Medical Informatics Europe '96
J. Brender et al. (Eds.)
IOS Press, 1996

Comparative Evaluation of Lossless Image Compression Techniques on Mammograms

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Abstract. Image compression has an increasing role in modern medical imaging affecting the preservation of the diagnostic information. In this paper a comparative evaluation of lossless techniques was performed by means of both subjective and objective criteria. Upon X-ray breast and breast phantom images (mammograms) the Lempel Ziv technique has provided the best performance results. Phantom images could be considered as objective reference images for the classification of image compression techniques and for the operational design of Medical Images Communication Systems.

1. Introduction

Modern Medical Imaging Systems (MIS) have to manipulate and synchronize high quality and size digital images with different "attributes and diagnostic value". [1]. Also, synchronization of the actions of geographically distributed MIS end-users demands the distribution of image examinations within restricted time margins [2] (e.g 2s in [3] irrespectively of the type and the number of included images per examination.

Reduction of the amount of image data with a parallel preservation of their "diagnostic value", is achieved through the use of the appropriate compression technique. Hitherto, a lot of effort has been invested in the evaluation of the performance of different image compression techniques applied upon different types of medical images [4-6]. The evaluation and the classification of each technique, according to the resulted "diagnostic value", has been made by means of: *subjective criteria* (different observers classified the resulted compressed images) [6], *objective criteria* (e.g. compression ratio, bit rate, computational time, Mean Square Error - MSE) [5] or *both objective and subjective criteria* [4].

However, direct utilization of these results in the modelling of MIS functionality is not possible, since non commonly accepted prototype images and criteria have been posed. This paper proposes a general methodology and criteria to evaluate the performance of different compression techniques based upon the:

a) *comparison of both compressed patient and reference images.* Typical patient mammograms and the TOR(MAX) Leeds breast phantom as reference image were used.

b) *standard mixed evaluation criteria.* Subjective criteria yielded by the general European Quality Criteria are employed for the quality control of the diagnostic X-

Ray modalities [7]. Objective criteria include MSE, compression ratio and computational time.

The utilization of phantom images opens new perspectives on the objective classification of compression techniques. The phantom should be used as a standard pattern for classifying image compression techniques, and determining the operational attributes of special communication protocols, within the distributed MIS [1].

2. Materials and Methods

The comparative evaluation of compression techniques was performed by applying them on breast and breast phantom images. Breast images were chosen because they require low contrast detectability and high spatial resolution. This is due to the absence of tissue with various atomic numbers within the breast, as well as, in the possible presence of small sized calcifications [11]. The Leeds TOR(MAX) breast phantom, one of the mammographic phantoms more widely used in quality control and in comparative evaluation of mammographic systems [12] was used. Its physical and geometrical characteristics mimic microcalcifications and low contrast lesions, which are important clinical indications. The phantom comprises a semicircular test plate (Figure 1) providing a realistic degree of X-ray attenuation during exposure [13].

The following implementation platforms were used:

- a SUN ELC SPARCstation with 8 Mbytes RAM, two SCSI hard disks (300 and 400 Mbytes) and a monochrome 19" monitor,
- a SUN IPC SPARCstation with 8 Mbytes RAM, a 200 Mbytes SCSI hard disk and a colour graphics 19" monitor, and
- a UMAX UC1200S Professional Scanner, interconnected in a LAN.

The employed image compression software includes:

- the Huffman, Adaptive Huffman and Lempel Ziv algorithms included into the SunOS 4.1.1 UNIX operating system,
- the Run Length [8] and Predictors [9,10] algorithms developed by the authors using the SUN SPARCstations C programming language.

Breast and breast phantom images were obtained with a mammographic unit (Mammomat - Siemens) under typical exposure conditions (28 kVp).

The mammograms were scanned taking into consideration that the size of original images varies, as it is possible for the diagnostic interest to be focused on the whole mammogram or within a bounded part (Region Of Interest- ROI) of it, and/or a test object of the phantom. Irrespectively of the size of the original image or ROI, the resulted image after the scanning has to be in standard size. Hence, different spatial resolution (varying from 100 to 1200 dpi) have been applied on original images, ROIs or test objects. Each pixel has an 8-bit constant depth (256 grey levels) and all resulted images have been organized according to the TIFF format.

The image compression algorithms have been applied separately to breast and breast phantom images. Also, combinations of the above algorithms have been applied. The examined coding techniques are listed in Table 1.

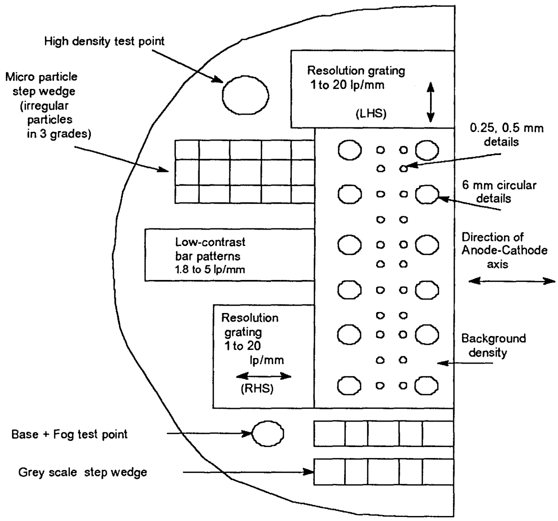

Figure 1: The Phantom Structure

The interpretation of the reconstructed images was based upon:
I. subjective criteria, such as visibility of fine details, spatial resolution in lp/mm, contrast, histogram matching and the subtracted image between the original and the reconstructed image, and
II. objective criteria, such as Mean Square Error (MSE), compression ratio and computational time.

MSE was calculated using the formula: $MSE = \frac{1}{N^2}\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}[f(x,y) - f'(x,y)]^2$

where f(x,y) and f'(x,y) denote pixel values of the original and the reconstructed image at the position (x,y), respectively. Also, the compression ratio is defined as the compressed to uncompressed data ratio (%).

To compare the various compression algorithms, first two, from the phantom test objects were selected: the test grating measuring spatial resolution and the micro-particle step wedge grating. Then we selected the patient images, digitized, compressed, decompressed and demonstrated them. The final evaluation of all reconstructed images was performed on the SUN IPC SPARCstation monitor. The quality test was carried out by visually comparing uncompressed and compressed images after the application of the different compression techniques. The images were presented to 6 observers in a random sequence. The observers viewed the reconstructed images and assigned an overall quality level for each image. The general European quality criteria employed in diagnostic radiology [7], were used as the basis to introduce a scale rate for evaluation of decompressed images. This rating scale method distinguishes five categories: 1 (bad), 2 (poor), 3 (fair), 4 (good) and 5 (excellent). A technique is characterized as optimum if it: a) maintains the diagnostic value of the image (diagnostic information), b) reduces the amount of data to the greatest extent possible, and c) requires the shortest computational time.

3. Results and Discussion

Table 1 depicts the compression ratio and computational times for ten different lossless compression techniques (A1 to A10). The Lempel Ziv technique (A3) provides the optimum compression ratio (up to 28.75%) as well as a very short computational time. Huffman (A1) and Adaptive Huffman (A2) provide comparable compression ratios (46.1%). However, A1 requires less computational time than A2. The Predictor based techniques (A4 to A9) provide worse results than the non-Predictor (A1 to A3). Involvement of Predictor 1 (A4 to A7) leads the subsequent lossless coders to a compression ratio increased about 18% in respect to cases A1 to A3; involvement of Predictor 2 leads also to an increment of about 8-10%. The Run length technique (A10) has the shortest computational time the worst compression ratio. When compressing the spatial resolution grating of the phantom, A10 provides slightly better results (47.41%) been similar to A1 and A2 techniques (46.1%); that is due to the existence of large black and white coloured regions.

Table 1: Computational Time (CT) and compression ratio for lossless compression techniques of phantom and breast images.

Code	Lossless Compression techniques	CT (s)	Compression ratio (%) Phantom Image TL	SR	MPSW	Breast Image
A1	Huffman	3.6	40.9	53.9	33.4	41.8
A2	Adaptive Huffman	10.7	40.94	53.89	33.41	41.79
A3	Lempel Ziv	2.4	71.25	68.9	64.84	65.69
A4	Predictor 1 - Huffman	10	22.1	25.9	28.7	21.7
A5	Predictor 1 - Ad. Huffman	20	22.08	25.81	28.72	21.67
A6	Predictor 1 - Lempel Ziv	8	60.88	55.9	62.7	56.4
A7	Predictor 2 - Huffman	9	29.7	25	28	29.8
A8	Predictor 2 - Ad. Huffman	19	29.63	24.99	28	29.71
A9	Predictor 2 - Lempel Ziv	8	63.28	54.61	61.6	59.23
A10	Run Length	1	16.25	52.59	11.8	16.17

TL: Total phantom image
SR: Region of the phantom corresponding to the Spatial Resolution object
MPSW: Region of the phantom corresponding to the Micro-Particle Step Wedge object

By considering the above results, one notices that the utilization of both objective and subjective evaluation criteria, has lead to very similar evaluation results. Our results are in accordance with those been described in [4-7]. Moreover, we notice that our analysis, has lead us to accept the results of the phantom images analysis as the upper performance bound, beyond which, worse or unspecified cases result. The performance of any compression technique, applied on any type of mammograms, could be rated in reference to this upper bound. Consequently, due to its special test objects, the phantom can be used as a standard pattern assisting in the evaluation of any image compression technique, or in the determination of the operational attributes of a special Communication Service Element.

In [1] an image communication performance scenario is presented, where the performance of Lempel-Ziv technique is discussed in respect to the total transmission time, the network bandwidth, and the performance capabilities of the end-users. It has been proved that this technique provides acceptable results ant it is suggested to be used as the basis for the implementation of appropriate communication protocols.

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