

Wave Atoms Decomposition Based Fingerprint Image Compression

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Summary

In spite of rapid progress in mass storage density, processor speeds, demand for image compression, data storage capacity and data-transmission bandwidth continues to excel the capabilities of the available technologies. Image compression primarily aims at reducing size and space for storing the image data. Modern fingerprint image compression and reconstruction procedures used by the US Federal Bureau of Investigation (FBI) are based upon the popular 9/7 discrete wavelet transform. In this paper we have devised a new technique for fingerprint image compression based on wave atoms decomposition. Wave atoms decomposition has been designed for augmentation representation of oscillatory patterns to convey temporal and spatial information. In this paper we considered linear vector quantization of decomposed wave atoms representation of fingerprint images. Subsequently quantized information is encoded with arithmetic entropy scheme. The proposed method produced better performs than FBI fingerprint image compression technique and the wavelet scalar quantization (WSQ).

Keywords :

Image compression, fingerprint images, wave atoms decomposition, discrete wave atoms

1. Introduction

Fingerprint images are digitized at a resolution of 500 pixels per inch with 256 gray levels. Therefore a single fingerprint card requires approximately 10 MB of storage; the investigation of an efficient compression standard, that can predominantly reduces the image size while retaining the minutiae (ridges, endings and bifurcations) information, is justified in conjunction with the size of FBI fingerprint database. But in the implementation of Image compression to output a compressed image that has been productive with good compression ratio and to store in very less memory and secured transfer of the image. The cardinal goal of image compression is to obtain the best possible image quality at an allocated storage capacity. Law enforcement, border security and forensic applications are some crucial fields where fingerprint image compression plays an important role. The archive consists of inked impressions on paper cards. A single card contains 14 different images: 10 rolled impression of each finger,

duplicate (flat) impression of thumb and simultaneous impression of all fingers together. In addition to the considerable savings in storage capacity, fingerprint image compression is also desired for effortless archiving and sweeping reduction in transmission bandwidth.

FBI compression standard has incorporated the bi-orthogonal 9/7 discrete wavelet transform (DWT) filter pair for highly reliable fingerprint compression and reconstruction since 1993. DWT was used due to its capability of space-frequency decomposition of images, energy compaction of low frequency sub-bands, and space localization of high frequency sub-bands. Image analysis using DWT is described using a pair of quadrature mirror filter (QMF) and a dual quadrature mirror filter (DQMF). QMF and DQMF are further decomposed into four sets of floating point coefficients: $h0(Lo_D)$, $g0(Hi_D)$, $h1(Lo_R)$ and $g1(Hi_D)$ define the wavelet and scaling functions for each of forward DWT and inverse DWT respectively.

Fingerprint images are decomposed using a 2D DWT which is applied using a separability approach along its rows and columns alternatively resulting into four smaller subsets. These subsets are further decomposed, quantized and coded using different coding techniques. Entropy based best basis selection (EBBBS) algorithm has also been proposed for improved sub-band decomposition.

The proposed image compression technique cutting edge over the FBI fingerprint image compression standard, the wavelet scalar quantization (WSQ). Data mining, law enforcement, border security, and forensic applications (Corpse identification, Criminal identification), Government applications (National ID cards, Driver's license) and for commercial purpose can drastically benefit from proposed compression technique.

2. Wave Atoms Decomposition

Fourier series decomposes a periodic function into a sum of simple oscillating functions, namely sines and cosines. In a Fourier series sparsity is destroyed due to discontinuities (Gibbs Phenomenon) and it requires a large number of terms to reconstruct a discontinuity precisely. Development

of new mathematical and computational tools based on multi-resolution analysis is a novel concept to overcome limitations of Fourier series. Many fields of contemporary science and technology benefit from multi-scale, multi-resolution analysis tools for maximum throughput, efficient resource utilization and accurate computations. Multi-resolution tools render robust behavior to study information content of images and signals in the presence of noise and uncertainty.

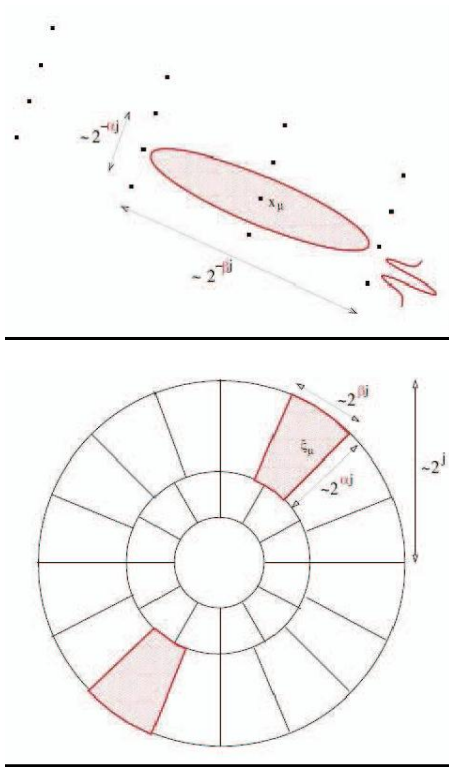


Fig 1. Wave atoms tiling in space and frequency.

Two distinct parameters α, β represent decomposition and directional ability and are sufficient for indexing all known forms of wave packet architectures namely wavelets, Gabor, ridgelets, curvelets and wave atoms.

Wave atoms are defined for $\alpha=\beta=1/2$ and essential support of wave packet in space (left) and in frequency (right) is shown in Fig. indexes the multi-scale nature of the transform, from $\alpha = 0$ (uniform) to $\beta = 1$ (dyadic). β measures the wave packet's directional selectivity (0 and 1 indicate best and poor selectivity respectively). Wave atoms represent a class of wavelet packets where directionality is sacrificed at the expense of preserving sparsity of oscillatory patterns under smooth diffeomorphisms. Two distinct parameters α, β represent decomposition and directional ability and are sufficient for indexing all known forms of wave packet architectures namely wavelets, Gabor, ridgelets, curvelets and wave atoms.

2.1 1D discrete wave atoms

Wave atoms are constructed from tensor products of adequately chosen 1D wave packets. Let $\psi_{j,m,n}(x)$ represent a one-dimensional family of wave packets, where $j, m \geq 0$, and $n \in \mathbb{Z}$, centered in frequency around $\pm \omega$ $j, m = \pm \pi 2^j m$ with $C12 \leq m \leq C2j$ and centered in space around $x_j n = 2^{-j} n$. One-dimensional version of the parabolic scaling states that the support of each bump of $\hat{\psi}_{j,m,n}(\omega)$ is of length $O(2^j)$ while $\psi_{j,m,n} = O(2^{2j})$. Dyadic dilates and translates of $\hat{\psi}_{j,m,n}$ on the frequency axes are combined and basis function, written as:

$$\Psi_{j,m,n}^i(x) = \psi_{j,m,n}^i(x - 2^{-j}n) = 2^{-j/2} \psi_m^i(2^j x - n) \tag{1}$$

The coefficients $c_{j,m,n}$, for each wave number $\omega_{j,m,n}$, are obtained as a decimated convolution at scale 2^j .

$$c_{j,m,n} = \int \psi_{j,m,n}^i(x - 2^{-j}n) u(x) dx \tag{2}$$

By Plancherel's theorem,

$$c_{j,m,n} = \int e^{i2^{-j}nk} \psi_{j,m,n}^i(\omega) u(\omega) d\omega \tag{3}$$

If the function u is discretized at $x_k = kh, h=1/N, k=1 \dots N$, then with a small truncation error (3) is modified as:

$$c_{j,m,n}^D = \sum_{k=2\pi(-N/2+1N/2)} e^{i2^{-j}nk} \overline{\hat{\psi}_{j,m,n}^i(k)} \hat{u}(k) \tag{4}$$

Since the data is supported inside two disjoint intervals of size $2^j+1\pi$, symmetric about origin (2^j+1 points) instead of an interval of length $2^j \times 2\pi$, sum is computed using a reduced inverse FFT inside an interval of size $2^j+1\pi$ centered about origin:

$$c_{j,m,n}^D = \sum_{k=2\pi(-2^j/2+12^j/2)} e^{i2^{-j}nk} \sum_{p=2\pi Z} \overline{\hat{\psi}_{j,m,n}^i(k+2^j p)} \hat{u}(k+2^j p) \tag{5}$$

A simple wrapping trick is used for the implementation of discrete wavelet packets and the steps involved are:

1. Perform an FFT of size N on the samples of $u(k)$.
2. For each pair (j, m) , wrap the product $\overline{\hat{\psi}_{j,m,n}^i} \hat{u}$ by periodicity inside the interval $[-2^j\pi, 2^j\pi]$ and perform an inverse FFT of size 2^j to obtain $c_{j,m,n}^D$.
3. Repeat step 2 for all pairs (j, m) .

The overall complexity of the algorithm is $O(N \log N)$ and the wavelet packets are decomposed into positive and negative frequency components, represented by

$$\hat{\psi}_{m,n}^j(\omega) = \hat{\psi}_{m,n,+}^j(\omega) + \hat{\psi}_{m,n,-}^j(\omega) \tag{6}$$

Hilbert transform $H \psi_{j m n}$ of eq. (6) represents an orthonormal basis $L_2(\mathbb{R})$ and is obtained through a linear combination of positive and negative frequency bumps weighted by i and $-i$ respectively.

$$H \hat{\psi}_{m,n}^j(\omega) = -i \hat{\psi}_{m,n,+}^j(\omega) + i \hat{\psi}_{m,n,-}^j(\omega). \quad (7)$$

2.2 2D discrete wave atoms

A two-dimensional orthonormal basis function with 4 bumps in frequency plane is formed by individually taking products of 1D wave packets. Mathematical formulation and implementations for 1D case are detailed in the previous section. 2D wave atoms are indexed by $\mu=(j,m,n)$, where $m=(m_1,m_2)$ and $n=(n_1,n_2)$

Construction is not a simple tensor product since there is only one scale subscript j . This is similar to the non-standard or multi-resolution analysis wavelet bases where the point is to enforce same scale in both directions in order to retain an isotropic aspect ratio. Eq. (1) is modified in 2D as:

$$\varphi_{\mu}^+(x_1, x_2) = \psi_{m_1}^j(x_1 - 2^{-j}n_1) \psi_{m_2}^j(x_2 - 2^{-j}n_2). \quad (8)$$

The Fourier transform of (8) is separable and its dual orthonormal basis is defined by Hilbert transformed wavelet packets in (10).

$$\hat{\varphi}_{\mu}^+(\omega_1, \omega_2) = \hat{\psi}_{m_1}^j(\omega_1) e^{-i2^{-j}n_1\omega_1} \hat{\psi}_{m_2}^j(\omega_2) e^{-i2^{-j}n_2\omega_2}. \quad (9)$$

$$\varphi_{\mu}^-(x_1, x_2) = H\psi_{m_1}^j(x_1 - 2^{-j}n_1) H\psi_{m_2}^j(x_2 - 2^{-j}n_2). \quad (10)$$

Combination of (8) and (10) provides basis functions with two bumps in the frequency plane, symmetric with respect to the origin and thus directional wave packets oscillating in a single direction are generated.

$\varphi_{\mu}(1)$ and $\varphi_{\mu}(2)$ together form the wave atoms frame and are jointly denoted by φ_{μ} . Wave atoms algorithm is based on the apparent generalization of the 1D wrapping strategy to two dimensions and its complexity is $O(N^2 \log N)$.

$$\varphi_{\mu}^{(1)} = \frac{\varphi_{\mu}^+ + \varphi_{\mu}^-}{2}, \quad \varphi_{\mu}^{(2)} = \frac{\varphi_{\mu}^+ - \varphi_{\mu}^-}{2} \quad (11)$$

3. Proposed Image Compression Technique

Wave atoms decomposition is used for sparse representation of fingerprint images since they belong to a

category of images that oscillate smoothly in varying directions. Schematic block diagram of the proposed method is shown in Fig.2 Discrete 2D wave atoms decomposition is applied on the original image in order to efficiently capture coherence of the fingerprint images along and across the oscillations.

An orthonormal basis $\varphi_{\mu}^+(x)$ ($\varphi_{\mu}^{(1)} + \varphi_{\mu}^{(2)}$) is used instead of a tight frame since each basis function oscillates in two distinct directions instead of one. This orthobasis variant property is significantly important in applications where redundancy is undesired.

Magnitudes of wave atoms decomposed coefficients, carrying low information content, are either zero or very close to zero hence these can be discarded without a substantial degradation in image quality. An appropriate global threshold is used to achieve desired transmission bit rate. After thresholding significance map matrix and a significant coefficient vector is generated. Significance map is a matrix of binary values that indicates the presence or absence of significant coefficient at specific location. The significance map is divided into non-overlapping blocks of 4x4. These non-overlapping blocks of significance map are vectorized and quantized using a K-means vector quantization scheme with 64 code words. Small blocks of data are used in order to minimize the error during vector quantization. The significant coefficients are quantized using a uniform scalar quantizer with 512 distinct levels.

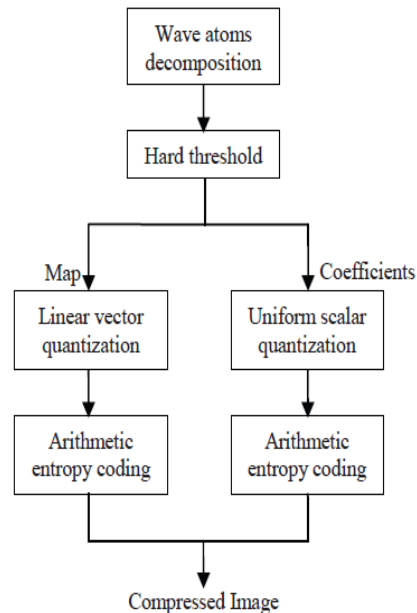


Fig. 2. Block diagram of developing compression algorithm

Quantized significance map and significant coefficients are encoded using an arithmetic encoder. Arithmetic coding is a variable length entropy scheme that attempts to minimize

number of bits by converting a string into another representation using more bits for infrequent characters and vice versa. As opposed to other entropy encoding techniques that convert the input message into component symbols and replace each symbol with a code word; arithmetic coding represents the entire message into a single number thereby achieving optimal entropy encoding.

4. Experimental Results

A good many fingerprint images used in FBI's WSQ standard have been compressed using the proposed method and significant improvement in Compression is achieved. Dissimilar metrics are proposed for investigating the quality of compression algorithms. Few methods such as Mean square error (MSE) and peak signal to noise ratio (PSNR) investigate similarity while others explore the level of dissimilarity between reconstructed and the reference image.

From the following Fig's. it is glaring that using wave atoms decomposition does an excellent job in preserving the very well details in a fingerprint image i.e. the finer points (ridges ending and bifurcations) at lower bit rates. Table 1 compares the PSNR obtained using proposed method with the FBI's WSQ compression standard at varying bitrates. As vide in Table 1 fingerprint compression based on wave atoms decomposition produces a pivotal improvement in PSNR at high compression ratios (low bit rates) in comparison with FBI's WSQ fingerprint compression standard.

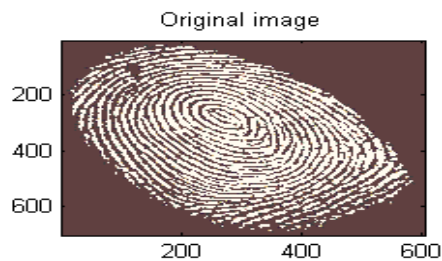


Fig.3 (a)

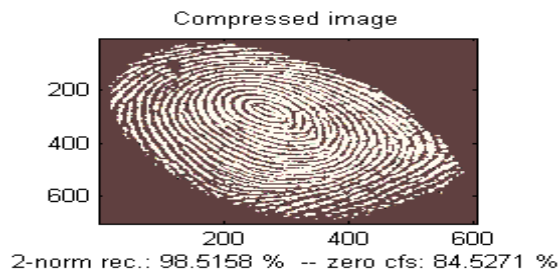


Fig.3 (b)

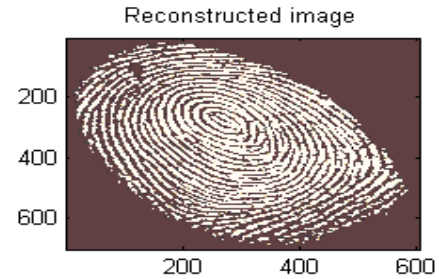


Fig.3 (c)

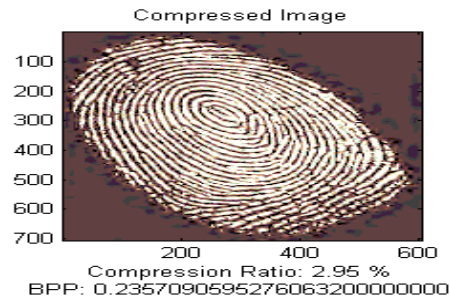


Fig.3 (d)

5. Conclusion

Application of wave atoms based decomposition for fingerprint image compression with the application of the global threshold with the arithmetic entropy coding culminates into a significant improvement in PSNR compared to FBI's WSQ fingerprint compression standard. The improvements in PSNR are more pronounced and distinct at lower bit rates and validate the fact that wave atoms multi-resolution analysis offers appreciably sparser growth, for oscillatory functions, than other fixed standard representations like wavelets, curve lets and Gabor atoms and captures coherence of pattern both across and along oscillations. Law enforcement, multimedia, and data mining related applications can benefit from our developed compression scheme.

Bit rate(bits per pixel)	FBI's WSQ PSNR(db)	Proposed method PSNR(db)
0.1	22.52	27.52
0.2	24.24	30.34
0.3	26.75	31.12
0.4	28.47	32.32
0.5	29.27	31.21

Table 1: Bit rate vs. PSNR for proposed method and FBI's WSQ.

Future Scope

The current image compression technique can be improved by creation a few appropriate enhancements which will result in increased utility of the application in future.

- This application made use of the Wave atom decomposition to achieve compression. Other wavelet family like DB6, Harr can also be used to obtain comparable results.
- In this application we have implemented global threshold, arithmetic entropy coding is advisable that if further advanced efficient encoding technique is implemented for lossless compression, better qualitative results can be obtained.

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