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Comparative Study on Various Fingerprint Image Enhancement Techniques

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Abstract: Fingerprints are the oldest and most widely used form of biometric identification. The performance of any fingerprint recognizer highly depends on the fingerprint image quality. Different types of noises in the fingerprint images pose greater difficulty for recognizers. However, fingerprint images are rarely of perfect quality. They may be degraded and corrupted due to variations in skin and impression conditions. Thus, image enhancement techniques are employed prior to minutiae extraction to obtain a more reliable estimation of minutiae locations. Image enhancement can be done using both spatial and frequency domain techniques. Most Automatic Fingerprint Identification Systems (AFIS) use some form of image enhancement. Therefore, this paper describes various techniques for fingerprint image enhancement.

Keywords: Image Enhancement; Spatial Domain; Frequency Domain.

INTRODUCTION

Wide usage of biometric information for person identity verification purposes, terrorist act prevention measures and authentication process simplification in computer systems has raised significant attention to reliability and efficiency`1` of biometric systems. Biometric science utilizes the measurements of a person’s behavioral characteristics (keyboard strokes, mouse movement) or biological characteristics (fingerprint, iris, nose, eyes, jaw, voice pattern, etc.). Fingerprint is one of the most promising methods among biometric techniques and has been used for individual authentication since 19th century. The two fundamental premises on which fingerprint recognition is based are: fingerprint details are permanent and fingerprints of individuals are unique. A fingerprint is formed of a group of curves. Historically, in law enforcement applications the acquisitions of fingerprint images was performed by using ink-technique. Now days they are captured as live-scan digital images acquired by directly sensing the fingerprint surface with an electronic fingerprint scanner. The fingerprint pattern displays different features at different levels. At level 1, the most evident structural characteristic of fingerprint is a pattern of the lines (ridges) flowing in various patterns. This level is also known as global level of fingerprint analysis. At this level fingerprint pattern exhibits one or more regions where ridge lines are characterized by high curvature and frequent termination. These regions or singular regions are commonly used for assigning a fingerprint to a set of five distinctive classes (arch, tented arch, left loop, right loop, double loop and whorl) with the aim of simplifying search and retrieval. At local level or level 2 fingerprint images are characterized by discontinuity of ridges. The two most prominent ridge characteristic, called minutiae are ridge termination and ridge bifurcation.

A typical fingerprint-based recognition system works in two distinct modes: enrollment and recognition. The purpose of the enrollment mode is to create a database. During this mode, an enrollee fingerprint is captured and processed in three stages: Fingerprint Reading, Image Preprocessing, and Feature Extraction. After the feature extraction stage, a set of representative features of the enrollee fingerprint is saved in the database. During the recognition mode, a fingerprint to be recognized undergoes the same three processing steps as in the enrollment mode. The result is compared with a feature set template from the database in the feature matching stage. A match score which measures the similarity between the query feature set and database feature set is calculated. Higher values indicate higher confidence in a match.

Need of Fingerprint Image Enhancement

Fingerprint enhancement can be conducted on either binary ridge images or gray-scale images. Binarization before enhancement will generate more spurious minutiae structures and lose some valuable original fingerprint information; it also possess more difficulties for later enhancement procedure, so it is inherent limitations of this process. Different techniques for gray-level fingerprint images enhancement have been proposed assuming that the local ridge frequency and orientation can be reliably estimated. Pixel oriented enhancement schemes like Histogram Equalization, Mean and Variance normalization Weiner filtering [1] improve the legibility of the fingerprint but do not alter the ridge structure. L. O Gorman et al. proposed the use of contextual filters for fingerprint image enhancement. Hong and Jain have shown that ridges and valleys in a gray fingerprint image, forms a sinusoidal-shaped plane wave which possesses a clearly-defined frequency and orientation and used Gabor filter. Shen et al. applied Gabor filter to image sub-blocks and concluded that a good quality block can be identified by the outputs of Gabor filter bank. Green-berg proposed the use of an anisotropic filter that is based on structure adaptive filtering. Sherlock and Monro and Kamei and Mizoguchi perform contextual filtering completely in the Fourier Domain. The main reason for performing enhancement is to eradicate the noise in the fingerprint images, illuminate the parallel ridges and valleys and protect the true configuration of them. [2] The efficiency of fingerprint image enhancement algorithm is greatly depends on the quality of the fingerprint images. In order to obtain robust performance of a finger print image enhancement algorithm, that can improve the transparency of the ridge structures, is very essential.

Fingerprint Enhancement Methods

R.C. Gonzalez and R.E. Woods [3] have explained in his book that there is no general theory of image enhancement. When an image is processed for visual interpretation, the viewer is the ultimate judge of how well a particular methods works. Most of the quality checks have been used as a criterion, which determines image rejection, or a performance measurement of image enhancement algorithm. There have existed a variety of research activities along the stream of reducing noises and increasing the contrast between ridges and valleys in the gray-scale fingerprint images. Most popular among of them are spatial domain and other is frequency domain enhancement technique.

Spatial domain refers to the image plane itself, and image processing methods in this category are based on direct manipulation of pixels in an image. Spatial domain process discussed above can be denoted by the expression:

$$g(x, y) = T[f(x, y)]$$

Where, f (x, y) is an input image, g (x, y) is an output image and T is an operator defined over the neighborhood of (x, y).

Frequency domain consists of modifying the Fourier transform of an image and then computing the inverse transform [Discrete Fourier Transform (DFT)] to get back to input image .Thus given a digital image f (x, y), of size M x N, the basic filtering equation in which we are interested has the form:

$$g(x, y) = \tau^{-1}[H(u, v)\, F(u, v)]$$

Where, τ^{-1} is the IDFT, F (u, v) is the DFT of the input image f (x, y), H (u, v) is the filter function and g (x, y) is the filtered output image. Specification of H (u, v) is simplified considerably by using functions that are symmetric about the center. This is accomplished by multiplying the input image by -1^{x+y} prior to computing its transform [3].

COMPARITIVE STUDY

L. Hong et al. [4] have incorporated a fingerprint enhancement algorithm in the minutiae extraction module. A fast fingerprint enhancement algorithm, which can adaptively improve the clarity of ridge and valley structures of input fingerprint images based on the estimated local ridge orientation and frequency, was applied. Based on the local orientation and ridge frequency around each pixel, the Gabor filter is applied to each pixel location in the image. The performance of the image enhancement algorithm was evaluated using the goodness index of the extracted minutiae and the accuracy of an online fingerprint verification system. Experimental results show that incorporating the enhancement algorithm improves both the goodness index and the verification accuracy.

S. Greenberg et al. [1] propose two methods for fingerprint image enhancement. The first one is carried out using local histogram equalization, Wiener filtering, and image binarization. The second method uses a unique anisotropic filter for direct gray scale enhancement. The results achieved are compared with those obtained through some other methods. Both methods show some improvement in the minutiae detection process in terms of either efficiency or time required.

Kim et al. [5] proposed an improved algorithm for enhancement of fingerprint image on the basis of the image normalization and Gabor Filter. Firstly, the adaptive normalization based on block processing is suggested for improvement of fingerprint images. An input image is partitioned into sub-blocks with the size of K x L at first and the region of interest (ROI) of the fingerprint image is acquired. Secondly, a new

technique for selection of two important parameters of Gabor filter is devised. The proposed algorithms are tested with NIST fingerprint images and show significant improvement in the experiments.
Zhang et al. [6] proposed an enhancement algorithm using a space-frequency federated filtering scheme is proposed, which adapts the filtering methods to the input images according to a pre-defined quality factor. The quality factor is calculated on the orientation field filtered image. Only parts of the images of which quality factor do not meet the requirement are filtered by the Gabor filter. Experiments show that the proposed algorithm is computationally efficient, with the same level of the enhancement performance.

Yang et al. [7] in his research work has proposed a novel filter design method for fingerprint image enhancement. Yang developed an improved version of the TGF, called the modified Gabor filter (MGF). The modification of the TGF made the MGF more accurate in preserving the fingerprint image topography. The remarkable advantages of the MGF over the TGF consist in preserving fingerprint image structure and achieving image enhancement consistency. Experimental results indicate that the proposed MGF enhancement algorithm can reduce the FRR of a fingerprint matcher by approximately 2% at a FAR of 0.01 %.

Chaohong Wu et al. [8] described a new approach to fingerprint image enhancement, which is based on integration of Anisotropic Filter and directional median filter (DMF). DMF join broken fingerprint ridges, fill out the holes of fingerprint images, smooth irregular ridges and remove some annoying small artifacts between ridges. Experiment results show that Gaussian-distributed noises are reduced by Anisotropic Filter and impulse noises efficiently by DMF.

Khan et al. [9] proposed decimation-free directional filter to provide output in the form of directional images as opposed to directional sub-band provided in previous DFB. Since the method need the fingerprint image be prepared before given to proposed DFB, require removing non-uniform illumination from the image. Final enhanced image result is constructed on a block-by-block basis by comparing energy of all the directional images and picking one that provides maximum energy.

Yun et al. [10] proposed an adaptive preprocessing method to improve image quality. In the first stage several features are extracted for image quality analysis and they go into the clustering module. After that adaptive preprocessing is applied to produce good quality images. Yun tested the proposed method on NIST DB4 and a private DB collected with careful consideration of image quality. Experimental results show that the proposed method is better than the conventional one. Further works, he proposed to develop image characteristic factors for the identification system in real world.

Fronthaler et al. [11] propose a method to enhance the quality of a given fingerprint with the purpose to improve the recognition performance. A Laplacian like image scale pyramid is used for this purpose to decompose the original fingerprint into 3 smaller images corresponding to different frequency bands. In next step contextual filtering is performed using these pyramid levels and 1D Gaussians, where the corresponding filtering directions are derived from the frequency-adapted structure tensor. All image processing is done in the spatial domain, avoiding block artifacts while conserving the biometric signal well. Fronthaler report on comparative results and present quantitative improvements, by applying the standardized NIST FIS2 fingerprint matcher to the FVC2004 fingerprint database along with two other enhancements. The study confirms that the suggested enhancement robustifies feature detection, e.g. minutiae, which in turn improve the recognition.

Sepasian et al. [12] proposed method to investigate the performance of a three-step procedure for the fingerprint enhancement, using CLAHE (contrast limited adaptive histogram equalization) together with Clip Limit, standard deviation and sliding neighborhood as stages during processing of the fingerprint image. In first step CLAHE with clip limit is applied to enhance the contrast of the small tiles to eliminate the artificially induced boundaries existing in the fingerprint image. In a second step, the image is decomposed into an array of distinct blocks and the discrimination of the blocks is obtained by computing the standard deviation of the matrix elements to remove the image background and obtain the boundaries for the region of interest. In final step by using a slide neighborhood processing, an enhancement of the image is obtained by clarifying the Minutiae in each specific pixel, process known as thinning. The analysis of its possible advantages is carried out through a simulated investigation.

Jun-tao et al. [13] proposed an enhancement algorithm based on edge filter and Gabor filter. In first step, a gray based algorithm is used to enhance the edge and segment the image. Then a multilevel block size method is used to extract the orientation field from segmented fingerprint image. In final step, Gabor filter is used to fulfill the enhancement of the fingerprint image. The experiment results show that the proposed enhancement algorithm is effective than the normal Gabor filter algorithm. The fingerprint image enhance by the algorithm has better enhancement effect.

Yoon et al. [14] proposed a latent fingerprint enhancement algorithm which requires manually marked region of interest (ROI) and singular points. The core of the proposed enhancement algorithm is a novel orientation field estimation algorithm, which fits orientation field model to coarse orientation field estimated from skeleton outputted by a commercial fingerprint SDK. Experimental results on NIST SD27 latent fingerprint database indicate that by incorporating the proposed enhancement algorithm, the matching accuracy of the commercial matcher was significantly improved.

Choudhary et al. [15] present a fingerprint image enhancement method which can adaptively improve the clarity of ridge and furrow structures of input fingerprint image based on the frequency and spatial domain filtering, local orientation estimation, local frequency estimation and morphological operation. The proposed Enhancement algorithm is tested on 100 fingerprint images which are selected randomly and without repetition from database DB-finger to evaluate the efficiency. There set of operation applied on the database DB-Finger that Improve the quality of fingerprint Image.

I.G. Babatunde et al. [16] modified some of the sub models of an existing mathematical algorithm for the fingerprint image enhancement to obtain new and improved versions. The new versions consist of different mathematical models for fingerprint image segmentation, normalization, ridge orientation estimation, ridge frequency estimation, Gabor filtering, binarization and thinning. The implementation was carried out in an environment characterized by Window Vista Home Basic operating system as platform and Matrix Laboratory (MatLab) as front end engine. The results show that the modified sub-models perform well with significant improvement over the original versions. The results also show the necessity of each level of the enhancement.

In his proposed method Sherlock et al. [17] has described finger print image enhancement, based on non-stationary directional Fourier domain filtering. Fingerprints smoothed using directional filter and orientation is matched to local ridge orientation. The enhancement consists of filtering followed by thresholding stage. Filtering produces directionally smoothed version of the image from which most of the unwanted information has been removed. Thresholding yields the binary enhanced image. Experiment result leads to significant improvement in speed and accuracy of AFIS.

J.S. Bartunek et al. [18] proposed a new method for fingerprint enhancement by using directional filters and binarization. They derived a technique where the proper size of the local area is automatically determined for each individual fingerprint. Frequency analysis is also carried out in local area to design directional filters. The proposed algorithm was tested on numerous finger-print images taken from the different databases. The proposed adaptive fingerprint binarization algorithm shows a good ability to tune itself to each fingerprint image.

S. Chikkerur et al. [19] introduces a new approach for fingerprint enhancement based on Short Time Fourier Transform (STFT) Analysis. STFT is a well-known technique to analyze non-stationary signals. The algorithm estimates all the intrinsic properties of the fingerprints such as the foreground region mask, local ridge orientation and local frequency orientation. Chikkerur compared the proposed approach to other filtering method and showed that their technique performs favorably. They also objectively measured the improvement in recognition rate due to enhancement and obtained a 17 percentage improvement in the recognition rate on a set of 800 images from the FVC2002 database.

Tanaya et al. [20] proposes a new method for fingerprint matching based on the features extracted using a new multi-resolution analysis tool called Digital Curvelet Transform. The curvelet coefficients extracted from enhanced fingerprint images act as the feature-set for a k-nearest neighbor classifier. The performance of this scheme has been evaluated on a small database of 120 images. A comparative study between the wavelet-based and the curvelet-based techniques has also been included. The high recognition rate achieved by using this method suggests an efficient solution for a small scale fingerprint recognition system.

A.M. Raicevic et al. [21] propose an adaptive filtering in frequency domain in order to enhance fingerprint image. To achieve this, the query image is first normalized to have desired mean and variance. The image is then divided into non-overlapping blocks and dominant ridge orientation is determined for each block to be used in the subsequent processes. The dominant ridge directions are then smoothed and subsequently the block-direction image is formed. The next step is to estimate the average ridge distance or frequency. The image is then enhanced using the directional filtering method. Two different directional filters (Butterworth and Gabor filter) are proposed where both of them enhance fingerprint ridge valley structure and attenuate existing noise. Experiment result of enhancement process produces more reliable feature extraction, less spurious minutiae and improves the overall AFIS accuracy.

P. Sutthiwichaiporn et al. [22] proposed fingerprint enhancement algorithm that enhances fingerprint based on spatial-frequency domain with two major contributions. First, the proposed algorithm employs matched filtering approach, then, input fingerprint is partitioned and assessed as high/low quality zone by using signal-to-noise ratio (SNR) approach. For high quality zone, signal spectrum with noise suppression is used to shape an enhanced filter in frequency domain. Then algorithm feed neighboring enhanced zone back in order to repair unreliable low quality region. By using overlapped block with the STFT approach, blocking artifacts can also be eliminated. The proposed method performs better on FVC2004 Db3 than Db2 because most fingerprints in Db3 contain combination of high quality zone and low quality zone in the same image. Also the proposed algorithm diffuses high quality enhanced zones into low quality zones by iterative feedback manner, resulting in good quality migration.

Nandini et al. [23] introduces hybrid type fingerprint image enhancement where in the Discrete Fourier transform (DFT) based adaptive regularized constraint total least square De-convolution is performed followed by Discrete Wavelet Transform (DWT) based maximum a posterior estimator. Proposed method is tested on standard Bio lab FVC2002 and experiment result on this dataset show that proposed method of enhancement and restoration has provided better improved representation of fingerprint for extraction of minutiae points which operates iteratively and switches between two different domains DFT and DWT. The overall system has shown an increased rate of recognition accuracy of the system especially when the fingerprints are degraded.

D.K.Misra et al. [24] proposed Finger print Image Enhancement based on energy minimization principle. For this purpose a system design using filters is proposed. Finger Print Images have ridge directions and ridge frequencies due to several peaks and valleys available on the surface of human finger. Both the features of the images are required to be enhanced, so two distinct filters in Fourier domain, one for enhancing ridge frequencies and other for ridge directions, have to be designed. Selecting image features i.e. frequencies and directions which minimize energy function based on energy minimization principle, a very good enhanced image can be produced. The energy function for selecting above image features is defined by intensities of the images obtained by the designed filters and smoothness of image feature is measured in proposed method also. Image features obtained by the above filters which minimize energy function too, can be utilized for many applications. Experiment result shows that proposed method reduces two third matching error rate compared with other methods.

V. K. Sagar et al. [25] presents research into the use of fuzzy- neuro technology in automated fingerprint recognition for the extraction of fingerprint features, known as minutiae. The work presented here is an addendum to work carried out earlier. In present research three minutiae extraction techniques presented are: classical approach, fuzzy approach and fuzzy neural approach. The hybrid fuzzy and neural network model performs the minutiae extraction in two stages, a fuzzy front-end and a neural back-end. Experiment results shows that using the fuzzy neural hybrid model, fingerprint minutiae extraction is more accurate since fewer false minutiae and more true minutiae are identified.

In this work D. Bennet [26] develop a novel method for Fingerprint image contrast enhancement technique based on the discrete wavelet transform (DWT) and singular value decomposition (SVD).This technique is compared with conventional image equalization techniques such as standard general histogram equalization and local histogram equalization. An automatic histogram threshold approach based on a fuzziness measure is presented. Then, using an index of fuzziness, a similarity process is started to find the threshold point. A significant contrast between ridges and valleys of the best, medium and poor finger image features to extract from finger images and get maximum recognition rate using fuzzy measures. The experimental results show the recognition of superiority of the proposed method to get maximum performance up gradation to the implementation of this approach.

K. Srinivasan et al. [2] proposed an efficient and robust fingerprint enhancement technique via fuzzy based filtering. In his work Srinivasan has employed a fuzzy modeling approach for removing the noise as well as for improving the luminosity of the ridges. Moreover, the fuzzy filter values are evaluated and superior results are produced in the image domain. The probabilities of gray values are measured from the position of the input image pixel. The proposed technique is implemented in MATLAB. The quality of the reconstructed images is determined by measuring the PSNR of FVC2002 fingerprint database. The proposed fingerprint enhancement system using fuzzy based filtering techniques gives high PSNR and low MSE when compared to the Gabor filtering based fingerprint enhancement method.

Yang et al. [27] proposed an effective two-stage enhancement scheme in both the spatial domain and the frequency domain for low-quality fingerprint images by learning from images. In his work Yang has employed a spatial ridge compensation filter in in the first stage enhancement to use the context information of the local ridge to connect or separate the ridges. Based on this spatial filtering, the broken ridges will be connected and the merged ridges will be separated effectively. In the second stage processing, the filter is separable in the radial and angular domains, respectively. Its parameters have adequately been determined by the information of both the original image and the enhanced image of the first stage instead of acquiring from the original image solely. The proposed technique is implemented in MATLAB. The quality of the reconstructed images is determined by measuring the TMR and FMR of FVC2004 fingerprint database. The proposed fingerprint enhancement system using two stage filtering techniques gives high TMR and low FMR when compared to the Gabor filtering based fingerprint enhancement method and STFT enhancement.

CONCLUSION AND FURTHERWORK

Review of literature on fingerprint image enhancement put forward attention that there are researches available in spatial domain filtering but very few research work found using filter in frequency domain. Also very few work could be found taking ridge frequency enhancement in review literature process. Though ridge orientation and ridge detection, on single pixel found very well in spatial domain filtering. There are few research work reviewed based on fuzzy concept and filter. From the review it is clear that fingerprint should be of good quality in order to extract features effectively. We could use block processing instead of pixel processing to reduce computational complexity in future. More over security can be implemented for protecting privacy in biometrics systems by coupling it with bio hashing.

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