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Fingerprint Image Compression Using Wavelets: A Comparison with JPEG

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Abstract: The problem of image compression is motivated mainly by the great amount of storage used by them. Because of the boom of multimedia applications, and the need for speed in data transmission over the Internet, means of reducing the resources needed by images become an important issue. Within image types, fingerprints are of great importance in person verification and documentation systems. Such systems are used intensively by both private and government organizations.

This paper describes the experience and results from a work [9] where the compression of fingerprint images was approached with different techniques. An implementation of the FBI fingerprint compression standard, WSQ was made and its performance was compared with the general-purpose image compression JPEG. This comparison was run on a large database of fingerprint images. In order to make this a fair comparison, JPEG was adjusted to this particular set of images, by altering its quantization table using a variation a well known bit allocation scheme. The results obtained with such a great number of samples show in a strong way that the WSQ method is superior to JPEG for the task of compressing fingerprint images.

Keywords: wavelets, JPEG, compression, image processing, fingerprints.

1. INTRODUCTION

Image compression arise as an answer to the problem caused by the great amount of resources images can occupy, both in storage space or in bandwidth. Medical, geological, satellite, document and movie images are typical examples of that. The physical or economical limitations of the mentioned resources are compensated by techniques like data compression.

MOTIVATION

There are many methods to compress images; each one of them based on different principles and techniques, and with different performance characteristics. Also, new formats and compression methods are being developed constantly. Because of that it is important to be able to decide when a new compression method must replace another one that is amply used. For the same reason a whole application or system that has been working for years isn't coded again each time a new programming language or paradigm is introduced. The change is reasonable only when the potential benefits are greater than the reengineering and transition processes.

For this task metrics must be taken, in the form of experimental tests or theoretical demonstrations. Any of these processes must show clearly the performance differences between the methods one is comparing.

FINGERPRINTS: WHY?

We define fingerprints to be the impression or physical reproduction of the drawings formed by the papillary crests of the yolks of the fingers on the hands. Their most important properties are:

. Fingerprints don't vary in the time, and...
. Fingerprints are unique to each individual.

For a fingerprint to be useful is necessary to be able to locate clearly the elements that characterize it as a unique object. These elements are denominated minutiae (or characteristic points). The minutiae are manifested as particular designs that appear in the crests (the lines) of the fingerprint.

Because the final decision about the capture of an individual resides on a human expert, the automated fingerprint identification systems must keep the images of the fingerprints that are searched.

Fingerprints are also used in several documentation processes (like passport, gun registration, police records, etc.). These processes may generate huge files on paper (media that deteriorates with time and various environmental factors, like rodents!). Digital storage of fingerprint records provides a solution to most of these problems, with an image collection that resist the passing of time and can be used and transmitted efficiently.

AN ESTIMATE OF THE STORAGE SPACE NEEDED FOR PAPER BASED FINGERPRINT RECORDS	
	size
1 person x 1 x record 0.1mm (1 gr.)	0.1mm (1 gr.)
10 million people x 0.1mm (1 gr.)	100 Km. (10 Tons.)
1 person x 10 fingers x 0.5 Mb	5 Mb
10 million people x 5 Mb	47.683 Tb.

THE CD-ROM DATABASE

In order to run the tests and analysis of the work it was necessary to construct an appropriate dataset of images. Although many of such datasets exist, none of them reflected the type of data the local law enforcement works every day. This served to evaluate also the quality of the current methods by which the local police are obtaining and storing its data. The dataset was burnt on a CD-ROM and has the following characteristics: from the templates the police us to capture the 10 fingerprints of a person (205mm x80mm), 1251 images were scanned at 500 dpi, 8bpp. The images were stored using the BMP format, the total space occupied was 619 Mb.

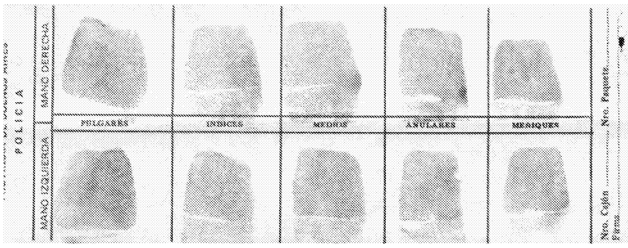


FIG. 1: EXAMPLE OF A FINGERPRINT RECORD USED BY THE POLICE OF BUENOS AIRES

2. IMAGE COMPRESSION: METHODS AND PRINCIPLES

The work in [9] began with a study on the state of the art in image compression in general. There, several methods that represent the different techniques used to attack the problem of image compression were analyzed and described, with an historical perspective. From this study three precise stages were encountered, that describe the general outline of a compressor/decompressor scheme:

T, is the *Transformation* stage. Here the data is usually decorrelated and most of the energy of the signal is concentrated on a small number of coefficients. Later, they can be efficiently coded with some adequate scheme, having then a minimum impact on the reconstructed image.

Q, the *Quantization* stage, where a one to many mapping takes place. This stage it is the responsible for the loss of information, and involves generally a bit allocation problem. For example if one chooses not to carry out the transformation stage, this process became a simple color reduction operation.

C, is the *Coding* stage. Here a two-stage strategy is usually used. First an entropy coding is applied, such as Huffman [6] or arithmetic code [10]. Later methods are used that take out profit of the topology of zeros mentioned in the transformation stage.

3. STANDARDS ARE IMPORTANT.

Given the family of applications and activities in which the fingerprints are used, it is important to define a standard for the exchange of that information. The advantages of working with a standard one allow users to not worry about any specific brand of hardware and/or software (a problem that is far from being solved nowadays...).

JPEG is today, thanks to the Internet, one of the most used standards for the exchange of photographic information. But the method suffers, in its design (at least previous to JPEG 2000), of a problem that degenerates the image beyond its utility for the detection of minutiae, when using big compression rates.

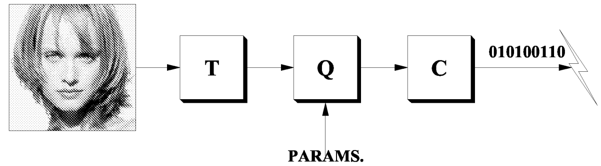


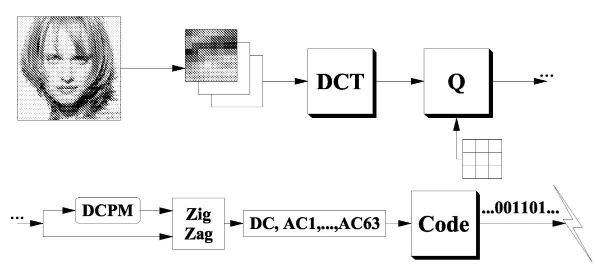
FIG. 2: GENERIC SCHEME OF A COMPRESSOR

4. ADJUSTING JPEG.

Because the comparison between WSQ and JPEG was inevitable, there was only a minor detail to be noted. JPEG is a "general purpose" image compression standard, and in its design it was devised to deal with certain kind of images (photographic, continuos-tone ones). To make this a fair comparison, JPEG should be adapted to a new dataset. But, the main objective of this work was, *to not modify the standard*, meaning that all the work to be done would be related to the re-parameterization of the JPEG data processes, not the processes themselves (specifically, the quantization table).

The components [11] involved in the JPEG's compression scheme were analyzed, searching for a way to increase their performance.

This analysis showed that the stage to be re-parameterized was the quantization. This stage involves at least one square matrix with 64 elements.



FINDING A NEW QUANTIZATION TABLE.

The design of quantization tables for JPEG is not trivial. The basic principle in finding each one of the 64-quantization steps is: *find those limit values such as if they are increased a "considerable visual degradation" is observed in the reconstructed image*.

For the task of finding those values it was used a method that can be considered an adaptation of the bit-allocation scheme known as the *greedy algorithm* (

sometimes called *marginal analysis* [3][4]). The method works in this way: "*for a given number of bits, distribute them between the coefficients who need them the most*". So, who needs the bits the most? Well, the coefficients that would introduce an unbearable amount of noise or *"considerable visual degradation",* if they were not given the bits (the method can be renamed as the *extortive algorithm*!).

A new variant of this method was developed to find the quantization table coefficients. The new algorithm distributes quantization levels instead of bits. In this way, it is expected to give a more realistic response to the needs of each sub-band (coefficients). The traditional approach distributes an integer amount of resolution bits, while this new variant increments each quantizer resolution in rational steps. In order to describe the method, we define:

R_i : Range of the $\boldsymbol{i}$ sub-band, (max value – min value)

$pdf_i(x)$: Probability density function estimate of the $\boldsymbol{i}$ sub-band.

$p_i(n) = \left\lceil \frac{R_i}{n} \right\rceil$: Quantization step for the $\boldsymbol{i}$th sub-band, ($\boldsymbol{n}$ quantization levels)

$q_i(x,n) = \left\lceil \frac{x}{p_i(n)} \right\rceil$: Quantization function de for the $\boldsymbol{i}$th sub-band, ($\boldsymbol{n}$ quantization levels)

$w_i(n)$: Estimates the error when the $\boldsymbol{i}$th sub-band is uniformly quantized, with $\boldsymbol{n}$ quantization levels.

$$w_i(n) = \sum_{x \in R_i} pdf_i(x).(x - q_i(x,n).p_i(n))^2$$

where $\sum_{x \in R_i} pdf_i(x) = 1$

W(i, step) : Estimation of the general distortion if the quantization levels for the quantizer at the $\boldsymbol{i}$th sub-band are increased in ***step***.

$$W(i,step) = w_i(n_i + step) + \sum_{j:0\ldots63, j \neq i} w_j(n_j)$$

The algorithm is outlined (in its simplest incarnation) in LISTING 1. At the end of the process, a 8x8 coefficient matrix is obtained, which has the number of quantization levels ($\boldsymbol{n_i}$) assigned for each sub-band; the quantization matrix will be calculated then by the simple operation $\boldsymbol{q_i(n_i)}$.

Some final details of the method are: finding the initial values given to each quantizer, controlling that ***step*** doesn't grow too much y finding the stop condition.

The initial value for each quantizer is calculated as follows: Given the range for the $\boldsymbol{i}$th sub-band and the quantization step of the quantizer proposed by the standard [11], the value is simply the quotient of these last two.

```
For every i (0..63)
        n_i = some initial value
endfor

step = 1.

while (stop condition if false)
        /*every iteration delivers 1 bit*/
        j=argmax(i: W(i, step))

        if j is a valid sub-band
                n_j = n_j + step
                step = 1
        else
                step = step + 1
        endif
endwhile
```

LISTING 1: PSEUDOCODE OF THE MODIFIED GREEDY BIT-ALLOCATION ALGORITHM

This value represents how many levels the standard quantization table (for most practical uses) would assign to the data. Then, the value is multiplied by a factor. This was found to be a good place to start.

$$n_i = \alpha.\frac{R_i}{qnorm_i}$$

where:

- n_i : number of levels of the $\boldsymbol{i}$th quantizer
- α : factor between 0 and 1
- R_i : Range of the $\boldsymbol{i}$th sub-band (max value – min value)
- $qnorm_i$: Step of the $\boldsymbol{i}$th quantizer (proposed by the standard).

The stop condition is defined as the relation between the error obtained when the new quantizer is used and the error produced when the quantizer proposed by the standard is used [11]. A factor β allows to tune this relationship by the user:

Err_with_new table >= β. Err_with_standard table

Where β is a factor between 1 y 1.5. In order to avoid that ***step*** grows without limit, it was decided that the value can't be greater than 128.

For the experiments, several runs were made with different values of α and β for a subset of representative images. It was determined that the values that produced the best tables were α = 0.6 and β = 1.0

COLLECTING STATISTICS.

In order to perform the task mentioned above, some work was to be done. Namely, it was necessary to know (estimate) the pdf of each sub-band. The image set for which JPEG was to be adapted for, was analyzed to find the histogram for each coefficient (a total of 64), that is a result of applying the Discrete Cosine Transform.

Ten representative images, with an average size of 700x700 pixels were analyzed. That implied an approximated total of 75690 samples per band. More than enough to estimate the pdf.

RESULTS

This new parameterization of JPEG was named *JPEG+*. The results showed an improvement (near 2db) in the acceptable error range (the zone above 30 dB). For lower error values the curves are almost identical. An interesting remark is that for the same compression parameter q, JPEG+ achieves higher compression ratios, this suggests a better performance than ordinary JPEG. One of the results obtained can be seen in FIG. 3. For the runs the implementation of the Independent JPEG Group was used.

After running the modified greedy algorithm the best quantization table obtained was:

23	16	14	22	31	45	39	43
17	17	20	26	27	37	33	43
20	19	21	29	39	51	37	33
19	21	30	24	49	34	30	26
24	26	30	30	33	26	20	24
34	38	33	44	27	20	21	19
49	50	35	43	28	17	15	13
52	84	59	31	18	13	12	12

TABLE 1: OPTIMAZED QUANTIZATION TABLE OBTAINED THROUGH THE MODIFIED GREEDY ALGORITHM

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

TABLE 2: OPTIMAZED QUANTIZATION TABLE OBTAINED THROUGH THE MODIFIED GREEDY ALGORITHM

5. WSQ STANDARD IMPLEMENTATION

WSQ stands for Wavelet Scalar Quantization and it's the method adopted by the FBI to the interchange of fingerprint images. Based on it, a variant was implemented (named *WSQ1*). The stages of transformation, quantization and entropy coding were analyzed, without special concern to the file formats proposed by the standard.

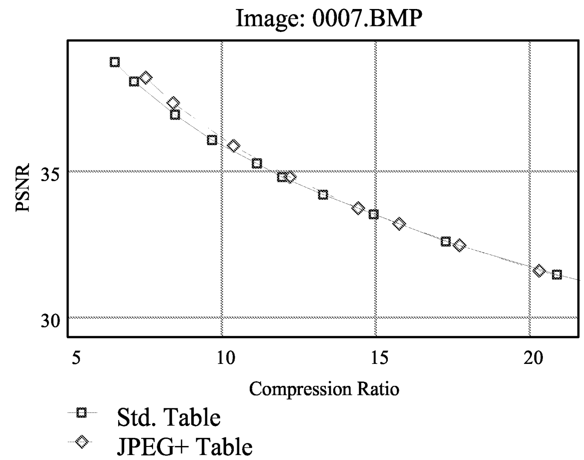


FIG. 3: COMPRESSION RATIO IMPROVEMENT FOR THE NEW QUANTIZATION TABLE.

The implementation made differs from the original in the file structure and in the stage of entropy coding. In WSQ1 an adaptive Huffman method was used, also some minor variations from the symbol table were introduced. There are no differences in the performance of WSQ1, compared with the NIST implementation (FIG. 4).

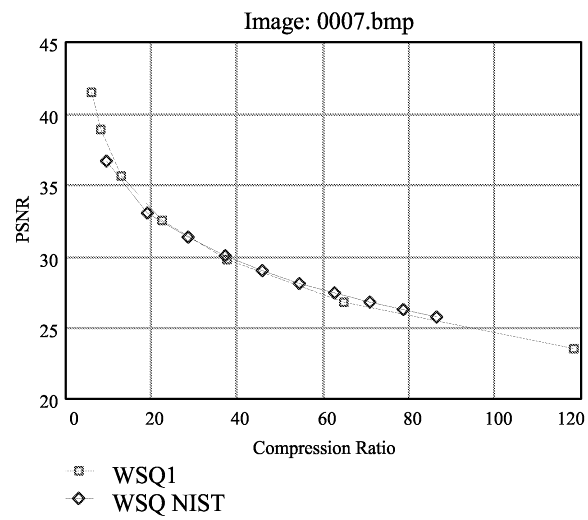


FIG. 4: DIFFERENCE BETWEEN WSQ1 AND THE NIST WSQ IMPLEMENTATION

6. JPEG+ VS. WSQ1

1251 pairs of curves showing the PSNR compression ratio relationship from JPEG+ and WSQ1 were generated, each pair referring to one image of the dataset. These curves were compared showing for all but five cases that WSQ1 was superior (those five are pathological cases were the curves cross at some point)

	# Curves
WSQ1 > JPEG+	1246
WSQ1 < JPEG+	0

Cross at some point	5
Total	1251

TABLE 3: RESULT OF COMPARING THE 1251 IMAGES

7. CONCLUSIONS

For the problem of compression digital fingerprint images, it was verified that the WSQ standard has a better performance than JPEG (one of, if not the most used, compression standards). The experiments conducted over a large number of samples give to this results a very strong emphasis.

In Fig. 5 it is shown the histogram for the compression ratios obtained in the PSNR bands between 28db and 32db. The expected compression ratio there is 94:1. It was also observed that the artifacts introduced by WSQ1 were more benign than those caused by JPG+. Wavelet theory also adds some attractive characteristics to image coding such as interpolation, progressive transmission and selective coding (which could prove very useful in fingerprints by selecting the minutiae as zones were the detail must be conserved).

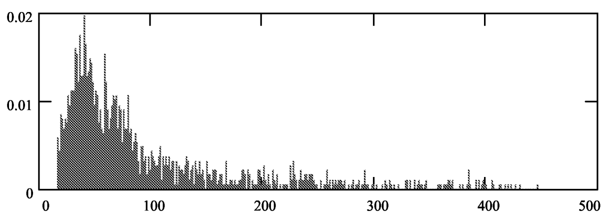


FIG. 5: DISTRIBUTION OF THE COMPRESSION RATIO FOR THE PSNR BETWEEN 28 AND 32 DB.

8. ACKNOWLEDGMENTS

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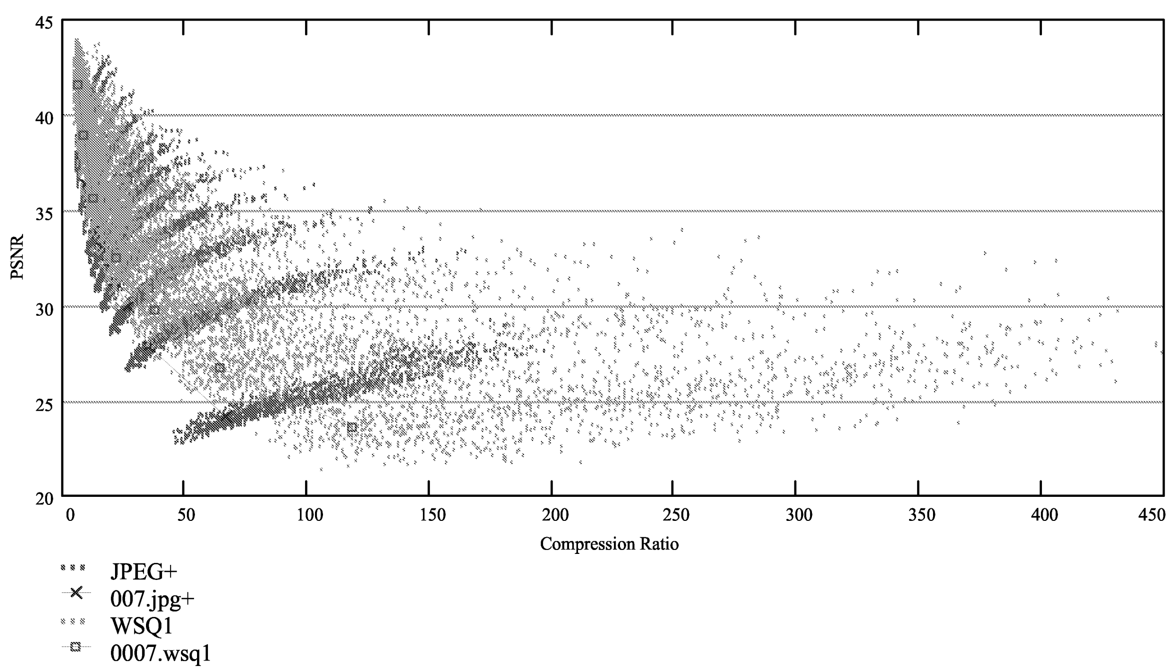

FIG. 6: RESULTS FROM THE COMPRESSION OF 1251 IMAGES USING JPEG+ AND WSQ1, EACH POINT REPRESENTS A COMPRESSED IMAGE WITH SOME METHOD AND SOME COMPRESSION PARAMETER *Q*