PROGRESSIVE FINGERPRINT IMAGES COMPRESSION USING EDGE DETECTION TECHNIQUE

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ABSTRACT

In this paper, a progressive fingerprint image compression (for storage or transmission) using edge detection scheme developed. The image is decomposed into two components. The first component is the primary component, which contains the edges, the other component is the secondary component, which contains the textures and the features. In this paper, a general grasp for the image is reconstructed in the first stage at a bit rate of 0.0223 bpp for Sample (1) and 0.0245 bpp for Sample (2) image. The quality of the reconstructed images is competitive to the 0.75 bpp target bit set by FBI standard. Also, the compression ratio and the image quality of this algorithm are competitive to other existing methods given in the literature [Bradley and Brislawn,1996]-[Sherlock and Monro,1996]. The compression ratio for our algorithm is about 45:1 (0.180 bpp).

Keywords: *Progressive Image Transmission, Fingerprint Compression, Edge Detection, Vector Quantization.*

الملخص

تم في هذه الورقة بناء خوارزم جديد للضغط المتتالي للبصمات الرقمية لإرسالها أو حفظها باستخدام كاشف الحواف. قسمت الصور إلى مركبتين (أولية و ثانوية). حيث أن حواف الصورة وضعت في المركبة الأولى ، بينما المركبة الثانية تحتوي على الهيئة و البنية الأساسية للبصمة . في هذا البحث استطعنا الحصول على شكل مبدئي للعينة (١) عند معدل ٠،٠٢٢٣ بته لعنصر الصورة و ٠،٠٢٤٥ بته لعنصر الصورة للعينة (٢). حصلنا على الصورة المسترجعة عند معدل ٠،١٨٠ بته لعنصر الصورة يعني بمعدل ضغط يصل إلى ٤٥ : ١. هذا الخوارزم يعطي نتائج تضاهي مثيلاتها من الخوارزميات الأخرى, على سبيل المثال خوارزم المباحث الفيدرالية الأمريكية القياسي للبصمات.

1. INTRODUCTION

Fingerprints are vital forensic tools used around the world by the police departments to identify suspects and bodies. It is also one of the biometrics currently being considered for identification and access control to facilities (systems and networks). With time, huge numbers of fingerprints images have been collected and stored in paper databases. These paper databases have proven not to be an efficient way to store fingerprints images especially with increasing demands for simple access and fastest transmission of these images between police departments. Fingerprints images can be digitized and stored in electronic memories. One problem to be faced when using digitization is how to obtain the finer details of the fingerprints? The image must be represented with huge number of bits, which will need a large memory and large transmission time or large bandwidth. To achieve higher compression ratios, regular structure of fingerprint images should be utilized by means of model based coding techniques [Acar and Gokmen,1994],[Chong and Gray,1992] and [Yamada and Tominaga,1993].

Several different methods have been reported for fingerprint compression in the literature. They can be divided into two categories [Ersoy et.al,1999]: (a) – fingerprint data compression techniques, which are based on *extracting and compressing essential data* in fingerprints like ridges and/or features. These techniques are not able to reconstruct the compressed fingerprint images [Chong and Gray,1992]and [Yamada and Tominaga,1993]. (b) – Fingerprint image compression techniques based on *transforms suited* for these kinds of images. Some other techniques belonging to this category, such as vector quantization are used [Kasaei and Deriche, 1997]. These techniques of category (b) cannot achieve higher compression ratio than that of category (a) because they did not utilize the regular structural properties of the fingerprints. There are many proposed algorithms in the literature which adopted category (b) such as the FBI standard for fingerprint compression [Bradley and Brislawn,1996].

The US Federal Bureau of Investigation (FBI) has developed a standard to compress digital fingerprint images so that the fingerprint images can be transmitted and stored efficiently with minimum loss to the vital details. This standard is referred to as Wavelet/Scalar Quantization compression (WSQ), which depends on a signal processing theory called the wavelet transform [Bradley and Brislawn,1996]. Several other algorithms using the discrete wavelets transform (DWT) concept have been reported in the literature [Sherlock and Monro,1996],[Sherlock and Monro,1997]and [Sherlock and Monro,1996]. The compact support of the basis functions of the DWT implies an ability to adapt to local image structures.

In this paper, we proposed a progressive compression scheme for the fingerprint which enables us to achieve high compression and in the same time reconstruct the fingerprint from the compressed data. The algorithm combines the advantages of the above mentioned two categories used for fingerprint compression. Edge detection technique enables us to progressively reconstruct the fingerprint image from ridge skeleton. In this approach, the compression is based on deriving the most important information about ridge and valley skeletons by using the Canny edge detection method. To reduce the numbers of detected edges to be compressed, predefined nameplates will be correlated with the extracted edges, and then extract the macro edge in sixteen directions (i.e. in steps of 11.25 degree). The aim of detecting macro edges is to reduce the number of gaps in the fingerprint edges, and therefore, to reduce the number of edges to be encoded. Itoh in [Itoh, 1996] has adopted Laplacian method with thresholding for gray scale images. However, his technique will not detect the edges for areas with small intensities variation in the image. Therefore, we propose using Canny edge detection method for fingerprint images having small variations at the ridges and the valleys. This technique will maintain the important features such as the end points and the bifurcation points which can be obtained from the ridge skeleton even at a very high compression ratio.

This paper is organized as follow: In section 2, the images compression using edge detection technique is presented. The progressive fingerprint images compression using edge detection method is discussed in section 3. In this section more detailed information for the proposed algorithm is presented. The simulation results are given in section 4. Conclusions and recommendations are presented in section 5.

2. IMAGE COMPRESSION USING EDGE DETECTION

The coding model employed for edge detection coding schemes is based on the multi-component source model [Yan and Sakrison,1997]. It decomposes the gray scale image into primary component, which contains the edge information, and secondary component, which represents the slow intensity variations. Many approaches put emphasis on the edge detection, representation and coding, which has a significant impact on the quality of the reconstructed image. Most of the edge detection schemes are thwarted by gaps in the data produced by local noise and readily follows by spurious boundaries, as well as the location errors of extracted edges, which will lead to edge discontinuity and incorrect intensity values [Kunt et.al, 1987].

In the literature many methods have been introduced for edge detection. In this paper, we adopted Canny method for edge detection, which depends on zero crossing for detecting edges even at small intensities variation. Also, Canny method has been found to have the lowest MSE for the reconstructed image, when compared with other edge-detection methods such as Sobel, Roberts, and Prewitt [Lim, 1990]. The method can be seen as a smoothing filtering performed with a linear combination of exponential functions, followed by derivative operations. The size of the exponential filter is related to the width of gray level transition region, as well as to the noise level in the image. The edge detection methods proposed in [Itoh, 1996],[Yan and Sakrison,1997],[Kunt *et.al*, 1987]and [Lim, 1990] are suitable for regular gray scale images but not for fingerprints image. In this paper, we propose a modified edge detection compression technique tuned for gray scale fingerprint images. In this technique, the fingerprint image is decomposed into primary component, which contains the edge information of the ridges (dark curves) and the valleys in the fingerprint, and secondary component, which represents the original structural properties of the fingerprint image.

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2.1. Extracting the unit edges

The edges are detected using Canny method. The scheme for unit edge detection is shown in Figure 1. Canny method is first applied to detect the edges in the fingerprint image. Then, a sub-block of 5x5 from the edge image will be correlated with a pre-selected eight nameplates. The aim of these nameplates is to replace the edges detected by Canny method with the corresponding nameplates [Itoh,1996]. This will reduce the number of edges in controllable way and keeping the important information about the ridge skeleton. These nameplates are shown in Figure 2. The correlation method is implemented according to the following equation:

$$R_n(x,y) = \sum_j \sum_k B_{sb}(x+j, y+k) T_n(j,k) \qquad (1)$$

Where n is an integer number equals to 0, 1, 2, …, 7, (j,k) are integer numbers depending on the size of the nameplate, B_{sb} is the sub-block taken from the image after thresholding, T_n is one of eight nameplates, and (x,y) are $L/5$ each, where L is the fingerprint dimension.If there exists n such that $R_n(x,y)$ is greater than or equal to a predefined threshold (P_{th}), a unit edge will be detected and replaced with the nameplates that satisfy the criteria given below:

$$R_n(x,y) \geq P_{th} \qquad \text{for all } (x,y) \qquad (2)$$

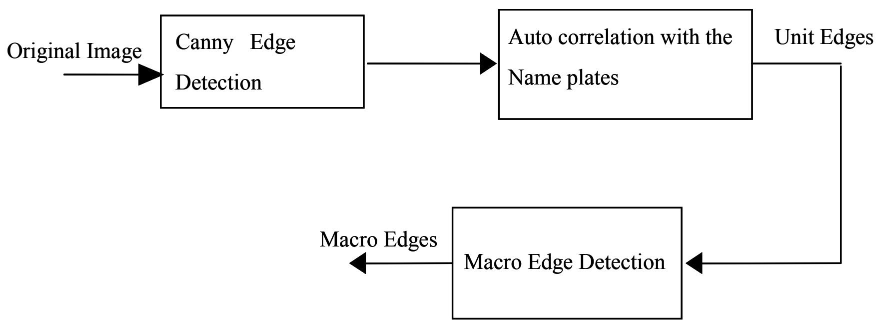

Figure 1. The unit edge detection process.

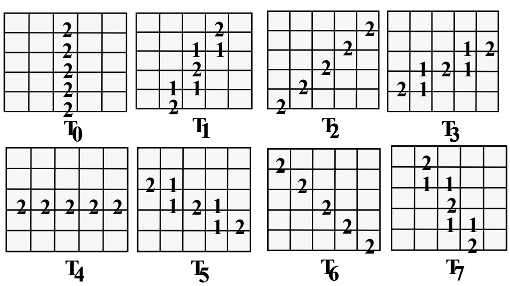

Figure 2. Eight directional small segment patterns.

2.2. Extracting Macro edge

After extracting the unit edges as discussed in the previous section, we will detect the macro edge (in sixteen directions only) along the circle around the designated unit edge. These directions will be 11.25 degrees each as presented in [Itoh,1996]. The aim of detecting macro edges is to reduce the number of gaps (edges connection), to give smoothing for the interpolation process, and to reduce the number of edges in the unit edge fingerprint image to be compressed. Also, it serves to keep the edges which are necessary to reconstruct the ridge skeleton with acceptable visual quality.

3. PROGRESSIVE FINGERPRINT COMPRESSION USING EDGE DETECTION

A progressive image transmission is adopted to overcome the edge discontinuity and incorrect intensity values problems of edge detection and to involve an approximate reconstruction of the image whose fidelity is built up gradually until either the viewer decides to abort the transmission or perfect reconstruction is achieved.

The applications benefiting from this algorithm are in transmitting the images over low bandwidth channels such as wireless channels and telephone lines. Examples for such applications are access to remote fingerprint image databases, electronic shopping, and security systems. The last couple of years have seen an explosive growth of business-to-customer activities over the Internet. The total dollar value of these web-based transactions is over several billion US dollars [Ratha *et.al*, 2000]. The present transaction over the web is not capable of assuring that the rightful owner of the credit card is the one who initiates the transaction. Furthermore, the present practice is not capable of linking the transaction to the rightful owner to the credit card. Very soon, credit card owners and credit card issuers will demand more reliable and secure authentication techniques that link the owner of the credit card and the transaction with the help of fingerprint [Ratha *et.al*, 2000]. For these applications, it is important for the viewer to recognize the content as early as possible in the transmission.

In this section, the encoding of primary and secondary components will be presented. For the primary component, a combination of Huffman code and vector quantization (VQ) is designed for the nameplates. This encoding process reduces the required bit to transmit the compressed macro edges.

3.1. Codebook design for the primary component

Two neighbor nameplates are assumed to be the codeword of the design codebook. The size of the codeword will be a sub-block of size 5x10 from any two combinations of the nine nameplates. The size of the codebook will be 9^2, which is self generated from the original nameplates. In this paper, we tested ten different fingerprints images to design an optimal codebook. A sub-block of 5x10 from the test fingerprint image is taken and compared with the eighty one possible combination of the codebook. One of the codebook will give an exact representation of the input sub-block. The index of this entry codeword will be sent at a rate of 7 bits (0.14 bit per pixel). To obtain a high compression ratio, the Huffman coding concept for the codebook indexes (to know how many times each combination of the nameplate will occur) is implemented. The ten test fingerprint images are used to design the Huffman code.

From the experimental results, we find that most of the nameplates combinations have zeros or ones times occurrence. These nameplates will be discarded to reduce the codebook entries. There are only 16 codeword, which will reduce the required bit rate for the first stage encoded image to be (4/50) bit per pixel (bpp). Designing a Huffman code for the 16 code vectors of the codebook can further reduce this rate. The first three layers primary components, which contain the high frequency, have been transmitted to give a general grasp of the image for a person who wants to browse through a remote database of fingerprint images. The overall progressive fingerprint images compression technique proposed in this paper is shown in Figure 3.

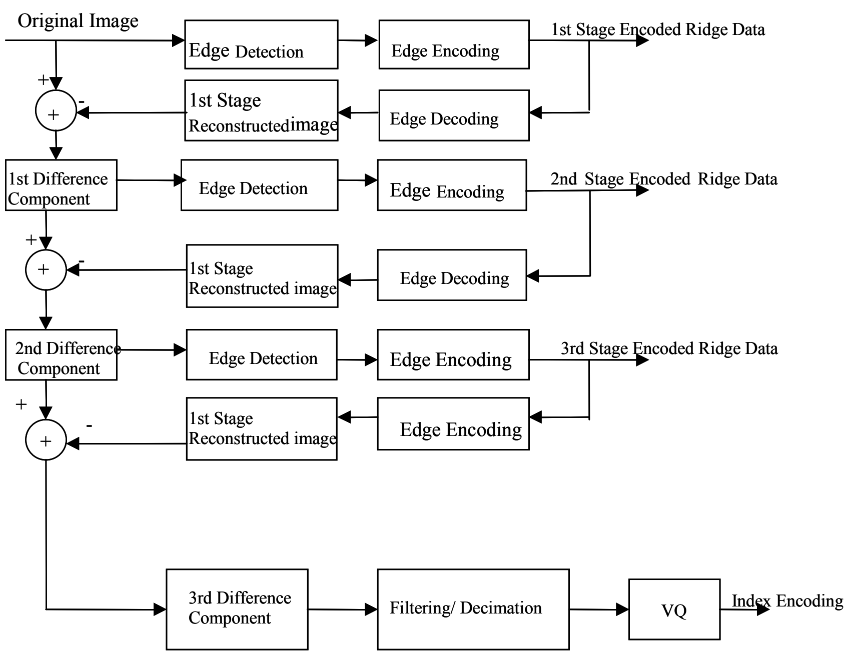

Figure 3. The overall proposed edge-detection encoding scheme for progressive image transmission.

3.2. Codebook design for the secondary component

The smooth component is the difference between the original image and the reconstructed primary component, which consists of summation of three stages of the reconstructed fingerprint images. This component will be decimated using minimum average entropy filter [Al-Asmari, 2002]. Then, the smooth component will be encoded using VQ. The codebook size is 256 vectors (codewords) each of length 16 pixels. 40960 vectors, which represent the ten decimated fingerprint images, are used to design the global codebook. The distortion measure (ε) is the mean square error (MSE). The ratio of the MSE between the new codebook and the previous codebook will be calculated according to the following equation:

$$R = \frac{E^k - E^{k+1}}{E^{k+1}} \quad (3)$$

Where R is the relative MSE, E^k is the MSE of the previous codebook, and E^{k+1} is the MSE of the new codebook. If the ratio $R \geq \varepsilon$, equation 3 will be repeated again until R became less than the target MSE Ratio (ε). In this paper ε is selected to be 10^{-4}. At the receiver, the two components (primary and smooth) have been added to form the reconstructed image.

4. SIMULATION RESULTS

A commonly used fidelity criterion measure for any compression scheme is the mean square error (MSE), and peak signal to noise ratio (PSNR). The main attributes of the MSE are its mathematical tractability and the fact that small values of MSE corresponds to perceptually high quality reconstructed images. These fidelity criterion measures are given below.

$$PSNR = 10\log_{10}\left(\frac{255^2}{MSE}\right) \quad \text{and} \quad MSE = \frac{1}{M \times N}\sum_{i=1}^{M}\sum_{j=1}^{N}\left(X_{ij} - \hat{X}_{ij}\right)^2$$

Where M and N are the image dimension, X is the original image, and $\hat{X}$ is the reconstructed image.

The experimental results in this paper are given for two samples from the ten tested fingerprint images. Figure 4 shows the original images of sample (1) and sample (2). The Canny edge detection method is implemented for these two test samples as shown in Figure 5 (a) and (b). As can be seen from this figure, it approximates the binary representation of the original images. The approach given in Figure 5 (c) and (d) reduce the edges by using the nameplates replacement proposed in this algorithm so we can have a great compression ratio. To further reduce the number of edges and keep those which have the important feature of the fingerprint, we apply the macro edge detection concept as shown in Figure 5 (e) and (f). These images (figure 5 (e) and (f)) are used to compress the fingerprint images to be stored or transmitted.

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Figure 4. The original fingerprint images: (a) Sample (1), (b) Sample (2).

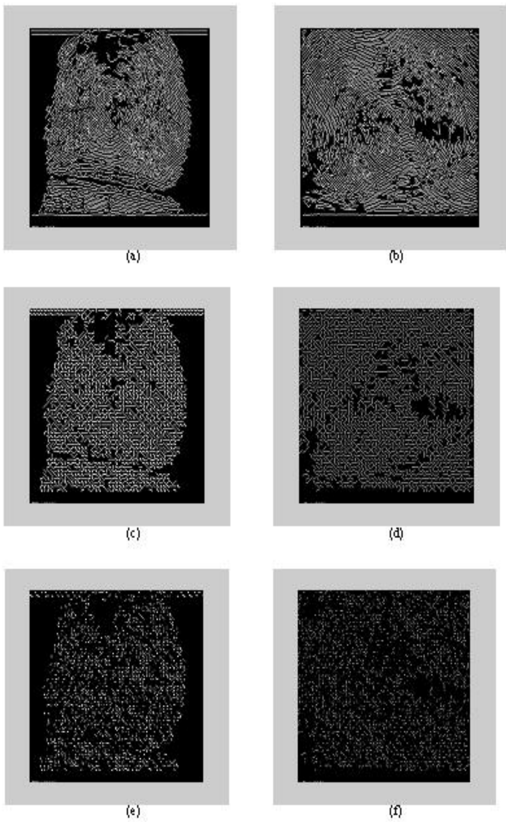

Figure 5. Canny edge detection for: (a) Sample (1), (b) Sample (2);
Nameplates replacement for: (c) Sample (1), (d) Sample (2);
Macro edge detection for: (e) Sample (1), (f) Sample (2).

Figure 6 shows the three stages reconstructed fingerprints at different peak signal to noise ratio (PSNR) in dB, and at different bit rate (bpp) as shown in Table 1. The reconstructed images in this figure are used to be added to the secondary reconstructed component. The visual quality of the reconstructed primary component is improved gradually as of transmitting additional information at an increased bit rate. Figure 6 can be considered to be the ridge data of the fingerprint images. The accumulative interpolation process (at the receiver side) for these data gave us primary information about the ridge skeleton of the fingerprint as shown in Figure 6 since the ridges represent the dark curves shown in the original fingerprint images. The first primary component can be reconstructed at an average bit rate as low as 0.0234 bpp (i.e. compression ratio of 342:1). The second stage primary (ridge) component will require almost twice this bit rate. Also, the third stage reconstructed primary component will require almost three times more than that needed for the first stage. The average bit rate required to accumulatively encode the three stages data is on the average of 0.0662 bpp (compression ratio of 121:1).

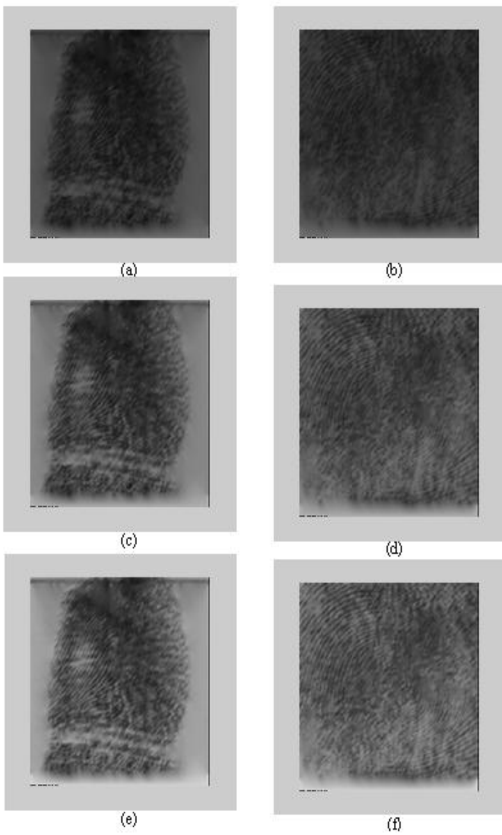

Figure 6. The 1st stage reconstructed fingerprint images: (a) Sample (1), (b) Sample (2);
The 2nd stage reconstructed fingerprint images: (c) Sample (1), (d) Sample (2);
The 3rd stage reconstructed fingerprint images: (e) Sample (1), (f) Sample (2).

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Table 1: The bit rate (bpp) and the PSNR (dB) for the three stages of the primary component.

Stage Number	Fingerprint image	Bit rate (bpp)	SNR dB
1St Stage	Sample (1)	0.0223	10.765
	Sample (2)	0.0245	9.621
2nd Stage	Sample (1)	0.0423	14.260
	Sample (2)	0.0531	13.280
3rd Stage	Sample (1)	0.0614	16.270
	Sample (2)	0.0771	14.550

The unique set of features like end points and bifurcation points are extracted from the original fingerprint image by many methods [Acar and Gokmen,1994], [Chong and Gray,1992], [Yamada and Tominaga,1993] and [Ersoy et.al,1999]. In this paper, an approximation of the features can be found by taking the difference between the original fingerprint image and the difference (secondary) component. Figure 7 shows the secondary component, which is the difference between the original image and the 3rd stage reconstructed primary (ridge) component. This component is closely representing the binarized image. Figure 7 (a) and (b) show the original component before encoded. This component is filtered first by an optimal filter given in [Al-Asmari, 2002], and then decimated by 2. The VQ discussed in the previous section is used to encode this image. The reconstructed secondary (end and bifurcation points) are shown in Figure 7 (c) and (d) at 0.1206 and 0.192 bpp; respectively. It can be seen from this figure that the visual quality is almost the same as a result of using filters optimized for fingerprint image decomposition.

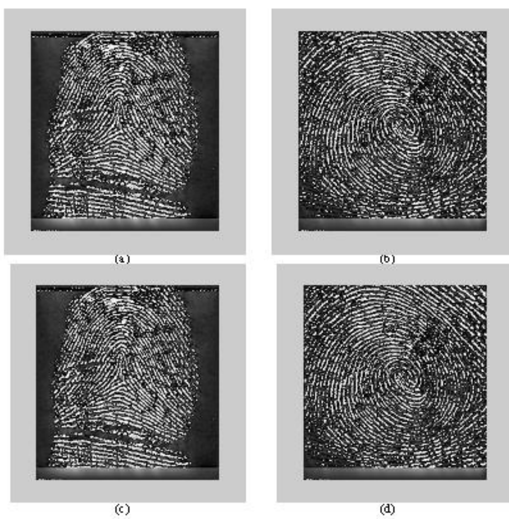

Figure 7. The secondary component for: (a) Sample (1), (b) Sample (2);
The reconstructed component for: (c) Sample (1), (d) Sample (2).

The fingerprint can be progressively reconstructed by sending the primary components first. Then, the encoded secondary component is added to it. This is called progressive compression. Our experiments showed that the quality and compression ratio could be improved by applying more stages of the primary components. However, in this paper we apply three stages only for simplicity purpose. Figure 8 shows the reconstructed fingerprints at an average bit rate of 0.182 bpp and PSNR of 32.15 dB for Sample (1), and 0.179 bpp and PSNR of 30.8 dB for Sample (2). This gives an average compression ratio of 45:1

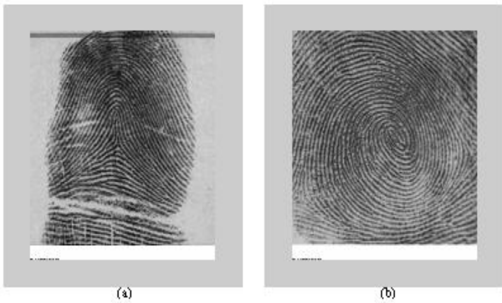

Figure 8. The reconstructed fingerprint images: (a) For Sample (1) at rate of 0.182 bpp and PSNR of 32.15 dB; (b) For Sample (2) at rate of 0.179 bpp and PSNR of 30.8 dB.

5. CONCLUSIONS

In this paper, we have described a progressive hybrid approach for compressing fingerprint images based on the Canny edge detection method. Reconstruction is achieved by adding the compressed primary component to the compressed secondary component. We have suggested using the VQ and Huffman code to encode the nameplates of the ridge edges. The average compression ratio of the primary component depends on the number of ridge chain. To improve the visual quality and the compression ratio, ridges can be enhanced and simplified before adding it to the secondary component to eliminate false features and excessive data. This can be achieved by increasing the number of encoded stages for the primary component to be more than 3.

The main contribution of this work is to provide an algorithm, which exploits the structural properties of fingerprint images to achieve high compression ratio with good visual quality. The original structural properties such as the relative location of ridge endings and bifurcations are well preserved in the secondary component. The other contribution of the proposed scheme is to unify the advantages of both fingerprint data compression and fingerprint image compression algorithms existing in the literature.

The quality of the reconstructed images is competitive to the 0.75 bpp target bit set by FBI standard [Bradley and Brislawn,1996]. Also, the compression ratio and the image quality of this algorithm is competitive to other existing methods given in the literature [Sherlock and Monro,1996],[Sherlock and Monro,1997]and [Sherlock and Monro,1996]. The compression ratio for our algorithm is about 45:1 (0.180 bpp).

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