Invited paper

STUDY ON OPTIMIZATION OF ARCHIVING CONDITION UNDER JPEG2000 AND ITS QUALITY EVALUATION FOR MEDICAL ULTRASONIC ECHO IMAGE

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Abstract

Medical ultrasonic echo image is indispensable diagnostic technique and a large number of the investigation is carried out every day. Therefore, the image compression technique is very important. Author has proposed a technique using Genetic Algorithm (GA) to optimize quantization condition in JPEG2000. The result has shown image quality evaluation by PSNR (the objective assessment) and one by ultrasonographer (the subjective assessment by PSNR) are sometimes not equivalent. In this research, some objective assessment methods and the subjective assessment are compared for 4 images whose diseases part and scanning method are different (image group A). The result shows the objective assessment by a contrast is more consistent with the subjective assessment than the objective assessment by PSNR. Next, proposed GA is modified by using the contrast factor and image group A to optimize an archiving condition. The compressed images by the modified GA are evaluated by the objective assessment by the contrast and the subjective assessment. In this experiment, other 4 images, which are not used to decide the archiving condition, are also used (image group B). As the result, the archiving condition is effective for not only image group A but also image group B. That means the results of the objective assessment by the contrast and the subjective assessment are equivalent whenever using the archiving condition optimized by the modified GA using some typical ultrasonic images. The result also suggests the objective assessment using the contrast factor can be used instead of the subjective assessment.

Keywords: Genetic algorithm, Image compression, Image quality evaluation, Medical ultrasonic echo image, Wavelet transform

Introduction

Medical ultrasonic echo image is indispensable diagnostic technique and a large number of the investigation is carried out every day. Therefore, the image compression technique is very important. JPEG baseline system is usually used for image compression. JPEG enables a user to optimize a condition of compression by control of the quantization table [1]. The quantization table defines the quantization step for each frequency component after DCT. The optimization of the quantization table for medical ultrasonic image has been investigated [2]-[4]. However, it is expected that JPEG2000 is more effective for medical image compression than JPEG since translation and dilation of mother wavelet in wavelet transform are similar to traveling of ultrasonic pulse wave and frequency dependent attenuation respectively. In addition, wavelet transform can select a kernel of transform, which is called mother wavelet. Therefore, wavelet transform which is used in JPEG2000 can express the features of medical ultrasonic echo image more than DCT [5]-[7].

Author has proposed the arithmetic method to optimize the quantization step in JPEG2000. This method decides the step according to a reciprocal number of an averaged wavelet coefficient in each frequency component. The results of this method have been evaluated highly by ultrasonographers in the quality of compressed images [8] and have shown better quality compared with the arithmetic method in the case of JPEG [9]. Unfortunately, however, one of the result of the subjective assessment of the image quality says the image quality of an image compressed by JPEG2000 is deteriorated, especially, in a low contrast region. In the case where ROI includes a low contrast region, the result of the subjective assessment about JPEG2000 doesn't show enough quality for diagnosis. Therefore, how the quantization step is optimized is remained as the most important problem.

Author has attempted to apply Genetic Algorithm (GA) to solve the problem. Although the arithmetic method uses the information in frequency domain only, GA uses not only frequency domain information but also space domain information, PSNR. PSNR is used as a condition of convergence of GA. This proposed GA method enables to optimize the quantization step while keeping the given PSNR level. As the result of experiment where an image with low contrast ROI is used, both of the result of the subjective assessment and the objective assessment (PSNR) show higher quality and lower bit rate than the arithmetic method case [10][11].

On the other hand, another important problem on medical image compression is how to evaluate the image quality, especially, the difference between the subjective assessment and the objective assessment. If the subjective assessment is required whenever an image is compressed, the working efficiency becomes lower. If a compression level where the quality of a compressed image can be highly evaluated by the subjective assessment has to be kept, the archiving efficiency becomes lower due to higher bit rate. Therefore, the objective assessment standard which is equivalent to the subjective assessment is strongly required.

Although PSNR is usually used for the objective assessment, its result is particularly different from the result of the subjective assessment in medical ultrasonic echo image compression [12]. This result suggests that PSNR cannot evaluate the quality of medical ultrasonic echo image which is not quantitative in the pixel value. Because PSNR evaluates the difference of pixel values though an absolute pixel value of medical ultrasonic echo image has little diagnostic information.

The purpose of this paper is to define a new method of the objective assessment whose result is equivalent to one of the subjective assessment. These are investigated : 1) preparing images which include low contrast ROI and whose region and method of scanning are different each other, 2) these images are compressed by the proposed GA, 3) the compressed images are evaluate some typical criteria for the quality of image, especially, for contrast, 4) selection of a criterion whose result is the closest to result of the subjective assessment, 5) The criterion is applied to the proposed GA as a condition of convergence instead of PSNR, 6) Other images (not in 1)) are compressed by the modified GA and the quality of image is evaluated by both the subjective assessment and the objective assessment.

The proposed GA and the quality evaluation of image

The proposed GA

The optimization method of the quantization step using GA [10][11] is described as follows.

Initial values of the quantization step (initial population) are set randomly on condition that the initial values include the standard value in JPEG2000 and value optimized by the arithmetic method. Wavelet transform level is fixed to three level. PSNR is used as fitness function and fitness value of the quantization step is calculated. Then a new population is generated by selection, crossover and mutation according to the fitness value. The rate of crossover is 80[%] and the rate of mutation is 5[%]. This process runs in several generations until the highest PSNR and compression ratio are achieved. The compression ratio is calculated from entropy of quantized wavelet coefficients by the obtained quantization step. Although the bit-plane coding is carried out in JPEG2000 originally, no coding process is carried out in this paper.

The quality evaluation of image by the subjective assessment

The image quality is evaluated by not only PSNR as the objective assessment but also ultrasonographers from Tokai University Hospitals as the subjective assessment. The process of the subjective assessment is as follows:

(1) 6 types of compressed image are generated within range of 30[dB] to 35[dB] in PSNR.
(2) The compressed image generated in 1) are presented randomly to ultrasonographers. Each compressed image is compared with original image.
(3) The information of image such as PSNR and compression rate are not given.
(4) The quality of image is classified into 3 levels as "an image can be archived in database as original image", "an image cannot be stored as original image but can be used for practical diagnosis" and "an image cannot be used for diagnosis".

In ref.[11], 4 kinds of ultrasonic echo image were used and 12 ultrasonographers took part in the subjective assessment.

Problem of the quality evaluation of image

If the results of the subjective assessment and the objective assessment show consistent positive correlation, the objective assessment only can be used to decide the compression ratio without the subjective assessment. As the result, working efficiency becomes higher. However, in the case of medical ultrasonic echo image compression, there are many cases where the results of the subjective assessment and the objective assessment do not show the same tendency. In previous research by author, a breast image showed this tendency significantly as shown in Figure1 [11].

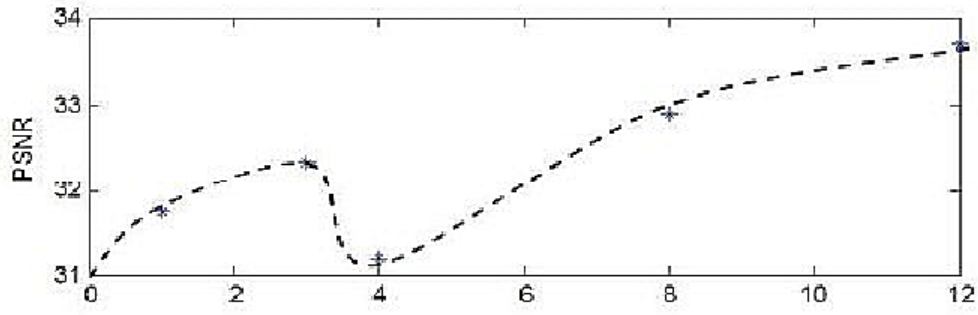


Figure 1. The relationship between the objective assessment (PSNR[dB]) and the subjective assessment in the case of breast image compression. X-axis shows the number of ultrasonographer who answered "the image could be used as original image".

Experiment of the quality evaluation of image

Conditions

Five objective criteria are used to evaluate the quality of compressed image. The results are investigated compared with the result of the subjective assessment. Reference images, compressed images and the result of the subjective assessment are come from Reference [11].

The reference images are shown in Figure 2. These are selected from points of view where ROI includes low contrast region, different scanning method and different region. The size of image is 512 pixel x 512 pixel x 8 bits in depth.

The five criteria to evaluate the quality of compressed image are selected from the quality evaluation methods related to contrast or variance factor. Because medical ultrasonic echo image is not quantitative and has important feature in edge information (at tissue-tissue interface). The equations are shown in Equation (1) to Equation (5). $x(i,j)$ and $y(i,j)$ are reference image and compressed image respectively.

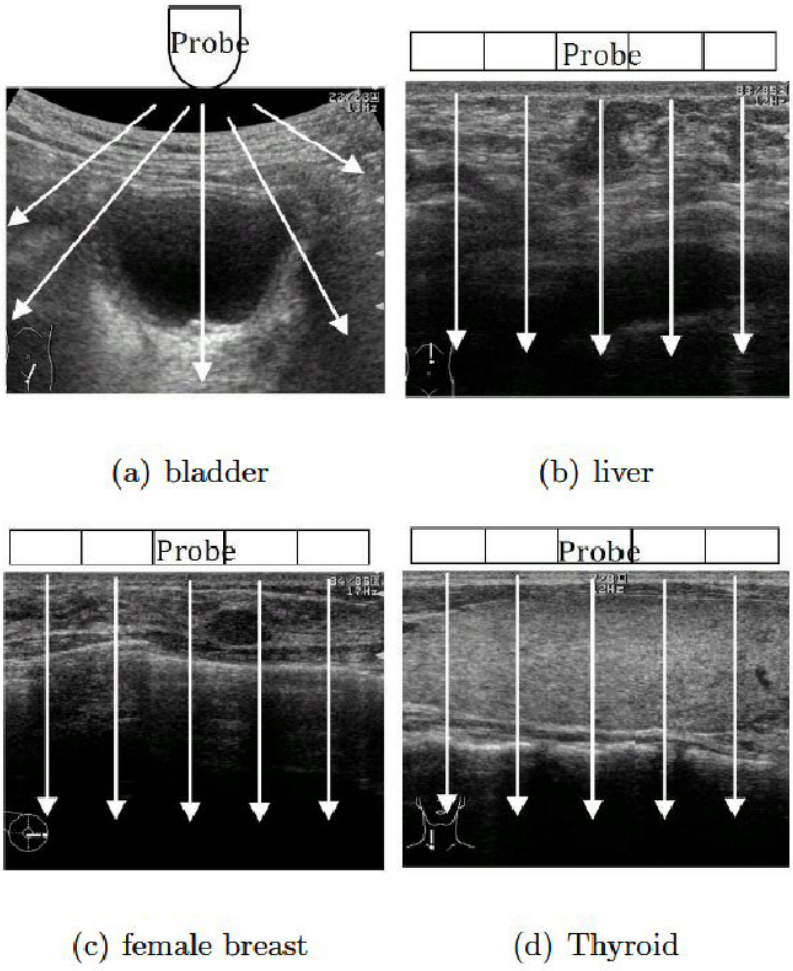


Figure 2. Reference images. Only bladder image was taken by a convex probe which insonified ultrasonic pulse beam as fan shape. Other regions (liver, female breast and thyroid) were taken by linear array probe which insonified ultrasonic pulse beams parallel each other.

Equation (1) Standard Deviation (SD)

$$\sigma_x^2 = \frac{1}{512 \times 512} \sum_{i=0}^{511} \sum_{j=0}^{511} (x_{i,j} - \bar{x})^2$$

$$SD = \frac{\sigma_y}{\sigma_x} \times 100[\%]$$

Equation (2) Contrast Comparison [13]

$$contrast = \frac{2\sigma_x \sigma_y}{\sigma_x^2 + \sigma_y^2}$$

Equation (3) Universal Quality Index (Q) [13]

$$Q = \frac{4\sigma_{xy} \bar{x} \bar{y}}{(\sigma_x^2 + \sigma_y^2)(\bar{x}^2 + \bar{y}^2)}$$

where

$$\sigma_{xy} = \frac{1}{512 \times 512} \sum_{i=0}^{511} \sum_{j=0}^{511} (x_{i,j} - \bar{x})(y_{i,j} - \bar{y})$$

Equation (4) Spatial Frequency Measurement (SFM) [14]

$$SFM = \sqrt{R^2 + C^2}$$

where

$$R = \sqrt{\frac{1}{512 \times 512} \sum_{i=0}^{511} \sum_{j=0}^{511} (x_{i,j} - x_{i,j-1})^2}$$

$$C = \sqrt{\frac{1}{512 \times 512} \sum_{i=0}^{511} \sum_{j=0}^{511} (x_{i,j} - x_{i-1,j})^2}$$

*comparison between SFM of reference image and SFM of compressed image.

Equation (5) Laplacian Mean Square Error (LMSE)

$$LMSE = \frac{1}{512 \times 512} \frac{\sum_{i=0}^{511} \sum_{j=0}^{511} (L(x_{i,j}) - L(y_{i,j}))^2}{\sum_{i=0}^{511} \sum_{j=0}^{511} (L(x_{i,j}))^2}$$

where

$$L(x_{i,j}) = x_{i+1,j} + x_{i-1,j} + x_{i,j+1} + x_{i,j-1} - 4x_{i,j}$$

Result

Figure 3 shows the relationship between the subjective assessment and the objective assessment (SD).

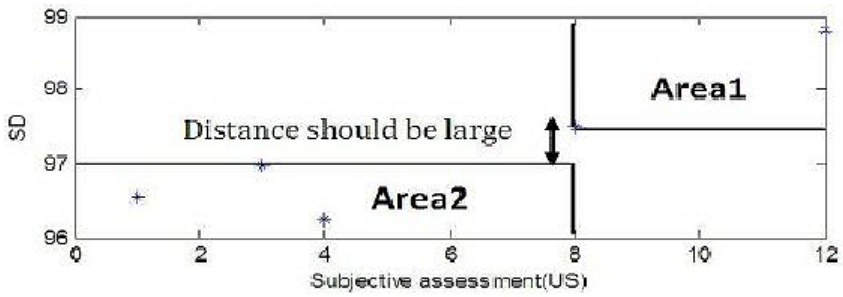


Figure 3. The relationship between the objective assessment (SD) and the subjective assessment in the case of breast image compression. X-axis shows the number of ultrasonographer who answered "the image could be used as original image".

The five criteria defined by Equation (1) to Equation (5) in 3.1 are investigated. Unfortunately, however, there is no criterion which shows consistent positive correlation between the subjective assessment and the objective assessment. Therefore, this research defines which criterion is the best as follows: First, a area where two third or larger than two third of ultrasonographers determines that the image can be used for practical diagnosis is extracted. This process defines Area1 in Figure 3. And the lowest value of the objective assessment in the area is decided. Secondly, by the same way, a area where less than two third of ultrasonographers determines that the image can be used for practical diagnosis is extracted. This process defines Area 2 in Figure 3. and the highest value of the objective assessment in the area is decided. Finally, the difference between the values of Area1 and Area 2 is calculated. A criterion which shows the largest difference is defined as the best criterion for the objective assessment whose relationship with the subjective assessment is consistent positive correlation.

The comparison among the five criteria after normalization is shown in Figure 4. This result is regarding female breast image (Figure 2(c)) which shows the lowest correlation between the subjective assessment and the objective assessment. As the result, (2) Contrast can be defined as the best criteria for the objective assessment. In this case, the lowest value of contrast in Area1 is 0.9997.

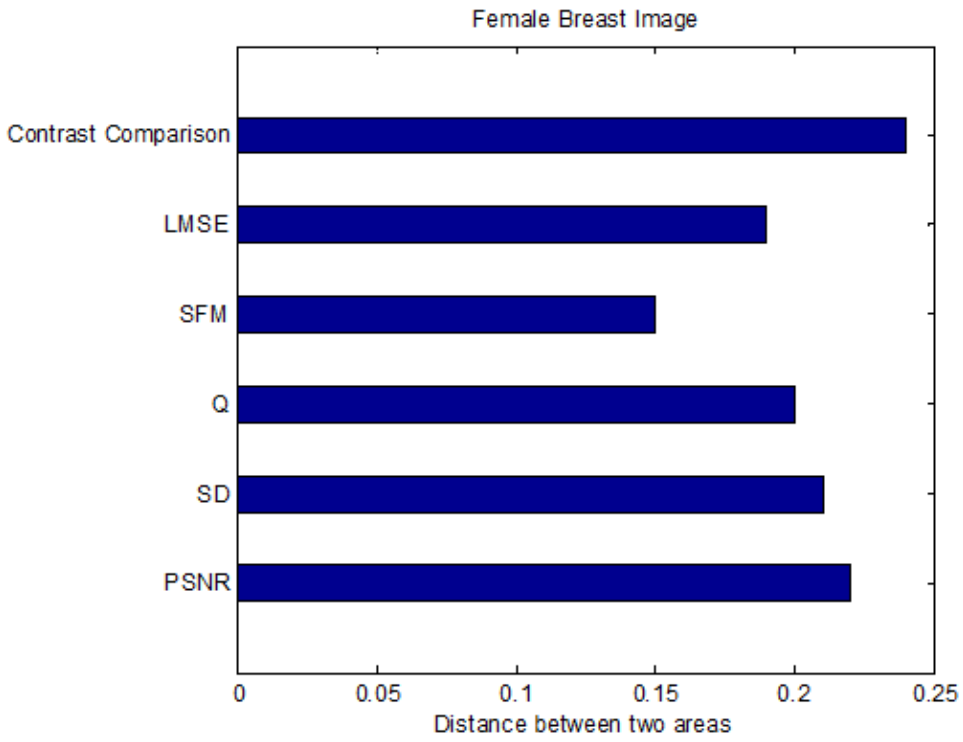


Figure 4. The comparison of the 5 criteria in the case of female breast image

Modification of GA

From the result in 3.2, the fitness function of GA to optimize the quantization step is changed to contrast from PSNR. This is called the modified GA. Figure 5 shows a result of image compression experiment (female breast, Figure 2(c)) by the modified GA.

The relationship between the value of contrast and the number of ultrasonographer who judges the quality of image enough for diagnosis shows consistent positive correlation. A border where two third of ultrasonographers answers "the image quality is enough for archiving as original image" is around 0.9997 in contrast.

Next, to show this result is independent of images (Figure 2), the modified GA is applied to other medical ultrasonic images. The images are shown in Figure 6 and the results are shown in Figure 7.

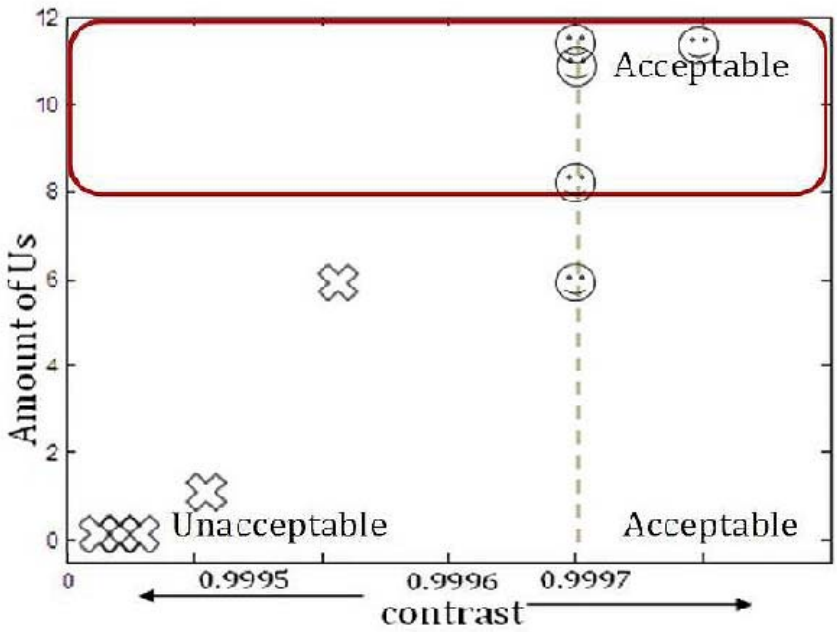
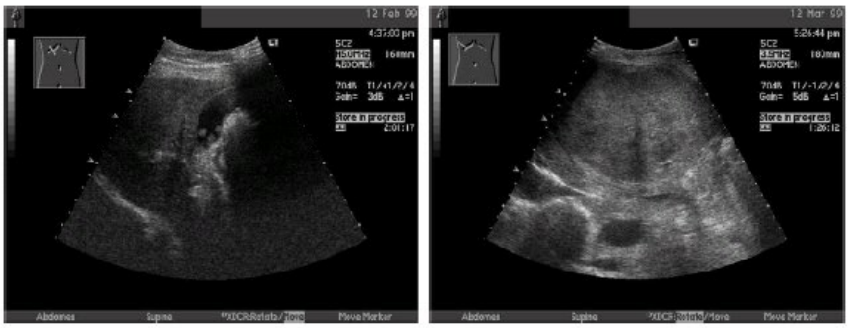
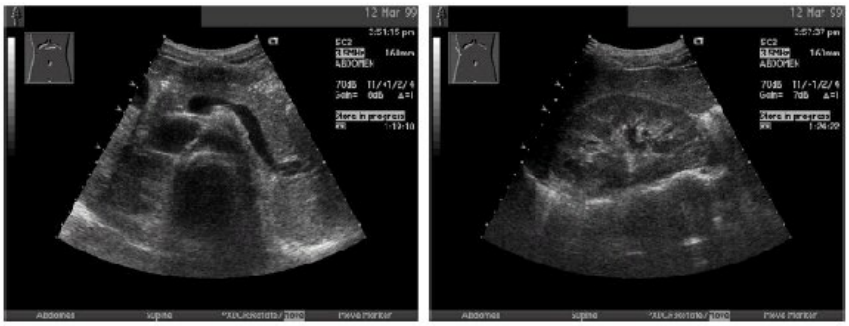


Figure 5. The result of the modified GA in the case of female breast image. The relationship between contrast and amount of US (the number of ultrasonographer who answered the image quality is enough for archiving as original image) indicates consistent positive correlation. A border of two third of ultrasonographers (8 ultrasonographers) is around 0.9997 in contrast.

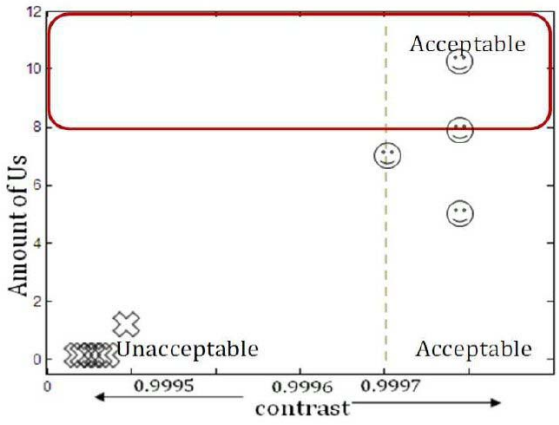


(a) Medical1 (b) Medical2

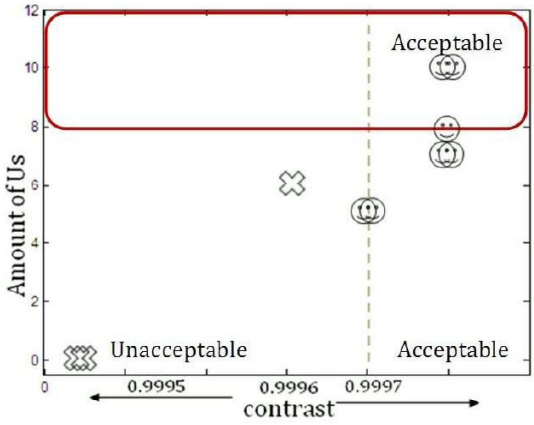


(c) Medical3 (d) Medical4

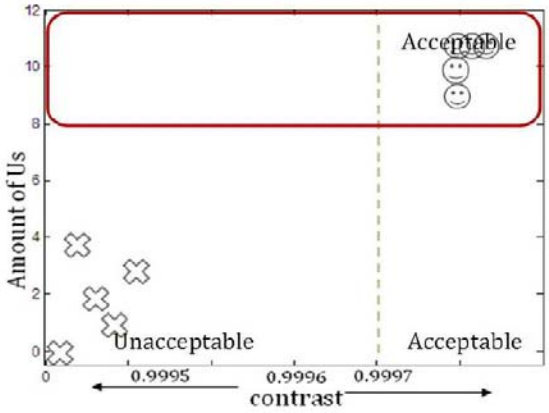
Figure 6. Reference images which are not used to optimize the quantization step. These images are used to prove that the optimized condition does not depend on an image.



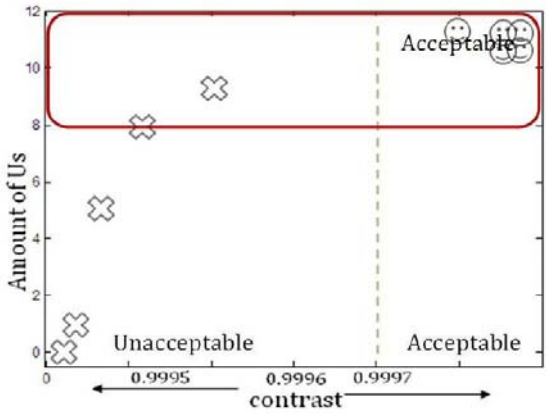
(a) Result of Medical1



(b) Result of Medical2



(c) Result of Medical3



(d) Result of Medical4

Figure7. The results of the modified GA in the case of images in Figure 6

Figure 7 shows the same tendency as Figure 5 in every image. It is also shown that two third or more than two third of ultrasonographers judges the quality of image is enough for archiving as original image whenever contrast is more than 0.9997. As the result, it is suggested that contrast is a criterion of the objective assessment which can evaluate the quality of medical ultrasonic image equivalently to the subjective assessment and the value at the border where an image can be archived as original image is 0.9997.

Conclusions

This paper investigates a problem regarding the difference between the subjective assessment and the objective assessment in the quality evaluation of compressed medical ultrasonic echo image. In this research, medical ultrasonic echo image are compressed by using JPEG2000 based on wavelet transform and the quantization step is optimized by GA. Since previous research result suggests the difference is significant in the case of female breast image, an image of female breast is examined mainly in this paper. Six criteria of the objective assessment including PSNR are compared with the subjective assessment by 12 ultrasonographers. The results show an evaluation result by contrast shows equivalent evaluation to the subjective assessment. As the result, it is suggested that contrast is a criterion of the objective assessment which can evaluate the quality of medical ultrasonic

image equivalently to the subjective assessment and the value at the border where an image can be archived as original image is 0.9997. And it is also shown that this result is independent of a kind of medical ultrasonic image.

These are remained as future work that how to decide the optimized quantization step not to depend on a kind of image and a criterion of the quality of image without reference image.

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