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ANALYSIS OF THE COMPRESSION RATIO AND QUALITY IN MEDICAL IMAGES

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Abstract. In the modern medical information systems documents are stored in the centralized storage. Choosing a proper, for the medical image storage, compression format is an important problem. This paper analyzes medical image compression in popular compression formats. For the compression format comparison there is proposed image quality evaluation algorithm based on the calculation of the mean exponent error value. Presented image quality evaluation experiment. Analyzed the distribution of the errors in medical images and explained the causes determining better than usual compression effect. Proposed complex solution of the medical image compression problem and specified compression format most suitable for the medical images.

Keywords: Compression, quality, algorithm, digital images.

1. Introduction

Most popular digital image format in medicine is DICOM (**D**igital **I**maging and **Co**mmunications in **M**edicine). DICOM isn‘t just a digital image-coding format. It is a comprehensive set of standards for handling, storing and transmitting information in medical imaging. It includes a file format definition and a network communications protocol. This protocol is an application protocol, it uses TCP/IP to communicate between systems. DICOM was developed to enable integration of scanners, servers, workstations and network hardware from multiple vendors into a picture archiving and communication system. DICOM file contains:

- Header with standardized as well as free-form fields.
- Body of image data.

One file can contain one or more images. It can be even animated sequence. Image data can be compressed using a variety of standards, including JPG, JPG2000, PNG, GIF, LZW and Run-length encoding (RLE). One of the key DICOM features is that medical images are always in the same file as the information about patient. More about DICOM in [1, 2]

When talking about quality, image compression algorithms can be divided into two groups:

- Algorithms, which compress images without data loss.
- Algorithms, which compress images with data loss.

PNG, LZW and RLE belong to the first group [3-5]. Such images can be restored to its original state at any time. GIF format also saves images without data loss but there is a condition required: images must be monochromatic with 8-bit intensity depth. JPG always-loose data when compressing images [6], JPG 2000 can perform in both ways. Lossy image compression gives higher ratio.

In the modern medical information management systems image compression storages meet dual and contradictory requirements. Content of the medical images must be saved with minimal information loss and highest compression ratio because of a big size.

This paper describes the search of compromise solution to identify the image compression method giving highest compression ratio and smallest image information loss. For this purpose it is proposed to compare compression methods using mean exponential error criteria. During analysis selected image compression formats are analyzed experimentally. Identified and proposed the most appropriate, for the medical images, compression solution.

2. Method for the image compression quality comparison

There are two different image compression methods: image compression with quality loss and without loss [7, 8].

Images compressed using first method can be restored to their previous state without distortion at any time. The second group of image compression methods compresses with better ratio, but there always are differences after image is restored from its compressed state. These differences can be bigger or smaller. In many image usage cases small differences are acceptable. When it is required to say whether differences are acceptable or not – distortion should be measured.

One of the ways to measure differences between original and compressed image is to calculate mean exponential error. This method was chosen because it accumulates exponential error from every image pixel. This means that even smallest differences will be evaluated. Mean exponential error is described by the following equation:

$$D = \frac{1}{N}\sum_{i=1}^{N} e^{\left|A_i - A_{gi}\right|}, \qquad (1)$$

where: D – mean exponential error, N – number of pixels in the image, A – intensity of the pixel i from the original image, A_{gi} – intensity of the pixel i from the compressed image.

Originally images are rectangular. For the real images, this expression must be modified. Rectangular images have two dimensions: X and Y. Modified for the two dimensional arrays (1) looks like this:

$$D = \frac{1}{X}\frac{1}{Y}\sum_{i=1}^{X}\sum_{j=1}^{Y} e^{\left|A_{ij} - A_{gij}\right|}, \qquad (2)$$

where: D – mean exponential error, X – image width, Y – image height, A_{ij} – intensity of the pixel ij from the original image, A_{gij} – intensity of the pixel ij from the compressed image.

Expression (2) already can be used for the calculation of mean exponential error in gray images. But pixels of the color images require more than one value for the description of the exact color. For this purpose, in the color images, color bands are used. For example, in the recently most usable color coding system RGB – there are three color bands: red, green and blue. The exact color of the image pixel is described by the combination of intensities from each color band. Gray images have only one band, RGB – three. Also there are color-coding systems with four bands and other. Expression (3) adapted for color images looks like this:

$$D = \frac{1}{X}\frac{1}{Y}\frac{1}{C}\sum_{i=1}^{X}\sum_{j=1}^{Y}\sum_{k=1}^{C} e^{\left|A_{ijk} - A_{gijk}\right|}, \qquad (3)$$

where: D – mean exponential error, X – image width, Y – image height C – number of color bands, A_{ijk} – intensity of the pixel ij in the color band k from the original image, A_{gijk} – intensity of the pixel ij in the color band k from the compressed image.

3. Implementation of the image comparison algorithm

At the beginning implementation must read image parameters. This means that it must determine image width, height and number of bands. Image width and height sets the size of the two-dimensional image intensity data array, number of bands – the count of arrays. Each band has its own array. When comparing two images of type gray, there will be two arrays. In the case of RGB color images, there will be six arrays.

When structure of the image is identified, implementation must read image data. The result of this action is two sets of pixel intensity arrays of the same structure.

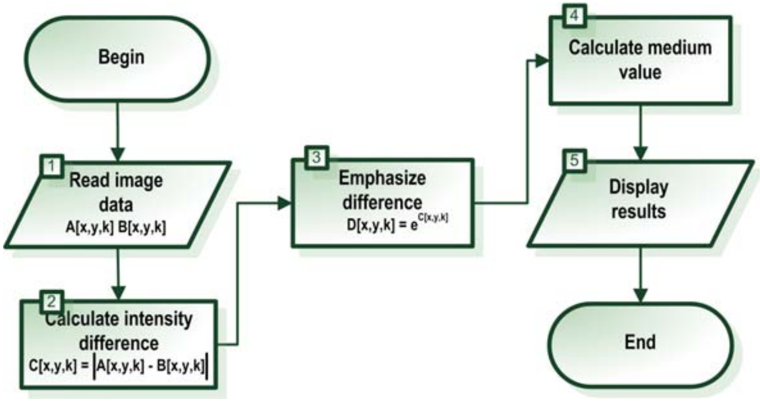

Figure 1. Image compare method implementation algorithm

Block (2) in the Figure 1 illustrates the calculation of pixel intensity difference. Corresponding pixel intensity values in the original and compressed images are subtracted. The Result of this action is the third set of pixel intensity arrays.

Detected differences are revealed in the block (3). Exponent of the base e is calculated for each pixel. This operation highlights small difference values which are also important but hard do detect. Image formed out of calculation results is called error map. Map is shown in Figures 2 and 3. In Figure 2 differences are hardly visible whereas in Figure 3 the view is clear. Without such operation small error values have similar low intensity and human eye simply can't recognize it.

Next algorithm block (4) calculates the final product – mean exponent error. All image pixel intensities from all color bands are summed up and the result is divided by number of pixel in the image. The Final result of such calculations is one number, which represents image quality. The value of 1.0 means that two images are identical, bigger values means bigger differences between images.

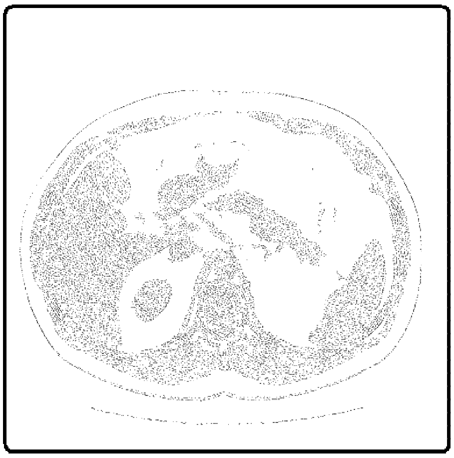

Figure 2. Image intensity difference map

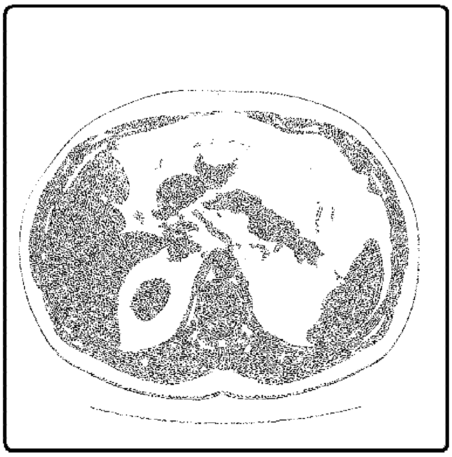

Figure 3. Exponent image intensity diff. map

4. Image compression quality analysis background

Several digital image coding formats were analyzed using software based on the algorithm described in the previous section. The goal of the analysis was to determine which compression algorithm saves images with highest quality at the highest compression ratios. Image coding formats used in the analysis were following: JPG, JPG 2000, GIF, PNG, TGA (with RLE compression), TIF (with LZW compression).

Two pools of digital images were selected for the analysis: monochrome medical images and generic color images.

Monochromatic images selected for the analysis are DICOM images with intensity depth of 12 bits. Images were acquired from ultrasound, magnetic resonance, computer tomography, X-ray medical equipment. Before calculations DICOM images were converted to 8 bit BMP images.

Color images selected for the analysis are 24 bit BMP images. Images were acquired with digital photo camera by taking pictures of the surroundings.

Before analysis, sample images were converted to several different image store formats. Selected formats use different image compression algorithms. Most interesting analysis objects were:

- Image quality.
- Image file size.

According to quality, image compression algorithms can be divided into two groups:

- Algorithms, which compress images without data loss.
- Algorithms, which compress images with data loss.

PNG, TIF/LZW and TGA/RLE belongs to the first group. GIF format also saves images without data loss but there is a condition required: images must be monochromatic with 8 bit intensity depth. Calculation results are presented in Tables 1 and 2.

Table 1. Monochrome image compression analysis results

Format	Size, KB	Size, %	Error
BMP	3917	100	1,0
GIF	2194	56	1,0
PNG	1902	49	1,0
JP2 (bp)	1410	36	1,0
TIFF/LZW	2236	57	1,0
TGA/RLE	2639	67	1,0
JP2 (100)	1410	36	1,0
JPG (100)	1561	40	1,1
JP2 (66)	214	6	28,0
JPG (66)	351	9	19,4
JP2 (33)	83	2	37,2
JPG (33)	233	6	27,5

Table 2. Color image compression analysis results

Format	Size, KB	Size, %	Error
BMP	3840	100	1,0
GIF	749	19	46,5
PNG	2216	57	1,0
JP2 (bp)	1806	47	1,0
TIFF/LZW	3873	99	1,0
TGA/RLE	3756	96	1,0
JP2 (100)	1806	47	1,0
JPG (100)	1047	27	10,7
JP2 (66)	163	4	38,2
JPG (66)	199	5	42,0
JP2 (33)	60	2	50,8
JPG (33)	122	3	51,5

5. Image compression quality analysis results

According to the analysis data, the best compression ratio without data loss is given by JPG 2000. Images stored in this data format need only approximately 40% of space required by uncompressed data. Similar results were achieved in the statistical medical image compression analysis described in [9]. About 50 percent ratio was given by PNG. GIF, TIF/LZW and TGA/RLE formats, gave approximately 60 percent compression ratio.

In the case of generic color images, GIF already gives an error. This error is approximately equal to the error of pictures compressed with JPG at 33 percent of quality. JPG 2000 ratio is about 10 percent lover than it was in medical images. TIFF/LZW and TGA/RLE methods are completely useless with generic color images.

In medical applications, distorted images are not allowed. The cost of incorrect medical decision made after analyzing distorted medical image is too high. Lossy image compression for medical images is inappropriate. Coming out of this limitation, according to results given in Tables 1 and 2 the best image format for storing medical images is lossless JPG 2000.

Compressing images with lossy compression formats gives much better ratios. JPG format is always lossy. Storing images in JPG at its best quality already gives small error while the results are worse than in the case of lossless JPG 2000. Setting lower quality in the JPG gives much higher compression ratios. For example, saving images in JPG at quality of 33 percent compresses image size approximately 10 times, at 66% about 15 times. Comparing quality of JPG and lossy JPG 2000, results are almost the same. Results of lossy color image compression are a bit different. Exponential error at the same ratios is much higher. The Ratio achieved with lossless JPG 2000 gives exponential error ~40, the same error level in medical images was achieved only compressing images with JPG 2000 at 33% percent quality level, where compression ratio was 50:1.

The reason of higher monochrome image compression ratio is visible in Figure 3, where compression error map is presented and Table 3, where exponential error values are calculated for all of the image segments.

Medical images have a lot of regions where intensity is changing slowly or even have a constant value. This feature is determined by medical equipment. Images are generated digitally and information is concentrated only in part of the image. From the image compression error maps, it is visible that biggest compression error values are located in the image parts with quickly changing intensity.

In Figure 3 such regions can be recognized as dark black regions. To express error distribution in numeric value the same image was divided into 64 sectors (8×8). Mean exponential error was calculated for each of them. In Table 3 mean exponential error values are given for each sector of the image compressed with JPG at the quality of 66 percent. These data show that even compressing images with lossy compression method such regions are compressed without errors. Lowering compression quality to 33% didn't affect the set of sectors with error value 1.0. This means that such sectors can be compressed with lossy compression at the worst quality, but reconstructed image will be still the same as the original one. Such medical image feature also explains why the most simple compression methods such as LZW or RLE gave reasonable results when compressing medical images, but performed poorly when compressing generic color images.

Table 3. Error values in the different image sectors

1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
1,00	1,00	2,04	5,71	3,73	2,99	1,00	1,00
1,16	14,80	13,40	19,95	37,05	30,40	13,07	1,25
7,26	19,01	28,27	33,61	56,34	40,44	10,12	9,76
15,83	36,95	34,18	11,90	19,35	3,22	1,94	26,02
20,20	9,04	1,00	24,66	24,37	1,25	15,34	18,20
2,54	15,63	19,40	39,23	28,26	27,26	11,18	1,78
1,00	1,92	5,07	6,94	6,57	3,57	1,67	1,00

In Figure 3 such regions can be recognized as dark black regions. To express error distribution in numeric value the same image was divided into 64 sectors (8×8). Mean exponential error was calculated for each of them. In Table 3 mean exponential error values are given for each sector of the image compressed with JPG at the quality of 66 percent. These data show that even compressing images with lossy compression method such regions are compressed without errors. Lowering compression quality to 33% didn't affect the set of sectors with error value 1.0. This means that such sectors can be compressed with lossy compression at the worst quality, but reconstructed image will be still the same as the original one. Such medical image feature also explains why the most simple compression methods such as LZW or RLE gave reasonable results when compressing medical images, but performed poorly when compressing generic color images.

According to the results of the analysis, lossy image compression gives much higher ratios, than lossless methods. But as it was mentioned before, distorted images are not acceptable in the medicine. Anyway, lossy methods can be used in the image transfers where channel bandwidth is low.

Transferring of the whole image compressed lossless with ratio 2:1 may take too long. Solution in such case could be:

1. Transferring of the lossy compressed image as the image map. Ratios there can be 50:1 and higher while it is still possible to understand the content of the image.
2. Selecting region of interest.
3. Transferring lossless image of the selected region.
4. Transferring the rest of the image as the background job.

Such a workflow would require transferring of excess data through the communication channel, but the decision based on the transferred image review could be made faster. Standard compression methods do not allow using such workflow without sending excess data, but it is possible to develop a method, which would let reuse data already sent in step 1 for the rest of transferring steps.

6. Conclusion

1. Created image compare method detects even smallest compression errors. The method gives two possible outcomes. Numerical value, for expressing image similarity in numbers and determining algorithm giving the best compression quality. Error map, for describing which image regions are compressed with biggest error. Error map helps to analyze image compression specific.

2. Best results from the group of lossless compression algorithms were shown by JPG 2000. When compressing lossy, JPG and JPG 2000 give very similar results.

3. Medical images have a lot of regions where intensity is changing slowly or even have a constant value. Such regions are compressed with higher compression ratio. Regions where intensity is constant are compressed without errors even with lossy compression

4. In medical applications image distortion is not acceptable. This limitation sets the requirement to use lossless compression only. According to the results of the analysis, images stored in lossless JPEG can achieve compression ratios up to 1:2. Transferring such images can take undesirably long if the bandwidth of the channel is low. Problem solution can be transferring of the lossy compressed image map. The ratio reaches 1:50 there. The image map allows user select required region of interest, which should be transferred, lossless first of all. Performing in such way most important information can be transferred faster.

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