Comparison of Digital Image Compression Methods in Spatial and Frequency Domains

Póth Miklós
Subotica Tech, Subotica, Serbia

Abstract – In this paper we compare one spatial domain and one transformed domain image compression methods. In the spatial domain we present the five modulus method (FMM), and in the transformed domain we present the JPEG method. Both methods are compared according to their compression ratio and signal to noise ratio with the original image. The testings were performed on 256x256 grayscale images.

Keywords: digital image compression, five modulus method DCT.

1. INTRODUCTION

Image compression gained much attention during the past decades because it helped storing image data in a more compact way. Efficient storage is very important because it saves memory space. This is especially important since the quantity of data produced increases day-by-day. Researchers and scientists come up with new compression algortihms all the time. The main goal of image compression is to reduce the redundancy that is included in the image. There are 3 types of redundancy:

- Coding redundancy;
- Psychovisual redundancy, and
- Interpixel redundancy

The main goal of image compression is to find the representation of the image that is less correlated than the original. Parts of the image that are not noticable for the human visual system can be ommitted without loss in the subjective quality.

The rest of this paper is organized as follows: Section II exlpains the spatial domain compresison technique, the five modulus method, section III explains the transformed image compression method, the JPEG. In section IV we present the results we obtained after testing our methods, and we conclude in Section V.

2. FIVE-MODULUS METHOD (FMM)

When image processing is done in the spatial domain, the operations are performed directly on image pixels, no transformation is needed. The method we expalin here reduces the standard deviation of the image by dividing each pixel value by 5. We will limit our research to grayscale images with 256 shades of gray (8-bit images).

The FMM method divides the digital image into 8x8 image blocks first. After that, each pixel is transformed to be a multiple of 5. This transformation has no effect on the subjecive quality of the image, since the maximum change in pixel intensity is 2, and can not be visible for the human visual system, see Table I.

Table I. Pixel values before and after the KMM transformation

Before		After		Before		After
0	→	0		243	→	245
1	→	0		244	→	245
2	→	0		245	→	245
3	→	5		246	→	245
4	→	5		247	→	245
5	→	5		248	→	250
6	→	5	...	249	→	250
7	→	5		250	→	250
8	→	10		251	→	250
9	→	10		252	→	250
10	→	10		253	→	255
11	→	10		254	→	255
12	→	10		255	→	255

After this, all pixel values will be the multiple of 5. An example is shown in Figure 1.

9	11	13	11	11	11	16	106
12	12	12	11	12	11	69	181
13	12	12	11	12	82	168	60
11	10	9	10	69	182	67	14
10	10	10	71	200	81	15	12
12	12	58	204	91	17	12	14
11	46	201	106	18	14	16	15
34	185	122	23	10	14	17	16

(a)

10	10	15	10	10	10	15	105
10	10	10	10	10	10	70	180
15	10	10	10	10	80	170	60
10	10	10	10	70	180	65	15
10	10	10	70	200	80	15	10
10	10	60	205	90	15	10	15
10	45	200	105	20	15	15	15
35	185	120	25	10	15	15	15

(b)

Figure 1. (a) Orignial 8x8 image block (b) Image block where all pixel values are divisible by 5.

The FMM method will be completed when we divide eachpixel value in the block with 5. This is shown in Figurew 2.

Prior to the transformation the standard deviation of the original block was 20.38, while aftre the transformation the standard deviation dropped to 4.03. From this reduction it can be concluded that the storage space will be considerably less for the transformed block than for the original one. The range of the pixels in the original image was (0-255), but because of the FMM the range was shrinked to interval (0-51).

2	2	3	2	2	2	3	21
2	2	2	2	2	2	14	36
3	2	2	2	2	16	34	12
2	2	2	2	14	36	13	3
2	2	2	14	40	16	3	2
2	2	12	41	18	3	2	3
2	9	40	21	4	3	3	3
7	37	24	5	2	3	3	3

Figure 2. block pixel values after division by 5

After that, the minimal value of the FMM block can be subtracted from the matrix that is shown in Figure 2. In this case that value is 2, and the matrix after this operation is showed in Figure 3.

0	0	1	0	0	0	1	19
0	0	0	0	0	0	12	34
1	0	0	0	0	14	32	10
0	0	0	0	12	34	11	1
0	0	0	12	38	14	1	0
0	0	10	39	16	1	0	1
0	7	38	19	2	1	1	1
5	35	22	3	0	1	1	1

Figure 3. Image block after subtraction of the minimal value.

The resulting block has lot of zero elements that is easy to compress. The impact of subtraction woluld be even greater if the range of the image block would be smaller, but even in this case more efficient compression is possible.

The original image consisted of 8-bit pixels (range 0-255), so for each pixel we needed 8 bits to store. The whole image required 256x256x8 bits for storage. In total it is 524288 bits, or 64kB. After the FMM manipulation, the range dropped to (0-51), so each pixel could be represented using only 6 bits instead of the original 8.

In this paragraph we'll explain the coding strategy of the transformed block. Since the range varies between 0 and 51, 6 bits are used to represent the minimal value of the block. The coding of the remaining values depends on the maximal value of the block. The smaller the maximal value, the more efficient the coding will be.

The coding gain is greater if the variaton of the block is smaller. For example, if the maximum value of the block would be 7 after subtraction, then each block entry could be coded using only 3 bits.

The quality measur used was the power signal –to-noise ratio that is defined through the following formula:

$$PSNR = 20\log_{10}\left(\frac{MAX_f}{\sqrt{MSE}}\right)$$

$$MSE = \frac{1}{mn}\sum_{0}^{m-1}\sum_{0}^{n-1}\|f(i,j) - g(i,j)\|^2 \tag{1}$$

In the above formula, m and n is the size of the image, f and g are the original and resulting images, respectively.
For different images we got different PSNR values, so the quality depends also on the content of the image. For the purposeof this research 10 test images were examined. The test images are shown in Figure 4.

Figure 4. Test images. Baboon, Barbara, Boat, Cameraman, Clock, F16, Lake, Lena, Peppers, Pirate

The results of the FMM compressions are summerized in Table II.

Table II. Power signal to noise ratio and comression percentage for the test images after FMM compression

Image	PSNR	Compression percentage
Baboon	39.90	51.21
Barbara	39.93	43.20
Boat	39.94	43.59
Cameraman	39.82	50.04
Clock	39.39	57.07
F16	40.12	48.47
Lake	39.89	40.66
Lena	39.84	44.37
Peppers	39.88	39.69
Pirate	39.83	41.25

In this paper we presented the 5-MM, but other modulus methods such as 3-MM, 9-MM, 15-MM also exist. For comparison purposes we show a zoomed detail from one test image (Lena) after those transformations. In comparison to the original image, signal to noise ratios are 52.88dB (3-MM), 48.09dB (5-MM), 42.83dB (9-MM) and 38.31dB (15-MM). Artifacts due to the modulus method are visible on the two lower images, the 3-MM and 5-MM produced no visible degradation of the image.

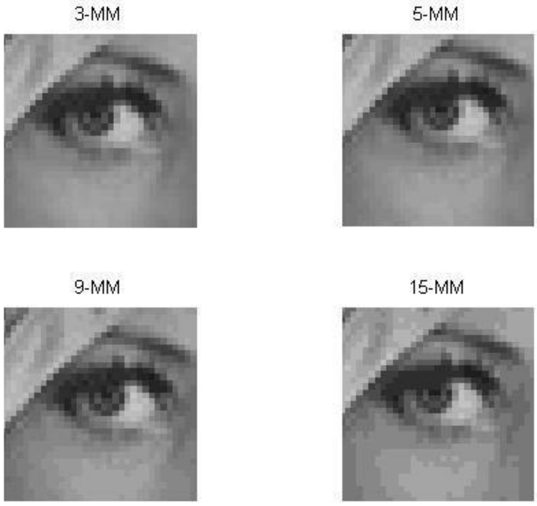

Figure 5. Detail of Lena test image after 3-MM, 5-MM, 9-MM and15-MM.

3. FREQUENCY DOMAIN IMAGE COMPRESSION

Two main types of image compression are the lossless and lossy compressions. Either lossy or lossless, the main goal is the same: to represent the digital image with fever bits. Lossless compression can retrive the original digital image after decompression. Because it is impossible to compress image with high compression factor without errors, the desired type of compression is the lossy one. During the mid-eighties of the last century the International telecommunication Union and the International standardization Union together worked out a standard for compressing still digital images. The standard is known as JPEG (Joint Photographic Expert Group). The JPEG became the international stadard in 1992.

The JPEG standard is based on the discrete cosine transform (DCT). DCT is capable of compacting the signal energy with high efficiency. The JPEG process consists of the following steps: dividing the image into 8x8 pixel blocks, subtracting 128 from all pixel values to make the (0-255) image range symmetric around 0, performing DCT on each block, quantization of the DCT coefficients using a predetermined quantization matrix, zig-zag coding to transform the 2-D block to a 1-D stream, run-length encoding and Huffman coding. The image is recovered from the stream using the inverse process.

The loss of information comes from the quantization step. The quantization matrix is not part of the JPEG standard, and the user can control the compression by varying the quantization matrix entries. Higher values in the quantization matrix will result in higher compression ratio and lower signal to noise ratio with the original image. The user has to decide how much quality he will trade for high compression ratio. Usually the desired quality is around 30dB. Below that value artifacts will become visible. The content of the digital image also has to be taken into consideration. Images with high frequencies are more sensitive to low quality quantization matrices. Those analysis hold only for the Y component of the image, the two color components are compressed in a slightly different way. Figure 7 shows the standard luminance quantization matrix (Q50) that was obtained empirically by a huge number of image processing experts. In the upper left corner ther are smaller entries what means that the DC component and low frequencies have a bigger ability to survive, while in the lower right corner numbers are bigger. After division and rounding, most of the high frequency components will be equal to zero.

16	11	10	16	24	40	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

Figure 7. Standard luminance quantization matrix

From the Q50 matrix it is possible to derive other quantization matrices. For quality level greater than 50, the standard quantization matrix is multiplied by $(100 - quality\_level)/50$. For quality levels less than 50, the standard quantization matrix is multiplied by $(50/quality\_level)$.

4. Results

After compressing the test images from Figure 4, we get the results that are presented in Table III. Two numeric parameters are used to evaluate the quality of the compression. Compression ratio (CR) is the quotient of the total numer of bits in the original image and the number of bits in the compressed bit stream. For 256x256 pixel 8-bit grayscale images the original image has 256x256x8 bits = 524288 bits. This number drops significantly after compression and varies between 40943 and 74022. Now it is easy to calculate the compression ratio (CR). CR vary between 7.08 and 12.81. The other parameter we measured was the signal to noise ratio that was defind in equation (1). Depending on the content of the image PSNR was between 29.35 and 34.69 dB. In most cases this is a satisfactory result with no, or very few visual artifacts.

Table III. CR and PSNR for test images compressed with JPEG and standard quantization matrix

Image	Bitstream	PSNR	CR
Baboon	59250	29.35	8.85
Barbara	63303	33.37	8.28
Boat	66067	31.86	7.94
Cameram.	54223	31.50	9.67
Clock	40943	34.69	12.81
F16	58458	32.61	8.97
Lake	74022	31.09	7.08
Lena	52342	33.58	10.02
Peppers	56106	34.14	9.34
Pirate	68075	31.59	7.70

5. Conclusion and Future Work

In this paper we compared one spatial domain (FMM)and one transformed domain (JPEG) image compression algorithm. Both methods introduced some image quality degradation. The degradation in the FMM came because we limited the pixel values to be multiplies of 5, thus the biggest change in pixel values was 2. This degradation is not noticable for the human visual system. This method achieved very high signal to noise ratio, and a somwhat modest compression ratio of around 50%. On the other hand, the JPEG compressed the original image around 10 times, what resulted in only 10% of the original size, but the price had to be paid for it. The other parameter measured (PSNR) was one order of magnitude lower than with the FMM.

In the future, the author plans to embed the FMM method into the JPEG process thus combining the positive and desired effects of both methods. The plan is to discover a new class of quantization matrices that will quantize the DCT coefficients with minimal degradation.

The author also investigated the effect of the quantization matrix on the signal to noise ratio. For this test the Cameraman test image was chosen. The quantization matrix was varied between 1 and 100 (all qualities), and for each one the signal to noise ratio was calculated. The results of this test are shown in Figure 8.

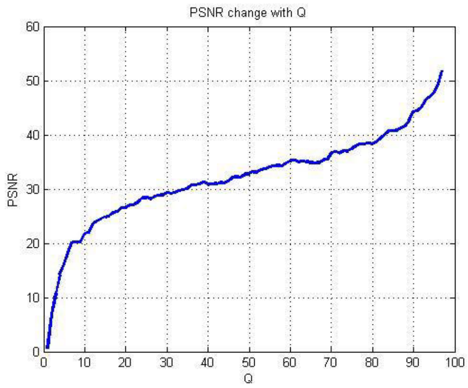

Figure 8. PSNR as a function of quantization matrix

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