

WAVELET SCALAR QUANTIZATION

B.Karuna kumar

Department of Electronics and Communication Engineering,
Government Polytechnic, Proddatur
Email: Karna_bonam2002@yahoo.com

Dr. K.Satya Prasad

Professor and Director of Evaluation
J.N.T.University, Kakinada,A.P
Email: Prasad_kodati@yahoo.co.in

-----ABSTRACT-----

Fingerprints are today the most widely used biometric features for personal identification. With the increasing usage of biometric systems the question arises naturally how to store and handle the acquired sensor data. Our algorithm for the digitized images is based on adaptive uniform scalar quantization of discrete wavelet transform sub band decomposition. This technique referred to as the wavelet scalar quantization method. The algorithm produces archival quality images at compression ratios of around 15 to 1 and will allow the current database of paper finger print cards to be replaced by digital imagery. A compliance testing program is also being implemented to ensure high standards of image quality and interchangeability of data between different implementations.

Keywords: fingerprint compression, discrete wavelet, binarization, adaptive quantization

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1. Introduction

In distributed biometric systems, the data acquisition stage is often dislocated from the feature extraction and matching stage. In such environment the sensor data have to be transferred via a network link to the respective location, often over wireless channels with low bandwidth and high latency. Therefore, a minimization of the amount of data to be transferred is highly desirable, which is achieved by compressing the data before transmission. When a typical fingerprint card is scanned at 500 dpi, with 8 bits/pixel, it results in about 10Mb of data. For 200 million cards, the total size of the digitized collection would be more than 2000 terabytes .Finger print images are routinely sent between law enforcement agencies. Overnight delivery of the actual card is too slow and risky, and sending 10 Mb of data through a 9600 baud modem takes about three hours.

Compression is, therefore, a must. At first, it seems that fingerprint compression must be lossless because of the small but important details involved. However, lossless compression methods produce typical compression ratios of 0.5. Most lossy image compression methods involve the loss of small details and are therefore unacceptable. This is where wavelets come into the picture. Our proposed work

wavelet scalar quantization (WSQ) is a lossy wavelet compression. We are carefully designed, it can satisfy the criteria above and results are efficient compression, where important small details are preserved, or at least identifiable.

Fingerprint images exhibit characteristic high energy in certain high frequency bands resulting from the ridge valley pattern and other structures. These minutiae characteristics are local discontinuities in the fingerprint pattern which represent terminations and bifurcations. A ridge termination is defined as the point at which a ridge ends abruptly. A ridge bifurcation is defined as the point at which a ridge forks or diverges into branch ridges. The ridge structure in fingerprint images is not always well defined, and therefore, an enhancement is required before compression [5]. In our work enhancement is carried out using local histogram equalization and wiener filtering and image binarization. To account for this property, the wavelet scalar quantization (WSQ) standard for lossy fingerprint compression uses a specific wavelet packet sub band structure, which emphasis the important high frequency bands [1]. Filter choice is classical pyramidal coding scheme specifically tuned for fingerprint compression. It is identified that biorthogonal filters are being superior to orthogonal filters and also they optimize filters for fingerprint compression. In this work a

special type of wavelet filter is suggested to adapt for the high frequency content [4].

2. Implementation

2.1 Enhancement: Extracting minutiae from fingerprint images is one of the most important step in automatic fingerprint identification and classification. So before compression enhancement is a must. The main stages of our proposed enhancement process conducted on a binary fingerprint images are shown in Fig (1).

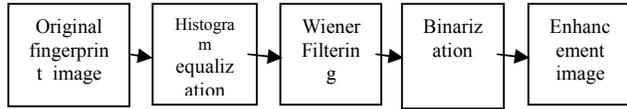


Figure-1: Filtering and binarization process

Histogram equalization defines a mapping of gray levels p into gray levels q such that the distribution of gray level q is uniform. We propose to use a pixel wise adaptive wiener filter method for noise reduction. The operation that converts a gray scale image into a binary image is known as binarization [4]. We carried out the binarization process using an adaptive threshold. Each pixel is assigned a new value (1 or 0) according to the intensity mean in a local neighborhood.

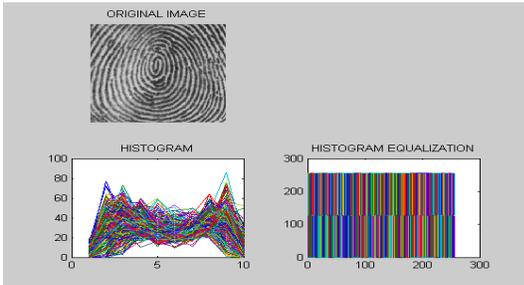


Figure- 2: Original image and its histogram

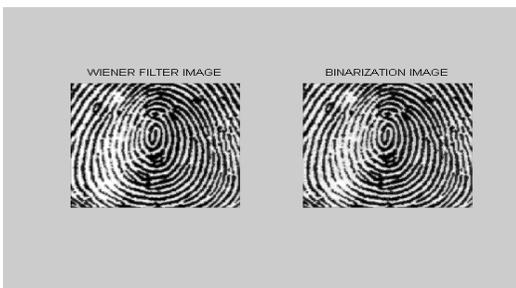


Figure-3: Wiener filtering result and binarization image

2.2 Compression /Reconstruction

Our method involved three steps

- 1) A discrete wavelet transforms.
- 2) Adaptive Scalar quantization of the wavelet transforms coefficients.

- 3) A two pass Huffman coding of the quantization indices.

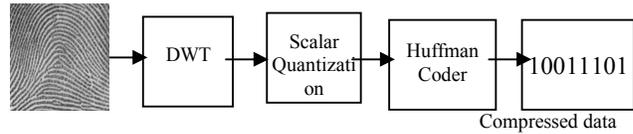


Figure 4 Compression process

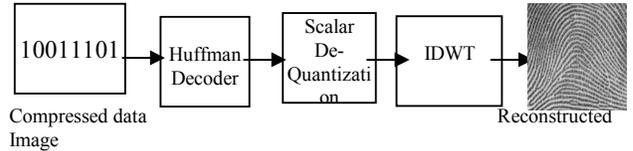


Figure 5 Image reconstruction process

We are using a symmetric discrete wavelet transform (SWT). To implements this transform symmetric filter coefficients are used. Our symmetric filter has 7 and 9 impulse response taps and they depend on the two numbers x_1 (real) and x_2 (complex) [1,6].

They are

$$x_1 = A = B - \frac{1}{6},$$

$$x_2 = -\frac{(A+B)}{2} - \frac{1}{6} + \frac{i\sqrt{3}(A-B)}{2}$$

Where $A = \left(\frac{-14\sqrt{15} + 63}{1080\sqrt{15}} \right)^{\frac{1}{3}}$

and $B = \left(\frac{-14\sqrt{15} - 63}{1080\sqrt{15}} \right)^{\frac{1}{3}}$

The symmetric wavelet filter coefficients are

$$h_o = [0.85269879 \quad 0.377402855 \quad -0.1106244$$

$$\quad \quad \quad -0.023849465 \quad 0.03782845]$$

$$h_1 = [0.788485616 \quad -0.418092273 \quad -0.0406894176$$

$$\quad \quad \quad 0.0645388826]$$

The method of wavelet image decomposition used in this work is different from those conventional methods. Wavelet transform is first applied to the image rows and columns, resulting in $4 \times 4 = 16$ sub-bands. The wavelet transform is then applied to the same manner to three of the 16 sub-bands. The last step is to decompose the top left sub-band into four smaller ones [1,2].

L1	L2	H1	H2
L3	L4	H3	H4
V1	V2	D1	D2
V3	V4	D3	D4

1st Level decomposition

L1L1	L1L2	L1H1	L1H2
L1L3	L1L4	L1H3	L1H4
L1V1	L1V2	L1D1	L1D2
L1V3	L1V4	L1D3	L1D4

L1 Sub band Decomposition

L2L1	L2L2	L2H1	L2H2
L2L3	L2L4	L2H3	L2H4
L2V1	L2V2	L2D1	L2D2
L2V3	L2V4	L2D3	L2D4

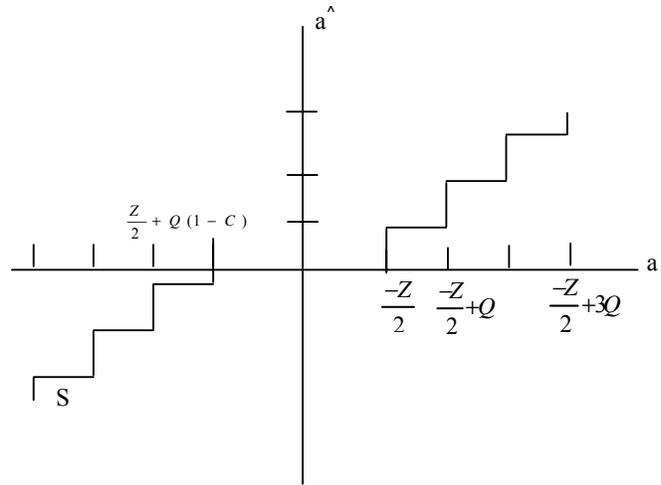
L2 Sub band Decomposition

L3L1	L3L2	L3H1	L3H2
L3L3	L3L4	L3H3	L3H4
L3V1	L3V2	L3D1	L3D2
L3V3	L3V4	L3D3	L3D4

L3 Sub band Decomposition

Figure 6 Symmetric Image wavelet decomposition.

The transform coefficients in the 64 sub-bands are floating point numbers to be denoted by 'a'. They are quantized to a finite number of floating-point numbers that are denoted by \hat{a} . The encoder maps a transform coefficient 'a' to a quantization index 'p'. The index "p" can be considered a pointer to the quantization bin where "a" lies. The decoder receives an index "p" and maps it to a value \hat{a} that is close, but not identical, to 'a'. The set of \hat{a} values is a discrete set of floating point numbers called the quantized wavelet coefficients. The quantization depends on



parameters that may vary from sub-band to sub-band, since different sub-bands have different quantization requirements.

Figure 7 Scalar Quantization

Fig(7) shows the setup of quantization bins for sub band "K". Parameter Z_k is the width of the zero bin, and parameter Q_k is the width of the other bins. Parameter "C" is the range [0,1]. It determines the reconstructed value \hat{a} . For $C=0.5$, the reconstructed value for each quantization bin is the center of the bin[4,7].

$$P_k^{(m,n)} = \begin{cases} \left[\frac{a_k^{(m,n)} - Z_{k/2}}{Q_k} \right] + 1, & a_k^{(m,n)} > Z_{k/2} \\ 0 & -Z_{k/2} \leq a_k^{(m,n)} \leq Z_{k/2} \\ \left[\frac{a_k^{(m,n)} + Z_{k/2}}{Q_k} \right] + 1, & a_k^{(m,n)} < -Z_{k/2} \dots\dots(1) \end{cases}$$

$$\hat{a} = \begin{cases} (P_k^{(m,n)} - C)Q_k + Z_{k/2}, & P_k^{(m,n)} > 0 \\ 0 & P_k^{(m,n)} = 0 \\ (P_k^{(m,n)} + C)Q_k - Z_{k/2}, & P_k^{(m,n)} < 0 \dots\dots(2) \end{cases}$$

The equation (1) shows how parameters Z_k and Q_k are used by the encoder to quantize a transform coefficient $a_k(m,n)$ to an index $P_k(m,n)$, and how the decoder computes a quantized coefficient $\hat{a}_k^{(m,n)}$ from that index.

Adopted C value is 0.44, and determines the bin widths Q_k and Z_k from the variances of the transform coefficients in the different sub-bands given below:

Step1:- Calculation of width, height, top left and bottom right position of the sub band
 Let the width and height of sub band k be denoted by X_k and Y_k , respectively.

We compute the six quantities

$$W_k = \left\lfloor \frac{3X_k}{4} \right\rfloor, H_k = \left\lfloor \frac{7Y_k}{16} \right\rfloor \quad (3)$$

$$X_{ok} = \left\lfloor \frac{X_k}{8} \right\rfloor, X_{1k} = X_{ok} + W_k - 1 \quad (4)$$

$$Y_{ok} = \left\lfloor \frac{9Y_k}{32} \right\rfloor, Y_{1k} = Y_{ok} + H_k - 1 \quad (5)$$

Step2: Calculation of variance of the sub band K

The variance σ_k^2 of the sub-band k from position (X_{ok}, Y_{ok}) to the position (X_{1k}, Y_{1k}) , assuming the position $(0,0)$ is the top-left corner of the sub band is given by

$$\sigma_k^2 = \frac{1}{W.H - 1} \sum_{n=X_{ok}}^{X_{1k}} \sum_{m=Y_{ok}}^{Y_{1k}} (a_k(m,n) - \mu_k)^2 \dots\dots (6)$$

Where μ_k denotes the mean of $a_k(m,n)$ in the region.

Step3: Calculation of bin width for the sub band and proportional constant Parameter Q_k is computed by

$$Q_k = \begin{cases} 1 & 0 \leq K \leq 3 \\ \frac{10}{A_k \log_e(\sigma_k^2)} & 4 \leq K \leq 59 \text{ \& } \sigma_k^2 \geq 1.01 \\ 0 & 60 \leq K \leq 63 \text{ or } \sigma_k^2 \geq 1.01 \end{cases} \dots\dots(7)$$

The Values of the constants A_k

$$A_k = \begin{cases} 1.32, & K = 52.56 \\ 1.08, & K = 53.58 \\ 1.42, & K = 54,57 \dots\dots\dots(8) \\ 1.08, & K = 55,59 \\ 1, & \text{Otherwise} \end{cases}$$

The bin width for sub bands 60-63 are zero. These sub bands consisting of the finest detail coefficients are simply discarded.

Step 4:- The width of the zero bin in set to $Z_k = 1.2Q_k$.

The last step is to prepare the Huffman code tables. Which are to be written on the compressed stream as they depend on the image A Huffman code table for sub band is prepared by counting the number of times, the code is repeated. The

counts are used to determine the length of each code and to construct the Huffman code tree. This is a two-pass job. One pass to determine the code tables and the 2nd pass to encode.

3. Results

In the concrete experiments we enhance the raw fingerprint image and then compress it. Record the compression ratio corresponding PSNR value and reconstruct the image. We tabulate (Table1) the compression ratios and PSNR values for different fingerprint images. We compared to the JPEG results (see Table 1) PSNR values are consistently higher: for ratio 12, PSNR ranges between 50dB to 60dB and 25dB to 30Db for JPEG respectively.

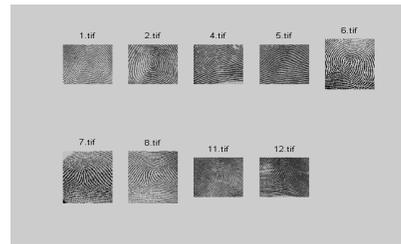


Figure 8 Fingerprint database

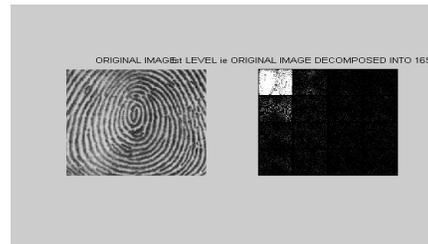


Figure 9 1st level sub band decomposition

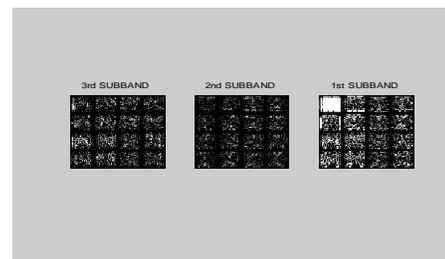


Figure 10 2nd level sub band decomposition



Figure-11:Reconstructed image

Algorithm	WSQ		JPEG	
	PSNR	CR	PSNR	CR
1.tif	56.309	13.269	99.232	1.568
2.tif	56.607	13.815	99.234	1.6128
4.tif	55.779	12.939	99.257	1.8102
5.tif	55.718	14.369	99.291	1.8613

Table -1: Comparative table for WSQ and JPEG

** Peak signal to noise ratio (PSNR) is calculated as follows

$$PSNR = 20 \log_{10} \frac{\max_i / p_i /}{RMSE}$$

* Compression Ratio (CR) is calculated as follows
 CR = N1/N2

N1—number of information carrying bytes in the original image.

N2—number of information carrying bytes in the encoded image.

Root mean square error (RMSE) =

$$\sqrt{\frac{1}{n} \sum_{i=1}^n (p_i - Q_i)^2}$$

Where Pi = pixel of original image, Qi = pixel of reconstructed image. Here the encoded image is MAT file.

3.1 Interesting features

Each of the 64 sub bands has been normalized independently for visualization as a gray scale image; this is why the background intensities appear to vary randomly. Independent normalization is necessary because the variance of these sub bands differ by much more than this visualization would lead one to believe. The variance of the lowest frequency sub band (upper left) surpasses the variance of the highest frequency band (lower right) by six orders of magnitude. This allows the encoder to deploy its resources more efficiently by allocating more bits to the bands with greater variances.

The sub bands along the top, which have been high pass filtered along rows and low pass filtered along columns, pick up the vertical line near the right edge of the picture. The sub bands along the left side, however, which have been high pass filtered along columns and low pass filtered along rows, pick up the horizontal lines at the top and bottom edges of the picture. Side-effect of this orientation selectivity is that the band in the upper-right corner, which has been low pass filtered twice along columns and high pass filtered

twice along rows, has conveniently isolated all of the scanner noise in this particular image.

Finally some of the sub bands represent aliasing due to the non-ideal nature of the digital filters used in the multirate wavelet filter bank. This aliasing is completely cancelled by the inverse DWT in the absence of quantization noise or floating-point round off error (“perfect reconstruction in perfect arithmetic”).

4. Conclusion and Feature Work

This paper proposed an efficient fingerprint compression algorithm using wavelets. The proposed technique is particularly preserve important small details in fingerprints such as ridges and sweat pores for matching purpose. Choosing wavelets for image coding applications is still a somewhat inexact science, depending on a lot of trail and error. In the future we can investigate whether the good PSNR and high compression performance of some technique tailored especially a target modality does carry over to matching.

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Speech Processing, Neural Networks & Ad-hoc wireless networks etc. *Dr.Prasad* is a Fellow member of various professional bodies like IETE , IE , and ISTE.

Authors Biography



B.Karuna kumar received B Tech. degree in Electronics and Communication Engineering from JNTU college of Engineering, Anantapur, Andhra Pradesh, India in 1993 and M.Tech. degree in Digital systems and Computer. Engineering from JNTU college of Engineering, Anantapur, Andhra Pradesh, India in 2004. He joined State Board of Technical Education, Hyderabad as Lecturer in 1995 and served in different constituent Colleges viz., Madanapalle, Anantapur and Proddatur. He has published 2 technical papers in International conferences. He is a member of various professional bodies like IETE, IE, and ISTE.



K.Satya Prasad received B Tech. degree in Electronics and Communication Engineering from JNTU college of Engineering, Anantapur, Andhra Pradesh, India in 1977 and M. E. degree in Communication Systems from Guindy college of Engg. , Madras University, Chennai, India in 1979 and Ph D from Indian Institute of Technology, Madras in 1989. He started his teaching carrier as Teaching Assistant at Regional Engineering College, Warangalin 1979.He joined Jnt University , Hyderabad as Lecturer in 1980 and served in different constituent colleges viz., Kakinada, Hyderabad and Anantapur and at different capacities viz., Associate Professor, Professor, Head of the Department, Vice Principal and Principal. He has published more than 50 technical papers in different National & International conferences and Journals and Authored one Text book. He has guided 4 Ph.D scholars and at present 12 scholars are working with him. His areas of Research include Communications Signal Processing, Image Processing,