is the variance of the reconstruction error, μ_V is the average luminance of a sub-block and μ_e is the average reconstruction error.

Initially we established a relationship between the variances of the sub-blocks and the local SNR's observed in the reconstruction of these sub-blocks. For this purpose, 100 echocardiographic images have been segmented in sub-blocks of 8x8 pixels. These sub-blocks were coded and decoded through the JPEG algorithm, adjusting the quality factor, Q, for 10, 15, 20, 25....90. Figure 2 shows a plot that establishes the relationship between the variance and the local SNR, calculated from the original and reconstructed versions, for the analyzed sub-blocks.

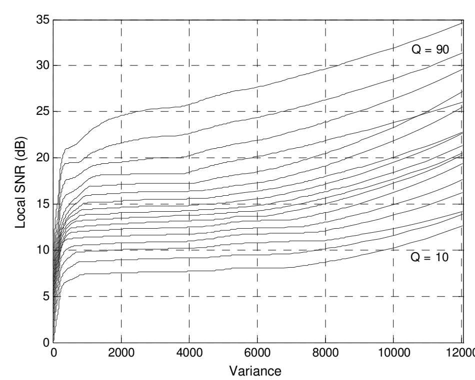

Figure 1. SNR X Variance

Figure 1 shows that, for a quality given Q, the larger the variance of the sub-block, the larger will be the observed SNR in the reconstruction. Moreover, for a given variance, the larger the value of Q, the larger will be SNR. It is also known that larger indices (Ind) in the codebook indicate normalization matrices that preserve a bigger amount of transformed coefficients. From this information it is possible to build a fuzzy inference system that receives as input parameters the quality factor and the variance of the sub-block and returns the index Ind of the normalization matrix that will be used.

The definition of the system is as follows:

- size of the codebook: IndMax = 32;
- minimum and maximum Variances: 0 and 12054;
- quality factors: 0 to 100.

Several membership functions [6] have been tested for each of the variables. The ones that led to the most satisfactory results were used.

The set of rules used by the inference system is the following:

- If Variance is Low, Then Ind is Low;
- If Variance is Average, Then Ind is Average;
- If Variance is High, Then Ind is High;
- If Variance is Low and Q is Average, then Ind is Low;
- If Variance is Low and Q is High, then Ind is Low;
- If Variance is High and Q is High, then Ind is High;
- If Q is Low, then Ind is Low.

Finally, the membership functions and the described rules define the surface shown in Figure 4, that relates Variance, Q and Ind.

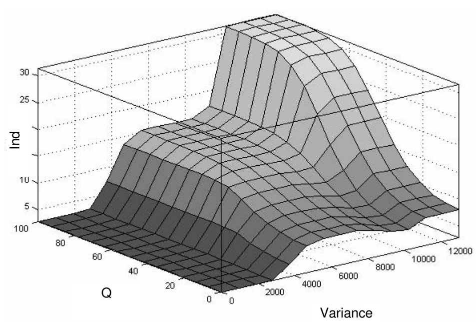

Figure 2. Relationship between Variance, Q and Ind

The proposed coding will generate a certain amount of additional information. As each sub-block is coded with a different normalization matrix, it is necessary to store, together with the data for the coded image, the index of the codebook used in the normalization of each sub-block. Thus, for a 32-matrices codebook, for example, each sub-block will receive additional 5-bits. If Nsb is the number of sub-blocks of an image and Nba is the number of additional bits for the sub-block, the total number of additional bits, Nbt, is given by Equation 7,

$$Nbt = Nsb \cdot Nba. \quad (7)$$

Equation 8 shows how it is possible to calculate the compression rate, Nbp, in bits/pixel, for the coded image,

$$Nbp = \frac{Nbc + Nbt}{Np}. \quad (8)$$

where Nbc is the number of bits used for coding the sub-blocks and Np is the number of pixels in the image. Thus, the smaller the value of Nbp, the higher is the compression rate.

V. RESULTS

For evaluation of the proposed coder, 100 echocardiography images acquired in real clinical exams have been used.

Equation 5 and the compression rate, as defined in Equation 8, were used for the objective evaluation of the coder, with respect to global SNR. In the subjective evaluation the visual satisfaction of the observer must be taken in consideration. The main goal of the algorithm proposed here is to maximize the compression rate while keeping the subjective quality of the image, through the imposition of a local criterion of quality. In order to obtain subjective evaluations of the method it would be essential to work with specialists in the medical area who can perform the evaluation. The subjective evaluation of the images has not been evaluated in this work, and it will be presented in future works. However, it is clear at this point that the results of this work should be very positive, since the method imposes a quality criterion to be reached.

In the evaluation of this algorithm, codebooks with 32 matrices and a Q of 10, 40, 70 and 90 were used. Table 1 compares the results for the standard and for the modified JPEG.

Table 1. JPEG x Modified JPEG

	Standard JPEG		Modified JPEG	
Q	Nbp (bits/pixel)	RSR global (dB)	Nbp (bits/pixel)	RSR global (dB)
10	0.243	10.973	0.394	11.377
40	0.480	16.141	0.570	16.665
70	0.688	20.552	0.578	17.120
90	1.075	28.241	0.648	17.579

Figure 3 shows the original image and Figure 4 shows the coded image.

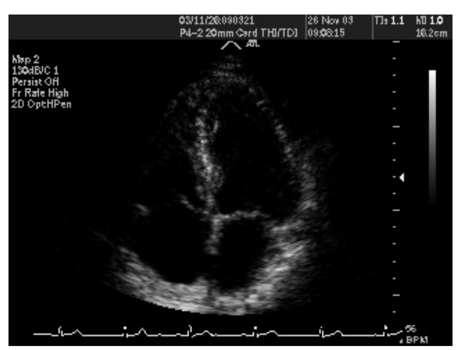

Figure 3. Original image 2

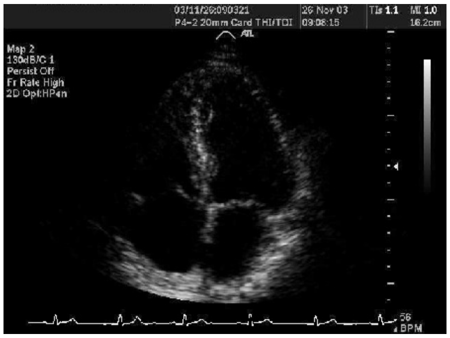

Figure 4. Coded image 2

VI. CONCLUSION

The JPEG algorithm is extremely powerful, yielding very high compression rates, but preserving the quality of the coded image. The techniques used in the JPEG algorithm are so efficient that it is unlikely that this standard will be surpassed just by introducing simple modifications of it. The group that created this standard is working on other methods for image compression that are based on more innovative paradigms. Many of these innovations were incorporated to the JPEG 2000 compression standard.

The initial motivation of this work was to improve the process of normalization of the transformed coefficients, suggested for the JPEG standard, in the hope of getting better compression rates in the coding of ecocardiograph images.

Regarding compression rate, the proposed algorithm has an inferior performance if compared to that of the JPEG standard. However, our algorithm has the advantage of allowing the user to guarantee a minimum local SNR, adapted to the characteristics of each sub-block. We believe that this feature will lead to images that have, subjectively, a better quality, even tough the gain in SNR seems only minor for lower values of Q. However, this belief will have to be tested in future works.

It is also important to say that this paper shows the results of the proposed algorithm only for coding of echocardiographic images. However it is reasonable to assume that the algorithm may be also useful for use in other kinds of digital medical images, for which accurate medical diagnosis is crucial.

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