Coding of Fingerprint Images Using Binary Subband Decomposition and Vector Quantization

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ABSTRACT

In this paper, compression of binary digital fingerprint images is considered. High compression ratios for fingerprint images is essential for handling huge amount of images in databases. In our method, the fingerprint image is first processed by a binary nonlinear subband decomposition filter bank and the resulting subimages are coded using vector quantizers designed for quantizing binary images. It is observed that the discriminating properties of the fingerprint images are preserved at very low bit rates. Simulation results are presented.

Keywords: Binary Subband Decomposition, Fingerprint Image Compression, Binary Vector Quantization

1. INTRODUCTION

Coding of digital fingerprint images is an important problem because fingerprint databases contain huge number of images [1]-[4]. For example, the FBI database has 30 million sets of fingerprints. The digitization of the database speeds up the querying and classification operations, but the storage problem is not solved until good compression algorithms are developed for fingerprint images. Recently, FBI selected a wavelet/scalar quantization algorithm for coding 8-bit scanned fingerprint images and for typical images, a compression ratio of 25:1 is achieved by this technique [4].

The previous work was concentrated on the compression of 8-bit gray level images [1]-[4], however, in many cases 8-bit resolution for fingerprint images is unnecessary because the fingerprint information is essentially binary (due to ink smearing, scanning noise etc. higher resolution digitization may be necessary in some cases). If a binary or 2-bit resolution fingerprint image show the so-called "minutiae" details which are necessary for identification then there is no need to represent this image in 8-bits. In this paper, algorithms for coding binary and 2-bit fingerprint images are presented.

Another important feature of our fingerprint compression algorithm is the use of binary and n-ary Vector Quantization (VQ). There has been an extensive work on compression of images with

wavelet decomposition followed by a quantizer and an entropy coder. Considering the nature of wavelet transform coefficients, it is evident that the vector quantization (VQ) scheme performs better than the scalar quantization. As a matter of fact, the state of the art Embedded Zerotree Wavelet compression algorithm [5] can be considered as a VQ scheme. This idea has initiated this work in the sense that VQ should be used in the compression of fingerprint images.

In Section 2, we review the binary subband decomposition structure and in Section 3, we describe our VQ design algorithm. We present simulation results in Section 4.

2. BINARY SUBBAND DECOMPOSITION

The sub-images obtained by Binary Subband Decomposition (BSD) are very suitable for high compression coding applications [7]. There has been various binary transformation studies dealing with the binary images [8]. In this paper, we use the nonlinear binary subband decomposition structure described in [8] as it allows the use of binary median filters which do not cause ringing effects at the boundaries of binary figure.

Consider the structure in Fig. 1. This is a simple polyphase decomposition structure which has perfect reconstruction property, regardless of the filter P. In our case, the filter P is a binary filter, i.e, it yields binary outputs to binary inputs. If the filter is chosen as an identity operator, then the structure shown in Fig 2 is equivalent to the polyphase structure of Fig. 1. In Fig 2, "$\oplus$" stands for the "xor" operation, which is equivalent to the modulo-2 addition. This choice of P also corresponds to the simplest Binary Wavelet Transformation [11] with a low pass filter $[1 \quad 0]$ and a high pass filter $[1 \quad 1]$. Within the Galois Field - 2 (GF-2) arithmetic, where all the operations are performed in modulo-2, this operation can be considered linear.
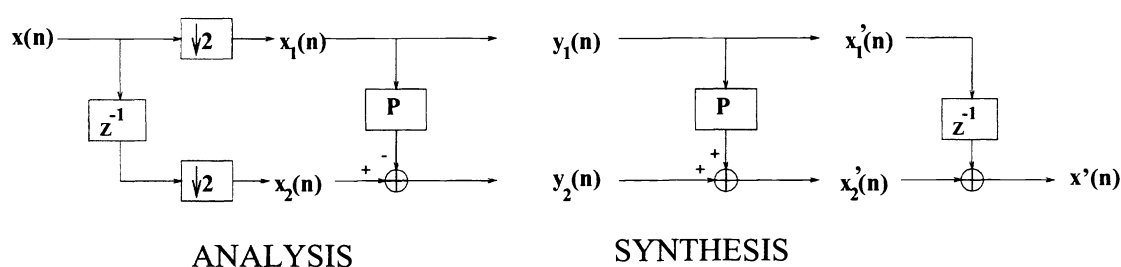

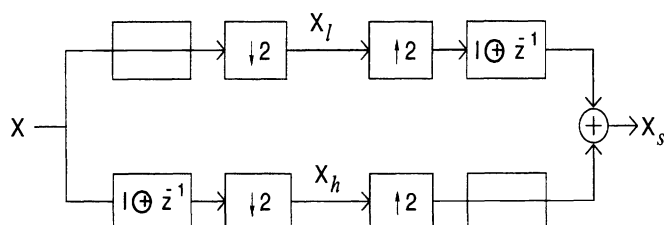**Figure 1.** *Polyphase analysis and synthesis structure*

Figure 2. A simple binary subband decomposition structure based on the "xor" operation.

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The filter in the polyphase representation can be nonlinear as well. For images containing sharp edges and flat regions, Nonlinear Subband Decomposition (NSD) usually produces better results than regular wavelet transforms in terms of coding efficiency [6]. The nonlinear decomposition filters in Fig. 1 are usually chosen as Order Statistics (OS) filters due to their smoothing nature. Recently, we showed in [7] and [8] that nonlinear subband decomposition filterbanks for GF(N) can be developed by using GF(n) arithmetic based filters in the structures of [10] and [6]. The use of the GF(N) arithmetic leads to coding and computational gains in textual image compression. Furthermore, the finite precision effects in real arithmetic is eliminated. In Figures 2 and 3 block diagrams of the two nonlinear GF(2) (binary) arithmetic filterbanks are shown. The first structure which is the simplest binary SD filterbank also corresponds to the binary wavelet transform [11] if $M(.)$ is a unit delay. As in [6], the nonlinear operator $M(.)$ should be a "half-band" operator for perfect reconstruction. An equivalent polyphase structure is shown in Figure 4 in which the filter P is related to M through the generalized "noble identity" concept [4]. Note that there is no restriction on P for perfect reconstruction contrary to the filter M in Figure 3.

In any coding algorithm, the goal is to remove the correlated portions of the original signal to achieve high compression results. The binary filter P should predict the samples of $x_2(n)$ to remove the unnecessary information in x_2 as much as possible. A good choice for P is a binary median filter with an anti-causal support due to its good performance at the edges which are critical in fingerprint images. The computational complexity of the binary median filter is very small since it only counts the number of "one"s inside the region of support and generates a "one" if that nuber is more than half of the region of support size, and "zero", otherwise.
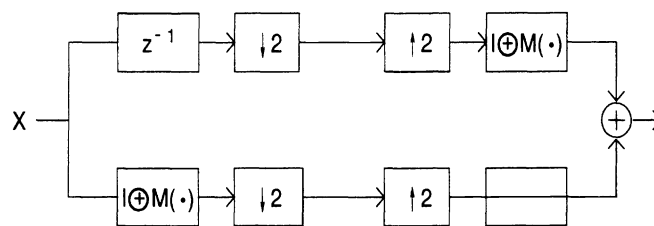

Figure 3. Nonlinear subband decomposition structure based on the binary order statistics filter $M(\cdot)$.
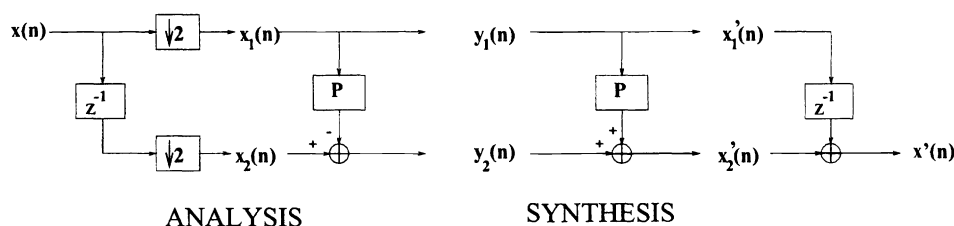

Figure 4. Polyphase nonlinear subband decomposition structure.

Additional filters can be added to the structure in Figure 4 as described in detail in [9] without disturbing the perfect reconstruction property. The generalized structures with perfect reconstruction property is shown in Fig 5.
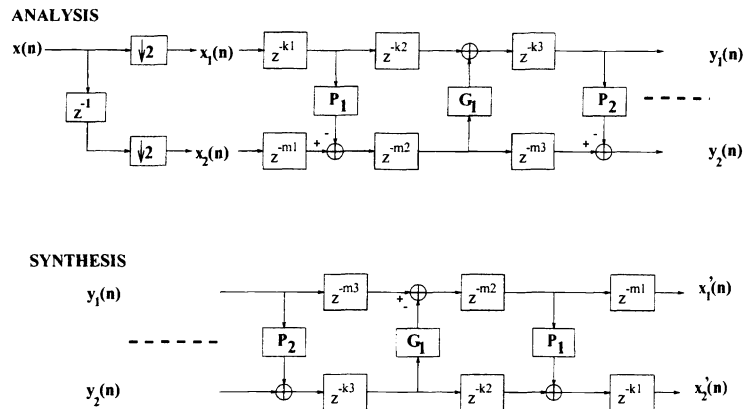
ANALYSIS

SYNTHESIS

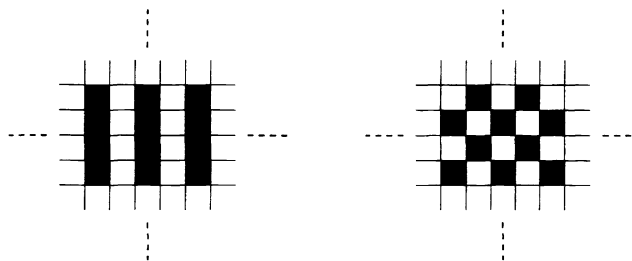**Figure 5.** Cascaded Perfect Reconstruction Building Blocks.

Figure 6. Regions of support for different downsampling schemes.

The two-dimensional decompositions of the images can be carried out in a separable manner. If the downsampling is in the hexagonal direction, then the decomposition is by default two-dimensional. In Figure 3, the perfect reconstruction is still possible provided that the region of support for the filter M is properly selected. In Fig. 6, typical regions of support for horizontal and quincunx downsampling methods are shown. The input pixels to the filter M should be the dashed pixels.

In this paper, the decomposition structures are implemented in GF(2) and GF(4) for binary and four-level fingerprint images. However, the coding scheme can be extended to continuos valued data as well.

3. VECTOR QUANTIZATION OF DECOMPOSED IMAGES

In this section, the encoding of the transform coefficients is considered. In our method, the fingerprint image is first processed by a two-dimensional nonlinear binary (or 4-level) SD structure. The resulting subimages are also binary (or 4-level) images.

Vector quantization of the data is known to be superior to scalar quantization in most cases [13]. Furthermore, the embedded transform coefficients can usually be quantized more effectively by vector quantization.

Vector quantization is applied to the decomposed image in various manners, and the coding efficiencies are compared. The first VQ method (M1) is applied individually on every subsignal.

For example, in a one-level decomposition, four binary vector quantizers are designed for each of the subsignals. In the second strategy (M2), we first merge the subimages by appending their bit-planes, then apply VQ over the merged image. This method requires a balanced subband decomposition of images. In the final method (M3), the tree structured decomposition subimage pixels are ordered in the way similar to the Embedded Zerotree Coding [5]. The embedded tree code words are then coded by a VQ.

Regular VQ design techniques [12]-[14] are modified to design the binary codebooks. The VQ for the method M1 is a direct extension of the Lloyd-Max quantizer. The quantizer starts with an arbitrary partitioning of the binary images. After this stage, the centroids are calculated. The centroid images usually do not have binary pixels. There are two approaches that can be used here. Either the centroids are kept gray valued and the iteration is repeated by setting the new vector boundaries according to the new centroids, or the centroids are quantized to binary and the new boundaries are calculated (Fig. 7). In the former approach, the quantization to binary is done after the last iteration. This way of designing the VQ codebook is found to be better both in terms of quantization quality and in terms of convergence speed. Actually, the later approach has a higher risk of converging to a local optimum or an oscillatory state due to the quantization step in every stage.
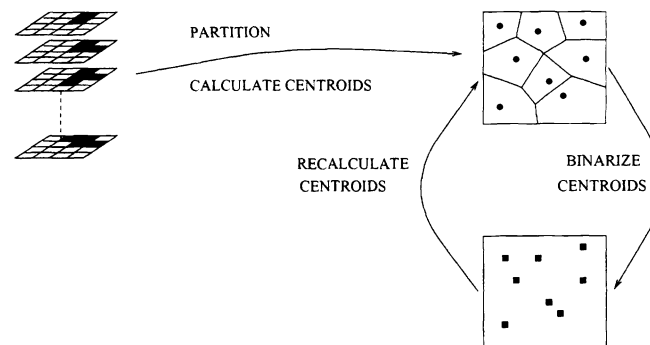

Figure 7. Binary VQ: Centroids are binarized at each iteration.

The VQ for method M2 is also similar to the Lloyd-Max quantizer. In fact, the same methods as in M1 are applied, but this time to the 4 level bit-plane-appended image.

The design of the codebook for method M3 is not as straightforwrad as M1 and M2. For this method, the vectors are formed as in Figure 8. The importance of the pixels are in a decreasing manner starting from the upper left components in the vector due to the tree structure (Fig. 8). The upper left corner pixels represent larger areas in the original image, so they should not be altered. As a result of this observation, the 4×4 upper left portion of the vectors that are generated from the image are always kept fixed during codebook generation. In most of the fingerprint images, we observed that there are approximately 8 different combinations of the upper left 4×4 portion of the generated vectors obtained by five level subband decomposition.

The transform coefficients other than the upper left 4×4 portion in the vector are quantized using a weighted matrix multiplication. In words, the two transform vectors are quantized to the
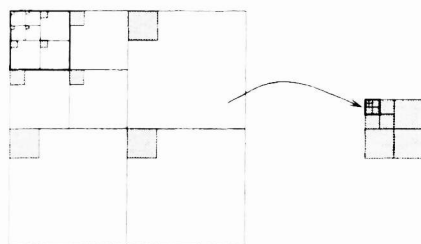
Figure 8. The embedded tree structure codeword.

Figure 9. Portion of the original binary fingerprint image.

same vector if the upper left parts are more similar to each other rather than the down and right parts. This only means a change in the distance measure between the points on the vector plane in Fig 7.

The quantization of four level transform coefficients which are obtained from four level images is similar to the above methods. Since the GF-N arithmetic preserves the perfect reconstruction property, we extended our simulations to four level images with four level decompositions and quantizations for improved image quality. The binarization steps in the above methods M1, M2 and M3 are simply replaced with the four level quantization steps.

In Figure 9, the original binary fingerprint image is shown. This image is compressed using the binary nonlinear SDVQ technique and the reconstructed images for two compression ratios

Figure 10. Reconstructed images at 0.057 bitpixel (left) and 0.072 bit/pixel (right).

Figure 11. A four level fingerprint image.

Figure 12. Reconstructed images at 0.08 bits/pixel(left) and 0.14 bits/pixel(right).

are shown in Figure 10. The image on the left (right) has a Compression Ratio (CR) of 17.4 (13.8). These CRs correspond to 0.057 bitpixel and 0.072 bitpixel, respectively. In the left (right) image 4x4 (2x2) quantization vectors are used. Both images contain the necessary information for identification. There is very little visual difference between the 0.072 bitpixel image and the original image.

In a database of 40 fingerprint images, we obtained an average CR of 14:1 with very high visual quality. If only the delta or core points, which are the discriminating parts in a fingerprint image, are to be preserved, CR's of about 20:1 to 30:1 are obtained.

The same test image shown in Fig. 9 is also compressed using the lossless binary image compression algorithms [7],[15] and a CR of 5.75 is obtained. The JBIG algorithm produces a CR of 5.11.

Four level images are also tested in our simulations. Consider the four level fingerprint image shown in Fig. 11. This image contains more details than the binary image. The simulation studies showed that higher comression ratios can be obtained with the four level images and the important curves such as delta or core points can still be clearly seen in the coded image. In Fig. 12, two encoded images are shown. The left one is compressed to 0.08 bits/pixel, and the right one is compressed to 0.14 bits/pixel. Both of the figures keep the characteristics of the fingerprint image shown in Fig. 11. The average four level coding results over a database of 40 fingerprint images are given in table 1. The methods are also compared to the Embedded Zerotree Wavelet (EZW) coder results [5]. At perceptually similar quality levels, our VQ based methods perform better than the

method	CR (PSNR=20dB)	CR (PSNR=14dB)
M1	13.0:1	23.0:1
M2	14.5:1	25.0:1
M3	15.5:1	26.5:1
EZW	13:1	18:1

Table 1. *Coding results (CR) for four level images at high and low perceptual quality levels.*

EZW. The same amount of difference in the compression ratios exists if the PSNR's are kept the same for similar perceptual quality as can be seen from Table 1.

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