Fingerprint Identification and Verification System using Minutiae Matching

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Abstract

Fingerprints are the most widely used biometric feature for person identification and verification in the field of biometric identification. Fingerprints possess two main types of features that are used for automatic fingerprint identification and verification: (i) global ridge and furrow structure that forms a special pattern in the central region of the fingerprint and (ii) Minutiae details associated with the local ridge and furrow structure. This paper presents the implementation of a minutiae based approach to fingerprint identification and verification and serves as a review of the different techniques used in various steps in the development of minutiae based Automatic Fingerprint Identification Systems (AFIS). The technique conferred in this paper is based on the extraction of minutiae from the thinned, binarized and segmented version of a fingerprint image. The system uses fingerprint classification for indexing during fingerprint matching which greatly enhances the performance of the matching algorithm. Good results (~92% accuracy) were obtained using the FVC2000 fingerprint databases.

1. INTRODUCTION

Fingerprints have been in use for biometric recognition since long because of their high acceptability, mmutability and individuality. Immutability refers to the persistence of the fingerprints over time whereas individuality is related to the uniqueness of ridge details across individuals. The probability that two fingerprints are alike is 1 in 1.9 x 10^{15} [1]. These features make the use of fingerprints extremely effective in areas where the provision of a high degree of security is an issue. The major steps involved in automated fingerprint recognition include a) Fingerprint Acquisition, b) Fingerprint Segmentation, c) Fingerprint Image Enhancement, d) Feature Extraction e) Minutiae Matching, f) Fingerprint Classification.

Fingerprint acquisition can either be offline (inked) or Online (Live scan). In the inked method an imprint of an inked finger is first obtained on a paper, which is then scanned. This method usually produces images of very poor quality because of the non-uniform spread of ink and is therefore not exercised in online AFIS. For online fingerprint image acquisition, capacitative or optical fingerprint scanners such as URU 4000, etc. are utilized which make use of techniques such as frustrated total internal reflection (FTIR) [2], ultrasound total internal reflection [3], sensing of differential capacitance [4] and non contact 3D scanning [5] for image development. Live scan scanners offer much greater image quality, usually a resolution of 512 dpi, which results in superior reliability during matching in comparison to inked fingerprints.

Segmentation refers to the separation of fingerprint area (foreground) from the image background [6]. Segmentation is useful to avoid extraction of features in the noisy areas of fingerprints or the background. A Simple thresholding technique [7] proves to be ineffective because of the streaked nature of the fingerprint area. The presence of noise in a fingerprint image requires more vigorous techniques for effective fingerprint segmentation. A good segmentation method should exhibit the following characteristics [8]:

It should be insensitive to image contrast It should detect smudged or noisy regions Segmentation results should be independent of whether the input image is an enhanced image or a raw image The segmentation results should be independent of image quality

Ren et al. [8] proposed an algorithm for segmentation that employs feature dots, which are then used to obtain a close segmentation curve. The authors claim that their method surpasses directional field and orientation based methods [9,10,11] for fingerprint image segmentation. Shen et al. [12] proposed a Gabor filter based method in which eight Gabor filters are convolved with each image block and the variance of the filter response is used both for fingerprint segmentation and quality specification. Xian et al. [13] proposed a segmentation algorithm that exploits a block’s cluster degree, mean and variance. An optimal linear classifier is used for classification with morphological post-processing to remove classification errors. Bazen et al. [14]

proposed a pixel wise technique for segmentation involving a linear combination of three feature vectors (i.e. gradient coherence, intensity mean and variance). A final morphological post-processing step is performed to eliminate holes in both the foreground and background. In spite of its high accuracy this algorithm has a very high computational complexity, which makes it impractical for real time processing. Klein et al. [15] proposed an algorithm that employs HMMs to remove the problem of fragmented segmentation encountered during the use of different segmentation algorithms.

For a good quality fingerprint feature extraction is much easier, efficient and reliable in comparison to a relatively lower quality fingerprint. The quality of fingerprints is degraded by skin conditions (e.g. wet or dry, cuts and bruises), sensor noise, non-uniform contact with sensor surface, and inherently low quality fingerprint images (e.g. those of elderly people, laborers). A significant percentage of fingerprints are of poor quality, which must be enhanced for the recognition process to be effective. Thereare two major objectives of fingerprint enhancement i.e. i) to increase the contrast between ridges and valleys and ii) to connect broken ridges. These objectives can be fulfilled by using a contextual filter whose characteristics vary according to the local context to be used for fingerprint enhancement instead of conventional image filters. The filter should posses the following characteristics:

It should provide a low pass (averaging) effect along the ridge direction with the aim of linking small gaps and filling impurities due to pores or noise.

It should have a band pass (differentiating) effect in the direction orthogonal to the ridges in order to increase the discrimination between ridges and valleys and top separate parallel linked ridges.

Sherlock et al. [16] proposed an algorithm for fingerprint image enhancement that employs position-dependent Fourier-domain-filtering-based orientation smoothing and thresholding technique. Greenberg et al. [17] proposed two schemes for fingerprint enhancement. One method uses local histogram equalization, Wiener filtering, and image binarization whereas the other method uses a unique anisotropic filter for direct grayscale enhancement. O'Gorman et al. [18,19] proposed a contextual filter based approach that utilizes four main parameters of fingerprint images at a given resolution i.e. maxima and minima of the ridge and valley widths to form a mother filter whose rotated versions are then convolved with the image to yield the enhanced output. Hong et al. [20] proposed an effective method based on Gabor filters for image enhancement. Gabor filters fulfill the requirements of a good fingerprint enhancement filter mentioned earlier as they possess both the differentiating and averaging effects. Slight modifications to this technique were made by Greenberg et al. [21]. Jiangwei et al. [22] modified the technique given by [20]. Their approach models the sinusoidal shape of the ridge-valley structure in a closer manner and gives better results. Tico et al. [23] made use of a ridge detecting technique based on the second directional derivative of the image to carry out fingerprint enhancement. Watson et al. [24] multiplied the Fourier transform of each 32x32 block by its power spectrum raised to a power k to produce an efficient technique that can find its use in online fingerprint recognition systems. Fingerprints possess two major types of features: special type of pattern formed by the ridge and furrow structures in the central region of the fingerprints and minutiae details associated with local ridges and furrows. Minutiae are minute details such as ridge endings (a point where a ridge ends abruptly) or a ridge bifurcation (where a ridge breaks up into two ridges). Minutiae are characterized by the position, direction and type (Ridge ending or bifurcation). The global features are used for fingerprint classification into six major classes whereas the minutiae details are used for fingerprint based person identification. Fingerprint analysts utilize the minutiae information for fingerprint identification and it is the most established technique in the field of AFIS. The accuracy of the technique is dependent upon the precision in the extraction of minutiae. There are two major type of
methods that are

1. Fingerprint database
2. Fingerprint features database
3. Enrollment Module

used for minutiae extraction i) binarization based methods and ii) direct gray scale methods. In binarization-based methods some information is lost during binarization that can degrade the performance of the minutiae extractor. Direct gray scale methods overcome these problems but may be difficult to implement and time consuming to operate. The typical approach for a binarization-based method involves a priori enhancement, binarization and then thinning. Various binarization and thinning approaches are discussed in [25, 26, 27, 28, 29]. Once a binary skeleton has been obtained, a simple image scan allows the pixels corresponding to the minutiae to be detected by finding the crossing number. The minutiae obtained as a result of minutiae extraction need to be filtered in order to remove the false minutiae introduced. Various minutiae filtering techniques are proposed in [30,31].

During enrollment the minutiae set obtained from an individual's fingerprint is stored as a template for that subject. In the authentication module, the fingerprint given as input is compared or matched with the templates to provide the decision of authentication. This process is known as minutiae matching. For minutiae matching to be effective the input fingerprint should be registered to the template fingerprint using the minutiae information of both the fingerprints. After registration the minutiae sets are compared using the spatial distance, which must be smaller than a particular threshold for two minutiae to be declared as matched. A minutia matching is usually performed by using Hough transform [32,33] or by pre- alignment [34].

Fingerprint classification is the process of classifying a given fingerprint into a number of classes such as left loop, right loop, whorl, arch and tented arch, double loop etc. Fingerprint classification is used for indexing in the fingerprint database and can greatly improve the performance of an AFIS. A typical fingerprint classification approach is based on the extraction of fingerprint singular points (core and delta) and the implementation of a rule based classification system that takes its decision based on the number and placement of core and delta in a fingerprint. Different classification algorithms are proposed in [35,36,37].

The rest of the paper is organized as follows: Section II gives details about the method used, section III exhibits the results with section IV giving the conclusions.

II. IMPLEMENTATION OF THE AFIS

This paper introduces a prototype automatic identity authentication system that is capable of authenticating the identity of an individual, using fingerprints. The main components of the AFIS are

The fingerprint database stores the fingerprint images. for this purpose. The features extracted from these fingerprints are stored in the features database along with the person ID. The objective of the enrollment module is to admit a person using his/her ID and fingerprints into a fingerprints database after the process of feature extraction. These features form a template that is used to determine or verify the identity of the subject, formulating the process of authentication. The component of the AFIS used for authentication is referred to as the authentication module. Figure 1 illustrates the different steps involved in the development of the AFIS. The details of these steps are given in the following subsections

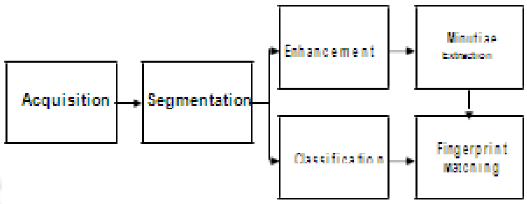


Fig. 1. Steps Involved in AFIS

I. Fingerprint Segmentation

Fingerprint segmentation is an important part of a fingerprint identification and verification system. However the time spent in segmentation is also crucial. The algorithms presented in [13] and [14] work quite well in the extraction of the required region but these algorithms have very high computational cost. We have developed an efficient algorithm that works with acceptable performance and has a lower computational cost. This algorithm is based only on the block coherence of an image. Coherence gives us a measure of how well the gradients of the fingerprint image are pointing in the same direction. In a window of size WxW around a pixel, the coherence is defined as:

$$Coh = \frac{\left|\sum_W (G_{s,x}, G_{s,y})\right|}{\sum_W \left|(G_{s,x}, G_{s,y})\right|} = \frac{\sqrt{(G_{xx} - G_{yy})^2 + 4G_{xy}^2}}{G_{xx} + G_{yy}} \quad (1)$$

$$G_{xy} = \sum_{h=-8}^{8} \sum_{k=-8}^{8} G_x(x+h, y+k)\, G_y(x+h, y+k)$$

$$G_{xx} = \sum_{h=-8}^{8} \sum_{k=-8}^{8} G_x^2(x+h, y+k)$$

$$G_{yy} = \sum_{h=-8}^{8} \sum_{k=-8}^{8} G_y^2(x+h, y+k)$$

Where G_X and G_Y are the local gradients along X and Y directions respectively. The resulting gradient coherence image is smoothed by the use of a Gaussian smoothing filter to give a coherence image C(x, y). The smoothed image is then binarized to produce a segmentation mask C_B. The binarization is carried out by global thresholding as

$$C_B(i, j) = \begin{cases} 1 & C(i, j) > M_C \;\; 0.5S_C \\ 0 & \text{Otherwise} \end{cases} \quad (2)$$

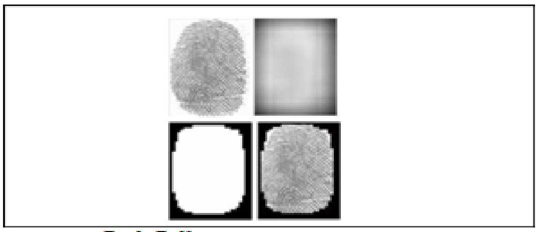


Fig 2: Different steps in segmentation
A B
C D
A. Original image, B. Coherence image,
C. Segmentation Mask. D) Segmented

M_C is the global mean of the coherence image and S_C is its global standard deviation. Holes in the segmentation mask are removed using morphological post processing. This mask on pixel -wise multiplication with the fingerprint image gives the segmented image. (see figure 2)

II. Fingerprint Enhancement

The fingerprint enhancement algorithm mentioned in [20] was found to be suitable for this application and was therefore used in the system. Better results are obtained using [22] but it is slightly more time consuming. This algorithm calls for the development of a ridge frequency image I_{RF} and ridge orientation I_{RO} image for a fingerprint. Gabor filters are used to enhance the fingerprint utilizing the ridge frequency and ridge orientation information obtained from the frequency and orientation images obtained earlier. The enhanced image I_E is then binarized using adaptive thresholding to give a binarized image I_{EB}. The binarized image is thinned to give I_T. The thinned version is used for minutiae extraction.(see figure 3)

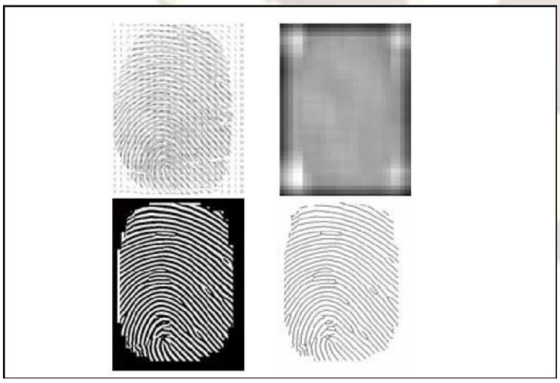


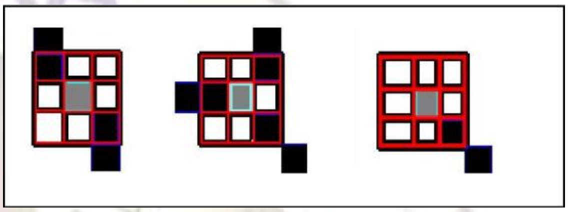
Fig. 3: Steps required for feature extraction
A B C D
A. Orientation Field, B. Ridge Frequency Image
C. Enhanced Image D. Thinned Image

IV. Minutiae Extraction

Minutiae extraction was carried out using the crossing number approach [39]. Crossing number of pixel 'p' is defined as half the sum of the differences between pairs of adjacent pixels defining the 8-neighborhood of 'p'. Mathematically

$$cn(p) = \frac{1}{2} \sum_{i=1..8} \left| val(p_{i \bmod 8}) - val(p_{i-1}) \right| \quad (3)$$

Where p_0 to p_7 are the pixels belonging to an ordered sequence of pixels defining the 8-neighborhood of p and val (p) is the pixel value.



Fig, 4: cn (p)=2,cn (p)=3 and cn (p)=1 representing a non- minutiae region, a bifurcation and a ridge ending

Crossing numbers 1 and 3 correspond to ridge endings and ridge bifurcations respectively. An intermediate ridge point has a crossing number of 2. The minutiae obtained from this algorithm must be filtered to preserve only the true minutiae. The different types of false minutiae introduced during minutiae extraction include spike, bridge, hole, break, Spur, Ladder, and Misclassified Border areas. (See figure 5)

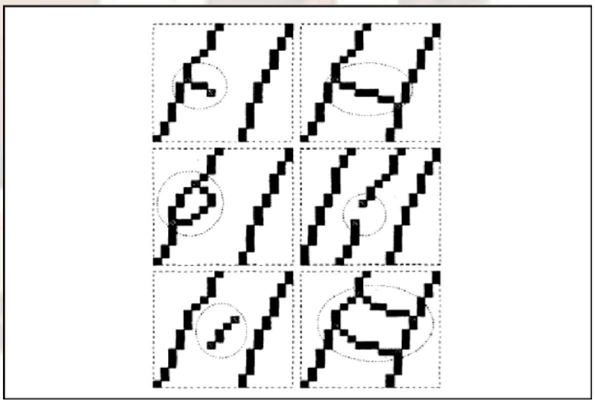


Fig. 5 Types of false minutiae
A B C D E F
A. Spike, B. Bridge, C. Hole, D. Break, E. Spur F. Ladder

The number of minutiae in a given area is also limited therefore the minutiae density must also be kept in check. In order to filter out these false minutiae a 3 level-filtering process is applied:

Level 1: Removes the false ridge endings created as a result of the application of minutiae extraction algorithm at the ends of the thinned image.

Level 2: Removes the first five types of minutiae mentioned above using the rule based morphological minutiae filtering approach given by [40].

Level 3: This stage limits the maximum number of minutiae present in the thinned image to a pre-specified threshold.

A minutiae m is described by the triplet m={x, y, } , where x, y indicate the minutiae location coordinates and denotes the minutiae orientation, which is the orientation evaluated for the minutiae location from the orientation image obtained during the enhancement process. The minutiae type is not being used during the matching process since minutiae type can be inverted due to enhancement and binarization steps.

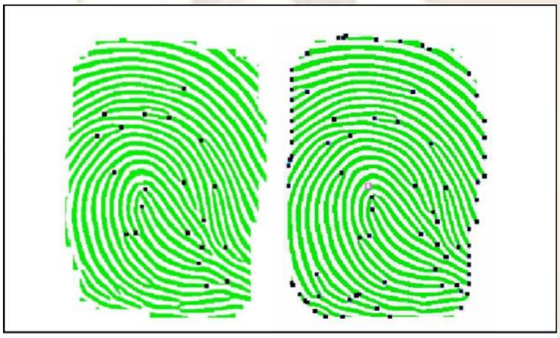


Fig. 6. Filtered and Unfiltered Minutiae Sets

V. Minutiae Matching

Let T and I be the representation of the template and input fingerprint, respectively. Let the minutiae sets of the two fingerprints be given by:

$T = \{m_1, m_2, ..., m_m\}$ $m_i = \{x_i, y_i, \ _i\}$, i =1..m

$I = \{m_1', m_2', ..., m_n'\}$ $m_j' = \{x_j', y_j', \ _j'\}$, j =1..n

A minutia m_j' in I and a minutia m_i in T are considered to be matched if their spatial and orientation differences are within specified thresholds r_0 and $_0$. Minutia matching was carried out by using the approach given in [32]. In this approach the minutiae sets are first registered using a derivative of the Hough transform (Figure. 7) followed by fingerprint matching using spatial and orientation-based distance computation. The matching algorithm returns a percentage match score, which is then used to take the match-no match decision based on the security criterion.

VI. Fingerprint Classification

Fingerprint classification was carried out by the extraction of the singular points from the fingerprint image using the approach presented by [41] (see figure 8). After the extraction of singular points the approach mentioned in [42] was used to perform a rule-based classification. The

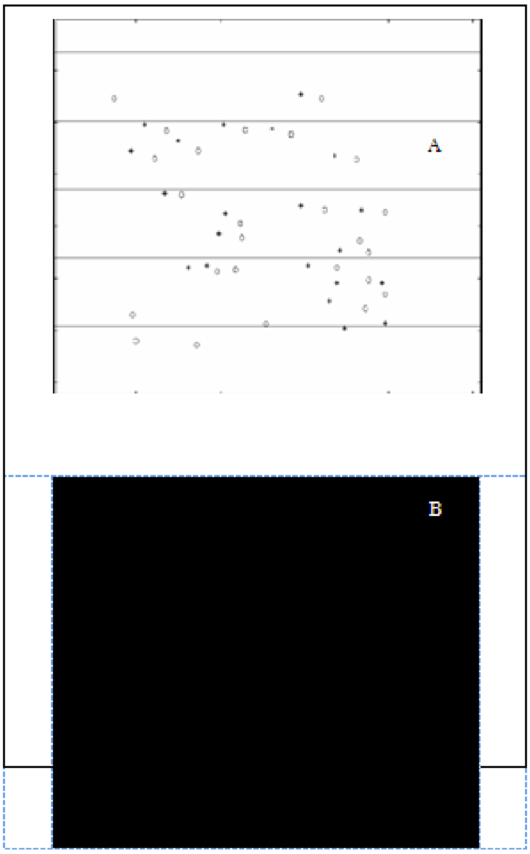


Fig. 7 A. Unregistered, B.Registered Minutiae Sets

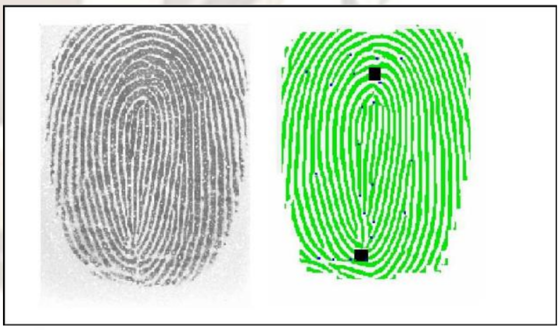


Fig. 8 Original Image an the extracted singular points introduction of fingerprint classification greatly improves the matching time especially for large databases.

III. RESULTS AND DISCUSSION

The system was tested on the FVC 2000 database [38]. The database used was developed using low cost capacitative fingerprint scanners. The database contains a total of about 800 fingerprints of 110 different fingers. The accuracy of the system is quantified in terms of false acceptance ratio (FAR) and the false rejection ration (FRR). An FAR of 1% was obtained for an FRR of 7% for this database. The Equal error rate (FAR=FRR) for the system mentioned was found to be 5% that implies an accuracy of 95%. The system can handle 180^{O} of rotation in a fingerprint image. The system was implemented using MATLAB 6.5 [43] and the time taken for processing a single fingerprint is 12s on a 2.2 GHz P4.with a 496MB RAM These results have been obtained without code optimization. The system will be implemented in C++ after code optimization, which would further reduce the total processing time.

IV. CONCLUSION:

The paper presents an overview of the different steps involved in the development of a fingerprint based person identification and verification system. We have also proposed the design and development of a minutiae based AFIS. The system developed is still a prototype version and needs improvements for decreasing the time spent during fingerprint processing and the reduction in the number of false acceptances and rejections made by the algorithm. Work is currently underway on some modifications to the matching mechanism, which would further improve the system's accuracy.

REFERENCES:

[1] W. F. Leung, S. H. Leung, W. H. Lau, And A. Luk, Fingerprint Recognition Using Neural Network, Neural Networks For Signal Processing - Proceedings Of The 1991 IEEE Workshop
[2] M. Hartman, "Compact Fingerprint Scanner Techniques" In Proc. Biometric Consortium Meeting, San Jose, Ca, June 1996
[3] J. Schneider, "Improved Image Quality Of Live Scan Fingerprint Scanners Using Acoustic Backscatter Measurements," In Proc. Biometric Consortium 8th Meeting, San Jose, Ca, June 1996.
[4] K. McCalley, D. Setalk, S. Wilson, And J. Schmitt "Improved Image Quality Of Live Scan Fingerprint Scanners Using AcousticBackscatter Measurements," In Proc. Biometric Consortium 8th Meeting, San Jose, Ca, June 1996.
[5] F.R. Livingstone, L. King, J.A. Beraldin And M. Rioux, "Development Of A Real-Time Laser Scanning System For Object Recognition, Inspection, And Robot Control," In Proc. Spie Telemanipulator Technology And Space Telerobotics, Boston, Ma, Sept. 1993. Vol. 207, Pp. 454-461
[6] "A Handbook Of Fingerprint Recognition", Maltino, Maio, Jain And Prabhakar. Springer Press.
[7] "Digital Image Processing", Gonzalez And Woods, Aw, Ma 1992
[8] Ren Qun, Tian Jie, Zhang Xiaopeng, Automatic Segmentation Of Fingerprint Images, Chinese Academy Of Sciences, P.R. China
[9] Mehtre, Murthy, Kapoor and Chatterjee, "Segmentation Of Fingerprint Images Using The Directional Image" Pattern Recognition, Vol. 20, 1987.
[10] Ratha, Chen and Jain., "Adaptive Flow Orientation Based Feature Extraction In Fingerprint Images", Pattern Recognition, Vol .28, 1995
[11] Maio and Maltoni, "Direct Grayscale Minutiae Detection In Fingerprints", IEEE Transaction On Pattern Analysis And Machine Intelligence, 1999
[12] Shen, Kot and Koo, "Quality Measures Of Fingerprint Images", In Proc. Int. Conf. On Audio And Video Based Biometric Person Authentication
[13] Xinjian Chen, Jie Tian, Jiangang Cheng, And Xin Yang, "Segmentation Of Fingerprint Images Using Linear Classifier", EURASIP JASP 2004:4 (2004)
[14] Bazen and Garez., "Segmentation Of Fingerprint Images", In Proc. Workshop On Circuits Systems And Signal Processing, , 2001
[15] Stefan Klein, Asker Bazen, And Raymond Veldhuis, "Fingerprint Image Segmentation Based On Hidden Markov Models"
[16] Sherlock, Monro and Millard., Algo For Enhancing Fingerprint Images, Electronic Letters, 1992
[17] Shlomo Greenberg, Mayer Aladjem, Daniel Kogan, "Fingerprint image enhancement using filtering techniques" Real-Time Imaging Volume 8, Issue 3 (June 2002) Pages: 227 – 23, 2002
[18] O'Gorman And Nickerson, "Matched Filter Design For Fingerprint Image Enhancement", Pattern Recognition, 1988
[19] O'Gorman And Nickerson, "An Approach To Fingerprint Filter Design", Pattern Recognition, 1988 [20] Hong, Wan And Jain, "Fingerprint Image Enhancement: Algorithm And Performance Evaluation", IEEE Transaction On Pattern Analysis And Machine Intelligence, 1998
[21] Shlomo Greenberg, Mayer Aladjem,

Daniel Kogan, Greenberg Et Al., "Fingerprint Image Enhancement Using Filtering Techniques", In Proc. Int. Conference On Pattern Recognition, 2000

[22] Yang, Liu, Jiang and Fan, "A Modified Gabor Filter Design Method For Fingerprint Image Enhancement", Elsevier Pattern Recognition Letters 2003

[23] Marius Tico, Vesa Onnia, Pauli Kuosmanen "Fingerprint Image Enhancement Based On Second Directional Derivative Of The Digital Image" EURASIP Journal on Applied Signal Processing 2002

[24] Watson, Candela and Grother, "Comparison Of FFT Fingerprint Filtering Methods For Neural Network Classification, Tech Report: NIST IR 5493, 1994

[25] Stock and Swonger. "Development And Evaluation Of A Reader Of Fingerprint Minutiae", Tech Report: No. Xm-2478-X-1: 13-17, Cornell Aeronautical Labs, 1969.

[26] Stock, "Automatic Fingerprint Reading", In Proc. International Carnahan Conf. On Electrical Crime Countermeasures, 1977

[27] Moayer and Woo," A Tree System Approach For Fingerprint Pattern Recognition", IEEE Transactions On Pattern Analysis And Machine Intelligence, 1986.

[28] M. R. Verma, A. K. Majumdar, B. Chatterjee., "Edge detection in fingerprints" Pattern Recognition, Volume 20, Issue 5 1987, Pages: 513 – 523, Year of Publication: 1987

[29] Coetzee Et Al., "Fingerprint Recognition In Low Quality Images", in proc of IEEE Pattern Recognition, 1993.

[30] Hung, "Enhancement For Feature Purification Of Fingerprint Images", in proc. Of Pattern Recognition, 1993