International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-2, Issue-8, August 2016
ISSN: 2395-3470
www.ijseas.com

Poor Quality Fingerprint Recognition Based on Wave Atom Transform

Waleed Abudalal[1], Mohammed Alhanjouri[2]
[1] Department of Computer Engineering, Islamic University of Gaza, Gaza Strip, State of Palestine
[2] Department of Computer Engineering, Islamic University of Gaza, Gaza Strip, State of Palestine

Abstract

Fingerprint is considered the most practical biometrics due to some specific features which make them widely accepted. Reliable feature extraction from poor quality fingerprint images is still the most challenging problem in fingerprint recognition system. Extracting features from poor fingerprint images is not an easy task. Recently, Multi-resolution transforms techniques have been widely used as a feature extractor in the field of biometric recognition. In this paper we develop a complete and an efficient fingerprint recognition system that can deal with poor quality fingerprint images. Identification of poor quality fingerprint images needs reliable pre-processing stage, in which an image alignment, segmentation, and enhancement processes are performed. We improve a popular enhancement technique by replacing the segmentation algorithm with another new one. We use Waveatom transforms in extracting distinctive features from the enhanced fingerprint images. The selected features are matched throw K-Nearest neighbor classifier techniques. We test our methodology in 114 subjects selected from a very challenges database; CASIA; and we achieve a high recognition rate of about 99.5%.

Keywords: *Fingerprint Recognition, Wave Atom, Image Enhancement, Image Alignment, Multiresolution Transform.*

1. Introduction

A biometrics system is a pattern recognition system that establishes the authenticity of a specific physiological or behavioral characteristic possessed by a user [1]. However, each biometric has its strengths and weakness, and the choice depends on the used application. Recently, using biometrics in recognition of persons is an emerging phenomenon in modern society, due to the wide need of security in many applications.

Fingerprint has several advantages over the other biometrics, such as: high university, high distinctiveness, high performance, easy collectability, high permanence, and wide acceptability [2]. Scientific studies in the mid-1800's proved two critical characteristics of fingerprint: the uniqueness and the persistence. The uniqueness means that every fingerprint from different fingers has its own ridge pattern. The persistence means that the fingerprint ridge patterns don't change throughout the life. Today, fingerprint identification system is included in Apple's latest iPhone, which is an important step in bringing biometrics to the mainstream [3].

There are dozens of techniques which are proposed in fingerprint enhancement and matching. Most of them have no difficulty in matching good quality fingerprint, but matching low quality fingerprint remains a challenging problem [4].

The identification process contains several stages, which are common in construction and organization as all biometric systems. After collecting the data; the fingerprint images; the process of identification can be divided into the following stages:

1.1. Pre-processing Stage:

Good quality fingerprint image has high contrast and well defined ridges and valleys, while poor quality fingerprint is marked by low contrast and ill-defined boundaries between the ridges and valleys. There are some factors of the uneven force and collection environment that degrade the quality of fingerprint image [5, 6, 7]:

- Presence of creases, bruises or wounds may cause ridge discontinuities.

- A dry skin can cause inconsistent contact of finger ridges with scanner surface causing broken ridges and low contrast ridges.
- Oily or wet skin make the valleys tends to fill up.
- Moister can cause the valleys to appear dark similar to ridge structure
- Sweat on fingerprints leads to smudge marks and connects parallel ridges.
- Variations in impression conditions, ridge configuration.

These factors lead to poor quality fingerprint images. Thus, current fingerprint recognition technologies are vulnerable to poor quality images [8]. In order to facilitate the extraction of the fingerprint feature points, an effective pre-processing step for fingerprint images is essential.

1.2. Feature Extraction Stage:

In this stage, we need to use a sufficient feature extractor algorithm to give distinctive features. There are over 150 known local ridge characteristics in fingerprint, which can be used for identification process. The most popular characteristics are called minutiae points which are the ridge endings, and the ridge bifurcations. A good quality fingerprint typically contains somewhere in between 40 and 100 minutiae [1]. Forensic experts use this representation which has now become part of several standard for exchanging information between different systems across the world, such as ANSI-NIST slandered [9]. For the past 100 years, the fingerprint features and matching techniques have been based on minutia points, but this technique is not useful when we can't extract enough and reliable minutia points due to poor quality fingerprint images, or the fingerprint image doesn't have a sufficient number of points [10]. For this reason, a lot of research have been done in extracting distinctive features from fingerprint images. Recently, researchers attempt to use the multi-resolution transform techniques such as: Wavelet transform, Curvelet transform, Bandlet transform, Contourlet transform, Shearlet transform, and Waveatom transform as feature extractors in many biometric recognition such as face recognition, palm recognition, fingerprint recognition, and etc. In this paper, we use the Waveatom transform as feature extractors in fingerprint recognition system.

1.3. Classification Stage

Once a set of features are extracted from the fingerprint image, the final goal is to confirm the identity of a person whose fingerprint has been previously enrolled into the system. The matching mechanism is the responsible to provide a likeliness score between two fingerprints. In this paper we will use a simple classifier which is the KNN classifier.

The rest of paper is organized as follows: in Section 2 the work related to the fingerprint image enhancement and alignment, and the feature extraction techniques is described. In Section 3 the theory of Wave Atom transform is described. Our proposed solution is described in Section 4, and the results of our fingerprint identification system are discussed in Section 5. Finally, the conclusion and future work are listed in Section 6.

2. Related Work

Fingerprint image enhancement can be conducted on either a binary ridge image or a grey level image [6]. A binary ridge image is an image where all the ridge pixels are assigned a value of 1 and the non-ridge pixels are assigned a value of zero. Binarization before enhancement often generates more spurious minutiae structures and lose some true ridge structure, therefore enhancement of binary ridge image has its inherent limitations, and therefore most enhancement algorithms are performed on grey images directly [11].

There are many techniques which are proposed to enhance the grey level image. One of the most popular approach for fingerprint image enhancement is the algorithm of Hong et al in [6]. The main steps of the algorithm include: Normalization, Local orientation estimation, Local frequency estimation, Region mask estimation, and Filtering with a bank of symmetric Gabor filters, which is designed according to image orientation, and frequency, and it used as a band-pass filter to remove noise. The performance of the algorithm is evaluated using the goodness index of the extracted minutiae and the performance of an online fingerprint verification system. The algorithm is tested on 50 poor quality fingerprint images, and the results show that the proposed algorithm improves the verification performance. They classified the image region into three categories; well

defined region, recoverable region, and unrecoverable region. They identifies the unrecoverable corrupted regions in fingerprint image, and removes them from further processing.

The first step of Hong [6] algorithm is the normalization process, in which an input fingerprint image is normalized, so that it has a pre-specified mean and variance. To uniform the intensity distribution of grey level image, many algorithms based on histogram equalization are proposed [12, 13], but the use of Histogram Equalization in fingerprint enhancement is not give the required enhancement, and not suitable for extracting minutiae from enhanced image. Similarly the use of contrast limited adaptive histogram equalization [14] gives a poor recognition rate of 70-75%. An optimization technique based on Particle Swarm Optimization (PSO) is proposed in [15] to maximize the information content of the enhanced image with intensity transformation function in order to enhance the contrast and minutiae detail in a fingerprint image. The results are compared with contrast limited adaptive histogram equalization (CLAHE), Wiener filter, Median filter. Various experiments were carried out on some fingerprint images, which are collected from CASIAFingerprintV5 and FVC 2004. The algorithm gets a higher values of entropy, number of edges and overall intensity of the images. Recently an optimization technique based on Bat algorithm is proposed in [16] which used as an optimizer for histogram manipulation of fingerprint images enhancement.

In order to achieve high recognition rate when comparing fingerprint images or even the features extracted from the fingerprint images, these images or features of both the reference sample and the test one have to be aligned. There are three major challenges involved in acquisition the fingerprint samples: translation, rotation and scaling [17]. Fingerprint translation refers to the position of a captured fingerprint with respect to the fingerprint image background, and for optimum functionality of an automated fingerprint recognition system, the fingerprint should be positioned in the central area of the fingerprint image background. Fingerprint rotation refers to the alignment of a captured fingerprint when measured against the image background, and for optimum functionality of a fingerprint recognition system, the captured image should sit at an angle of approximately 0 degrees (more or less upright) relative to the vertical axis [18]. The most effort of research of addressing these challenges is focused on translation and rotation issues, because capturing fingerprint images doesn't lead to scaling problem since most fingerprint images could be scaled as per the dpi specification of the sensors.

Various techniques are proposed to solve the rotation problem, and each of them has its advantages and disadvantages. One of them is proposed in [19], which depends on finding both a core point and a delta point in the fingerprint image to estimate the re-alignment angle. In particular the translation invariance is accomplished by locating the reference point. The drawback of this solution in addition to the difficulty of finding delta point, is that it will fail when dealing with Plain Arch (PA) fingerprint class, which doesn't contain a core or delta point. Another instance where this algorithm may fail, is when dealing with Tented Arch (TA) fingerprint class, which has a single core and a single delta, with the core located almost directly above the delta. Many singular point detection techniques, however, find it relatively difficult to detect this delta point. Another instance where this method is likely to fail is when dealing with the Left Loop (LL) and the Right Loop (RL) fingerprint classes. Although these types of fingerprints have both the core point and the delta point, in most cases the delta point is not captured.

Because of the problem of finding a reference point in the Plain Arch fingerprint class, researchers attempt to solve this issue by different techniques [20], [17]. The only problem with this recent development is that this technique is dedicated only to those fingerprints that belong to the PA class. This is a problem, because this solution requires to classify the fingerprint types, then to use the appropriate reference point location method before re-aligning the fingerprint.

An independent and efficient approach is proposed in [18]. Their approach doesn't depend on a particular fingerprint class, and so it can be used for all types of fingerprint classes. They use a new reference point (TFCP), which determined after segmentation process, and it lies on the center of ROI area. From this point, they determine the rotation angle and direction of rotation. We choose this technique in this paper, and implement their

proposed algorithm, but we replace the segmentation process with another one to get better results.

The rotation problem is handled in [21] by cyclic rotation the extracted feature values in the matching stage. Similarly, in [22] the feature values of each template fingerprint is rotated with 5 angles; -20, -10, 0, 10, 20; and when matching, the test image is compared for all templates. The drawback of these solution is that they are a time consuming solution.

The other solution of translation and rotation issues is what is called the registration. Registration means that you have to choose a base image, then you have to translate the test image to lie exactly on the base image, and so to achieve the maximum response between the two images. Registration is a popular concept in image process which can achieve the translation and rotation invariant. An approach based on fingerprint registration is proposed in [23], in which the best alignment of two fingerprint images, template and input, is achieved by maximization of mutual information (MI) between features extracted from their orientation fields, i.e., maximization of similarity measures between two fingerprint images.

Another approach based on measuring the similarity between a set of rotated fingerprint images of the registered image over an angular range $-40 \leq \theta \leq 40$, and the input image, is proposed in [24]. The translation is achieved by using the position of the core point in both images. The drawback of this solution is that generating a set of rotated fingerprint images in angular range $-40 \leq \theta \leq 40$, and an angle spacing 1 degree, then comparing each of these rotated image with the input one, will be a very expensive computations. In addition to this high computations, some fingerprint images have been rotated more than 40 degree in each directions.

Anyway, using the registration techniques to solve the alignment and translation problems in fingerprint recognition system, may be a good solution, but it will cost a lot of computations and doesn't work well in all cases of fingerprint image qualities.

The features of fingerprint images can be extracted from global level, and local level. The global level doesn't has a distinctive characteristics that used for classification and identification of fingerprint images. At the local level, there are some characteristics can be used to distinguish between different fingerprint images. Minutiae is the most widely local level characteristic used in fingerprint identification. Minutiae contains ridge ending and ridge bifurcation.

It is nicely to refer here that there are some features behind the Minutiae, which can be used for matching. These different features contains: orientation-based minutia descriptor, FingerCode, ridge feature map, orientation map, and density map. Researchers attempt to combine between these features to improve the recognition rate of fingerprint identification system. One research on comparison of combining between these features is proposed by [25]. They conclude that beyond four features, the improvement is limited, so they suggest to limit the number of used features to 4.

Recently, researchers go to use other features techniques, to overcome the limitations of minutiae based. They tend to use the frequency based algorithms at different transform to extract unique features for fingerprint images.

A comparison study of three frequency based feature extraction techniques is proposed by [26]. They use Discrete Cosine Transform (DCT), Fast Fourier Transform (FFT) and Discrete Wavelet Transform (DWT) to create a feature vector for matching fingerprints images by using Euclidean distance. The results show that DCT and FFT perform better than DWT technique. However, their algorithm doesn't achieve a good recognition rate, since they do not perform any enhancement process on the fingerprint dataset, and the size of 32 extracted features is small for good matching.

The use of Curvelet transform has been proposed by many researchers as a technique for feature extraction. The one used by [22] include enhancement process, core point detection, cropping of ROI of size 175x175, resizing this ROI to be 512x512, then applying Curvelet transform for 5 scales, and encode three statistical features (Energy, entropy, and standard division) from each. The feature vector size is 164x3 for each image. Using similarity distance matching on 30 classes from FVC2004 database, they achieve a good results. However, using 492 features is a large number of features compared to the number of classes they test. Furthermore, they solve the rotation problem by rotating the ROI of template with 5 angles, then comparing the test image with all of these templates,

so a multiple of 5 overhead computation will be occurred.

Similarly, another approach using the Curvelet transform is proposed in [27]. They divide the ROI area into 4 parts 32x32 subimages, then apply the Curvelet transform on each subimage with different scales and angles, then a standard deviation is taken for each subimage to reduce dimensionality of Curvelet's coefficients, then concatenate the feature vector from each one to be ready for comparison. They achieve the maximum recognition rate on 15 classes from FVC2004 database. However, this high recognition rate is due two reasons: first they determine the core point manually, so there is no core point algorithm is used, and second the small number of classes, and the efficient number of samples per finger. Furthermore, it seems that the selected fingerprint images are chosen in such away to be far from orientation problem, since they do not refer to the rotation problem in their report.

Another approach that using the Curvelet transform as a feature extraction is proposed in [28]. Their algorithm include image enhancement process, core point detection, alignment process, cropping the ROI of size 50x50, applying Curvelet transform to extract the feature vector, then use the mean and standard deviation statistics to get the final feature vector which will be matched with the K-nearest neighbor algorithm. They test their solution on a small database of selected 10 classes from FVC2002 dataset, and get a high recognition rate of about 90%. They reject the fingerprint images which their core point is near the image borders. I think this high recognition rate is due to very small testing dataset, however their solution is a robust algorithm. Another hint for their alignment process, is that their alignment process depends on rotation the test and the rest of training images according to the reference image. The reference image is chosen as the maximum energy response by applying Gabor filter to all fingerprint class samples. This process is known as a registration process.

A different feature extraction technique based on Contourlet transform is proposed by [29]. The algorithm contains image enhancement process, core point detection, cropping the ROI of size 192x192, then dividing the ROI into two non-overlapping blocks with the core point at the center, followed by applying the Contourlet transform on each block, then the feature vector extracted from each block based on Generalized Gaussian density (GGD). The results are matched by using KNN classification on 25 classes from FVC2004 dataset. The results show an improvement in recognition rate with respect to algorithms based on wavelet transform. We can observe from the report that they don't refer to the alignment problem, which is an important process in fingerprint identification.

Another approach based on correlation matching between the input image and the test image is proposed by [30]. The authors use the Radon transform to extract the rotation features from fingerprint images. They test their algorithm on 10 classes from FVC2004 dataset. One drawback of their solution is that they assume that the fingerprint images are already aligned, so they don't refer to the alignment problem.

Another approach based on Wave Atom transform is proposed by [31]. The algorithm contains image resizing step to be a size of 64x64, then the Wave Atom is applied to the cropped image, then use the bidirectional two-dimensional principal component analysis (B2DPCA) to reduce the feature vector dimension and to prepare the final feature vectors which are classified using the extreme learning machine (ELM). They evaluate their algorithm on 100 classes of the three databases FVC2000, FVC2002, and FVC2004. They get a recognition rate of 93%, 87%, and 89% respectively. The proposed algorithm doesn't include an enhancement process, however it shows the powerful of B2DPCA algorithm for dimensionality reduction, and ELM as a classification algorithm. According to my research, this is the only paper I found, which uses the Wave Atom transform as a feature extraction technique for fingerprint identification.

An early approach based on wavelet decomposition is proposed by [32]. They don't use enhancement process, but they depend on finding a reference point in fingerprint image, so they find it manually. Their algorithm include locating the core point, cropping the ROI around the core point, then dividing the ROI into non overlapping blocks, then applying the wavelet decomposition on each block to extract a global feature vector of length 48 which is classified by using K-NN. The results show a high recognition rate on a database of size 13 classes fingerprint images.

In [33] the fingerprint image is firstly converted to grey scale image, then a 3 level DWT is applied to grey scale image and feature extraction is done using the mean and variance. Feature database is created in which 24 features of a person's fingerprint is stored. Finally feature matching is done using Euclidean distance matching technique. They select 25 person's fingerprint images from CASIA-Fingerprint V5 (200-299). The system gives false acceptance rate as 2.3 % and false rejection rate as 0.9%. One drawback with this approach is that they don't refer to the rotation and translation problems, although the selected database; CASIA fingerprint V5 (200- 299); has a strong rotation level and translation within the same class. We cannot find a class with vertically oriented within this range of CASIA.

Recently, an approach based on Gabor filter bank is proposed in [34]. They use the Gabor filter bank to extract fingerprint image features. Their approach includes: normalization, segmentation, cropping the selected region of interest (ROI) from the scanned image, locate the reference point, then the Gabor filter is applied on the ROI to extract the feature vectors. Finally the feature vectors of query fingerprint image is compared using the Euclidian distance with database fingerprint images. The features extracted from the Gabor filter response; ridge frequency, width of Gaussian envelope, and filter orientation; is transformed into a feature map, which is circularly tessellated with different 5 bands and 8 sectors with consideration of reference point as a center of an image. The algorithm is evaluated using a selected of 20 classes from FVC2000 and 50 classes from DBIT fingerprint databases, and achieve an average efficiency of 82.95 % and 89.68 % respectively.

3. Wave Atom Transform

Waveatom was presented by Demanety and Ying [35], and it is a new type of two-dimensional multi-scale transformation, and still meets the parabolic proportional scaling relation and anisotropic characteristics of curve wave. The name of wave atoms comes from the property that they also provide an optimally sparse representation of wave propagators, a mathematical result of independent interest, with applications to fast numerical solvers for wave equations [35].

Wave atoms interpolate exactly between directional wavelets and Gabor, in the sense that the period of the oscillations of each wave packet (wavelength) is linked to the size of the essential support (diameter) by the parabolic scaling. Figure 4.7 shows phase-space localization of the wave packets, on the right of Figure 1, the frequency plane is divided into wedges. The wedge is formed by partitioning the frequency plane into radial and angular divisions. The radial divisions (concentric circles) are for band-passing the image at different resolution/scales. The angular divisions divide each band-passed image into different angles. To consider each wedge, the band-passed image should be analyzed at scale j and angle θ, and we will require that [35]:

- In x, the essential support of $\varphi(x_\mu)$ is of size $\sim 2^{-\alpha j}$ vs. $2^{-\beta j}$ as scale $j \geq 0$, with oscillations of wavelength $\sim 2^{-j}$ transverse to the ridge;
- In frequency ω, the essential support of $\hat{\varphi}(\omega)$ consists of two bumps, each of size $\sim 2^{\alpha j}$ vs. $2^{\beta j}$ as scale j, at opposing angles and distance $\sim 2^{j}$ from the origin.

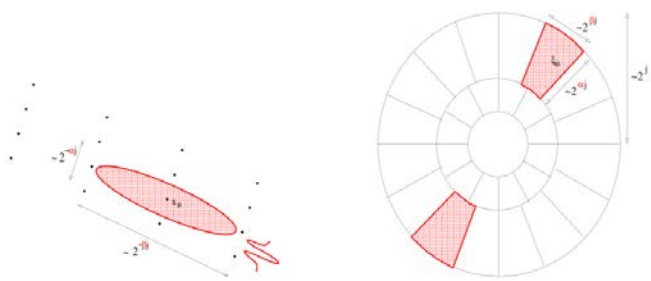


Fig. 1: Waveatom Transform in Spatial Space (left) and in Frequency (right)

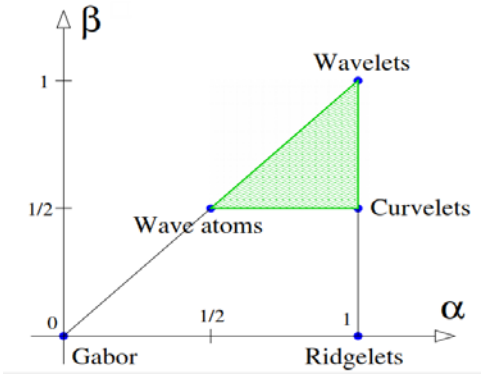


Fig. 2: Identification of various transforms as (α, β) families of wave packets.

We hope that a description in terms of α and β will clarify the connections between various transforms of modern harmonic analysis. Curvelets correspond to $\alpha = 1$, $\beta = 1/2$, wavelets are $\alpha = \beta = 1$, ridgelets are $\alpha = 1$ and $\beta = 0$, and the Gabor transform is $\alpha = \beta = 0$. Wave atoms are defined as the point $\alpha = \beta = 1/2$. The situation is summarized in Figure 2.

4. Our Fingerprint Identification Process

4.1 Fingerprint Images Preprocessing:

This stage contains the following two steps: fingerprint image alignment, and fingerprint image enhancement.

Alignment Process: There are three major challenges involved in acquisition the fingerprint samples: translation, rotation and scaling. Fingerprint translation and rotation processes are the most important steps in any automatic fingerprint recognition system, since capturing fingerprint images doesn't lead to scaling problem since most fingerprint images could be scaled as per the dpi specification of the sensors [18]. In order to achieve a high recognition rate, the fingerprint images have to be aligned and translated accurately. We implement the proposed algorithm in [18]. This approach is independent of fingerprint classes, and can be used for all fingerprint classes. The algorithm is simple and efficient, and contains the following processes: 1) Segmentation: in which the foreground region is separated from the background region. 2) True Fingerprint Center Point Location: in which an optimum center point (TFCP) is determined, which lies on the center of foreground area. 3) Fingerprint Re-alignment: in which the direction and the rotation angle are determined.

Fingerprint Enhancement Process: One of the most popular and an effective fingerprint enhancement algorithm is proposed in [5]. The enhancement algorithm is based on short time Fourier transform (STFT) Analysis, and on contextual filtering in the Fourier domain whose parameters depend on the local ridge frequency and orientation. The idea of this algorithm is to create an adaptive filter whose parameters depend on the contextual information of fingerprint image to be able to recover corrupted and occluded regions. The contextual information includes the ridge continuity and the regularity, which is obtained by computing the intrinsic images through the short time Fourier transform (STFT) analysis. The intrinsic images represent the important properties of the fingerprint image as a pixel map. These include: Orientation image, Frequency image, and Region mask.

Our Modifications: The alignment technique [18], and the fingerprint enhancement technique of [5] are both depend on the segmentation algorithm, which is obtained by thresholding, and for automatic determination of threshold value, the authors use the Otsu's optimal thresholding [36]. But in case of bad quality fingerprint images as our CASIA database, especially the problem of humidity in fingertip, which cause some important regions to be dark or black. This cause the thresholding technique to consider this black regions a part of the background area, and so it will be ignored. We solve this problem by replacing the process of computing the Energy map by the segmentation technique proposed by [37] as we did in the alignment step.

4.2 Feature Extraction:

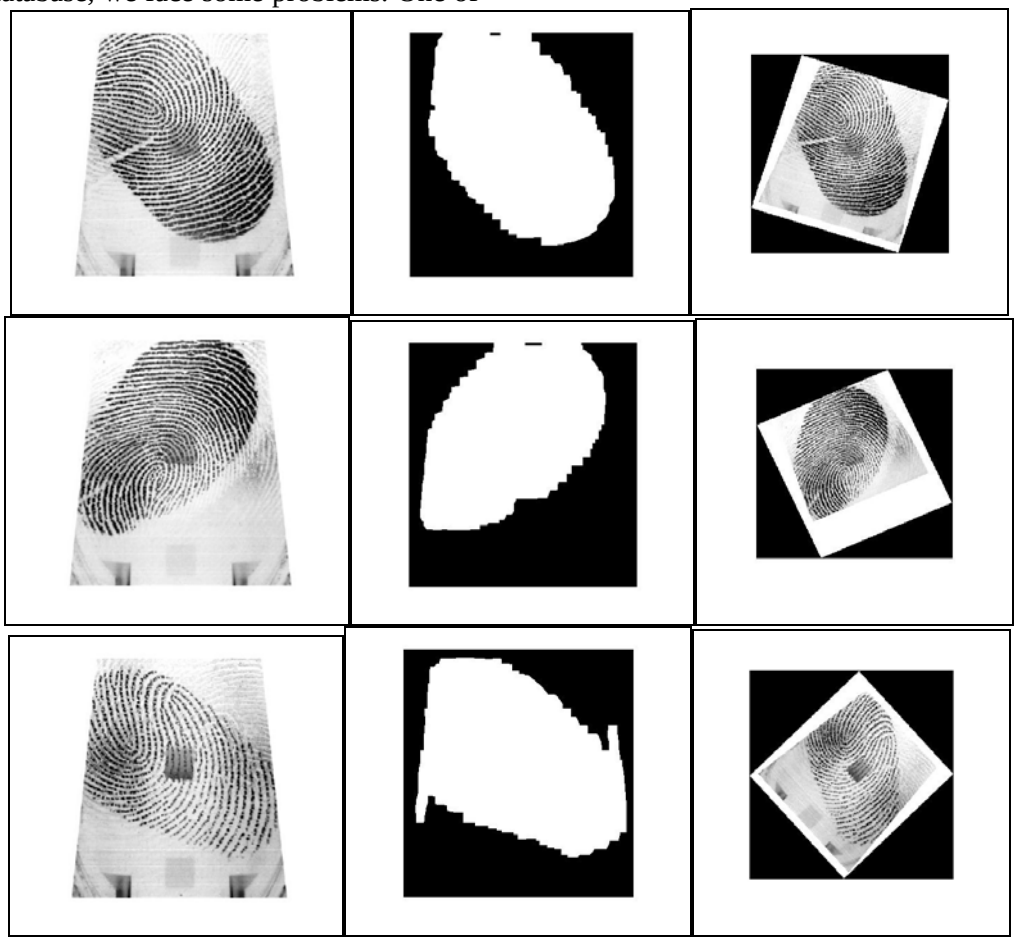
We determine the singular point location by using the idea of complex filters [38]. After locating the reference point or core point in the fingerprint image. We crop an N x M subimage from the fingerprint pattern with core point at the center. This can be called 'central subimage'. The size of

subimage is taken once as 128x128. Then we divide this central subimage into a number of non-overlapping blocks of size W x W, i.e. W=64. Then we apply the Wave atom, or Curvelet for each of the non-overlapping blocks at Scale = S and Angle = A. After that we take the standard deviation of each of the multiresolution transforms coefficient sets for each scale and angle. Thus the obtained standard deviation for each of the four blocks of a fingerprint image constructs the global feature vector together. The obtained features vector size depends on the applied multiresolution transform.

5. Result and Dissection

5.1 Alignment Results:

When we perform the alignment process on the CASIA database, we face some problems. One of them is the existence of some black regions within the white regions, and this means that these black region is considered a part of the foreground region, i.e. this segmentation technique is fail when dealing with poor quality fingerprint images. And another problem is the non-smooth contour of the image segmentation. Both of these problems affect the performance of the used alignment technique, since the alignment technique is based on navigation along the x-coordinate and the y-coordinate, and so while incrementing the navigation variable, it will stop navigation when finding a black pixel, since it finds the contour of image segmentation. This will affect the TFCP location, and the upper point location, and as a result it affects the determination of C1, C2, and C3.



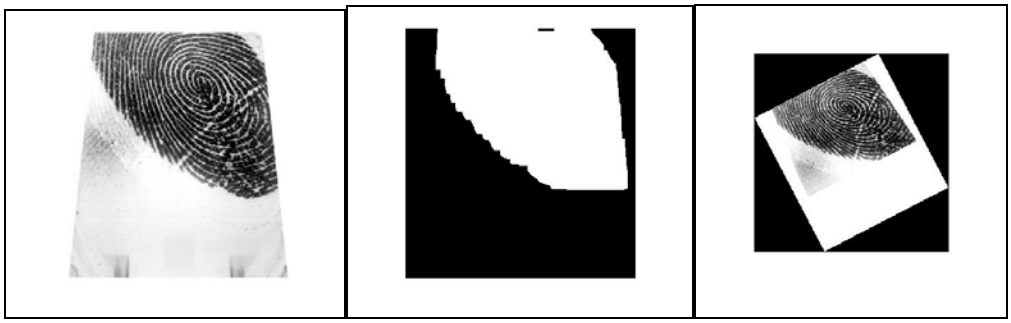
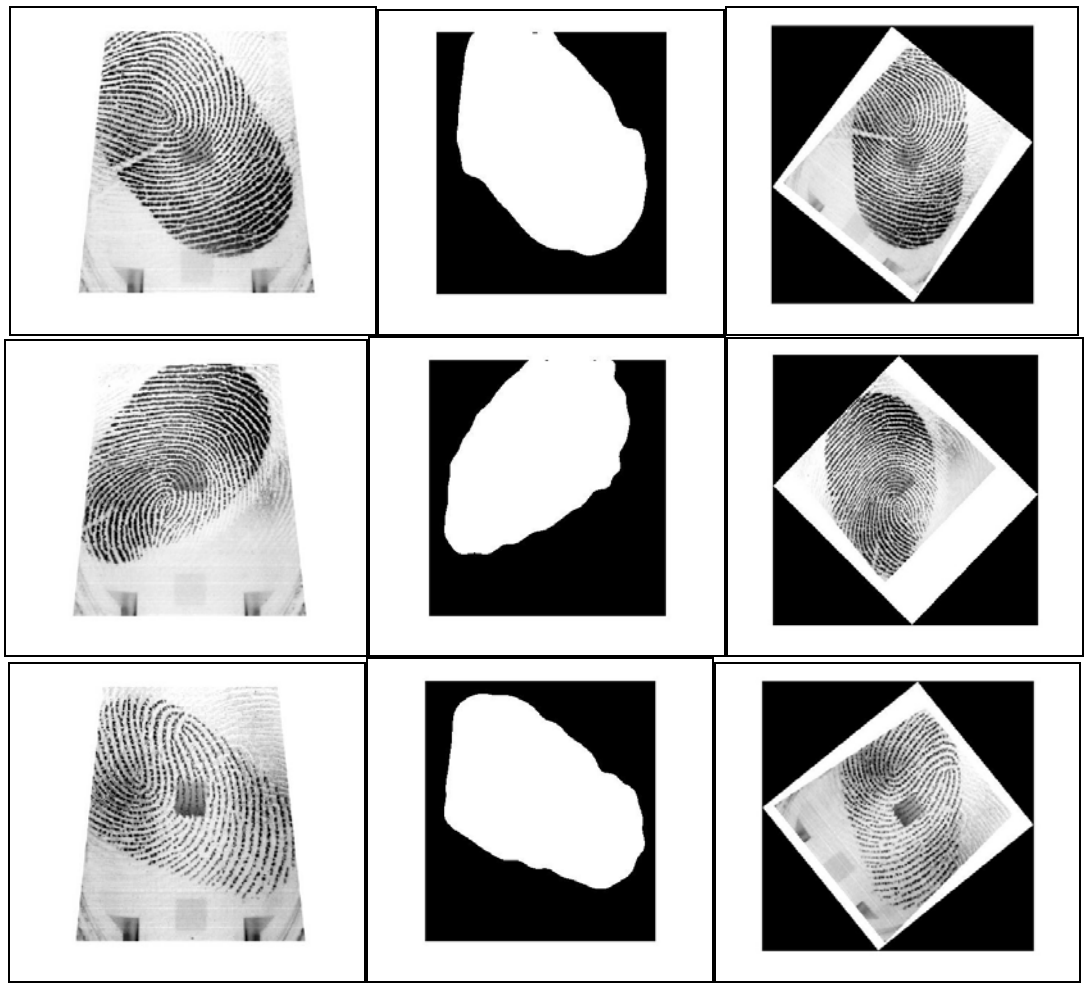


Fig. 3: Image Rotation result according to image segmentation. The left image is the original. The result of segmentation are in the middle column according to [18], and the result of rotation are in the last column. The images are taken from CASIA.



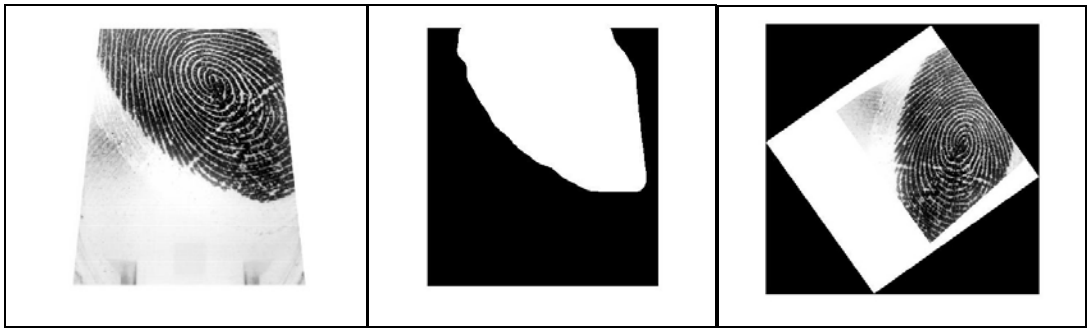


Fig. 4: Image Rotation result according to image segmentation. The left image is the original. The result of segmentation are in the middle column according to [37], and the result of rotation are in the last column. The images are taken from CASIA.

We solve the problems above by using the segmentation algorithm described in [37]. Figure 3 shows the results of alignment, which depends on segmentation process of [18], and Figure 4 shows the results of alignment, which depends on segmentation process of [37]. From both figures we see that the proposed solution is more accurate than the other.

The segmentation process leave some small black parts in the top boundary of fingerprint image, especially in fingerprint which its upper part is lost. We solve this problem by implementing a method which can eliminate these parts.

5.2 Enhancement process results:

We use the enhancement algorithm proposed by [5], in which the region mask is obtained by thresholding the energy image. When we apply the algorithm on CASIA database, we cannot obtain an optimum segmentation in some images. This is because of the very bad qualities of the fingerprint images, where the humidity and dryness get together in the same fingertip, and this leads to segment some parts and to lose the others. Sometimes the opposite is true, that some fingerprint images contains some traces of the previous scanned fingertips, and this leads to segment some parts which doesn't belong to the fingertip, anyway this is rarely occur, but it is exists in the CASIA database.

Although the used algorithm of rotation is robust, it has some drawbacks. The algorithm performs well in the images of relatively complete mask, i.e. without cuts in the image boundaries, especially if the image is cut in more than one side, such as the images of CASIA database.

Furthermore the background regions are not clean as the other databases such as FVC family. It contains some small grey blocks in different regions. For this reason we replace the segmentation step of Chikkerur algorithm with the algorithm proposed by [37], which we use it in the alignment step. This will give a slight improvement in some poor quality images with a lot of creases and wounds as shown in Figure 5. We also see that both enhancement algorithm can connect the discontinuities of the ridges, and improve the contrast between ridges and valleys, however the enhancement results of the modified algorithm give a better region mask image than the original.

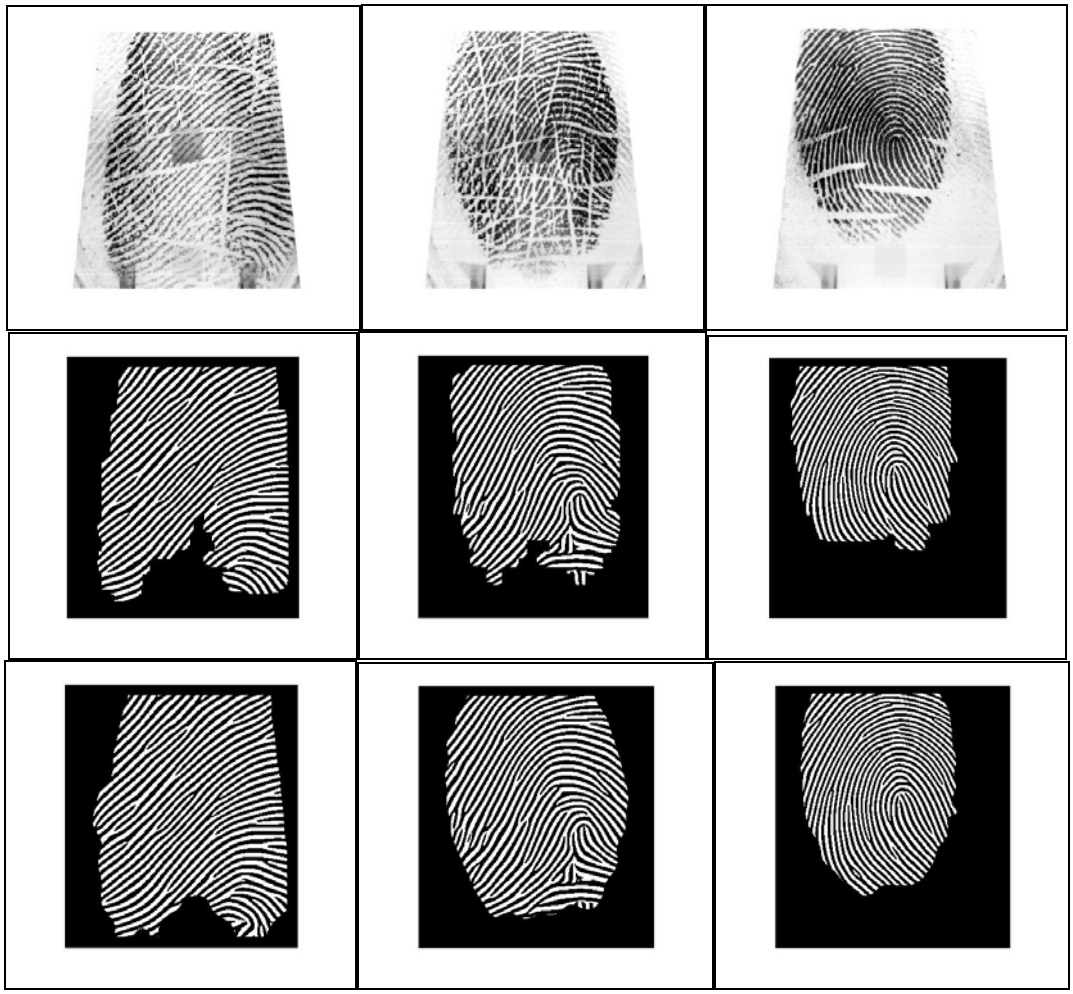


Fig. 5: Enhancement result of both the original technique and the modified one. The upper row shows some bad samples with a lot of creases of CASIA-V5 database. The middle row shows the result of the original technique. The last row show the result of the modified technique.

Another reason that degrades the quality of fingerprint images is the dryness of fingers, which leads to fragmented and low contrast ridges. Figure 6 shows some of these images and the result of the original and the modified algorithm. The Humidity of the fingertip may degrade the quality of the fingerprint images. Some samples of these types, and the results of the original and the modified enhancement algorithm are shown in Figure 7. We see that this problem is the most agent that affected by the segmentation process. The modified algorithm results are clearly better than the original one.

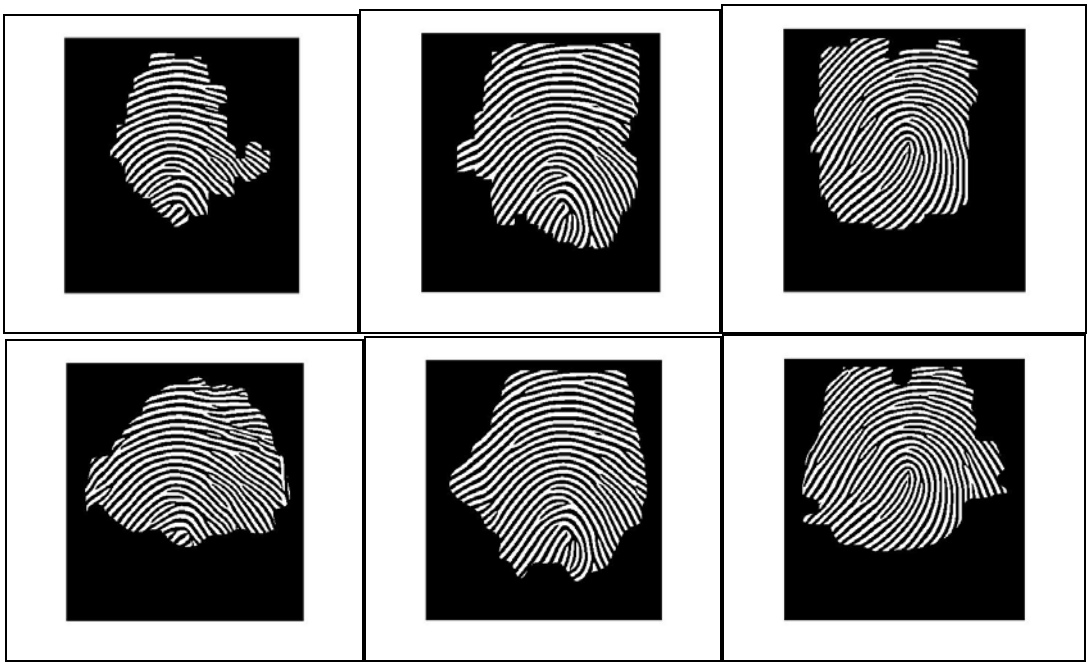


Fig. 6: Enhancement result of some dry fingertip samples for both the original technique and the modified one. The upper row is three samples images from CASIA-V5. The middle row shows the result of the original technique. The last row show the result of the modified.

5.3 Core point result and cropped area:

We use the complex filters algorithm [38] to determine the singular point location. Before enhancement process the proposed algorithm can detect the core point in some fingerprint images, and fail in others. But after enhancement process, its performance increase. The result of applying this technique on our database successes in most fingerprint images, and fails only to detect the core point in 6 images, three of these images are partial fingerprint and they don't have core points, and the others are poor ridge structure images, that the algorithm determines a location around the accurate core point. Figure 8 shows some of these fingerprints images. In the left loop and right loop fingerprint image classes, the algorithm can detect the core point accurately, as shown in Figure 9.

Fig. 7: Enhancement result of the humidity in some fingerprint samples for both the original technique and the modified one. The upper row is three samples images from CASIA-V5. The middle row shows the result of the original technique. The last row show the result of the modified.

However, the proposed core point detection algorithm performs well in all fingerprint classes, we face a problem in detection the Whorl and double loop fingerprint types. These types of fingerprints have two core points. In some fingerprints, the algorithm detects one core point in some samples, and detects the other in the other samples of the same person as shown in Figure 10. This will affect the cropped area which taken from the image to be entered to the feature extraction process. In our database, the percentage of Whorl and double loop is 17%.

After detection the core point, a region of size 128x128 around the core point is cropped. This region is used to extract the features from it, since this region contains information which used to identify the fingerprints image. Furthermore, we need to minimize the features as soon as possible, to build a fast recognition system. We face a problem in this process, that the core point locations near the image boundaries have much missed information, which considered as a black regions as shown in Figure 11. In our database, the percentage of these black regions is 22.8%.

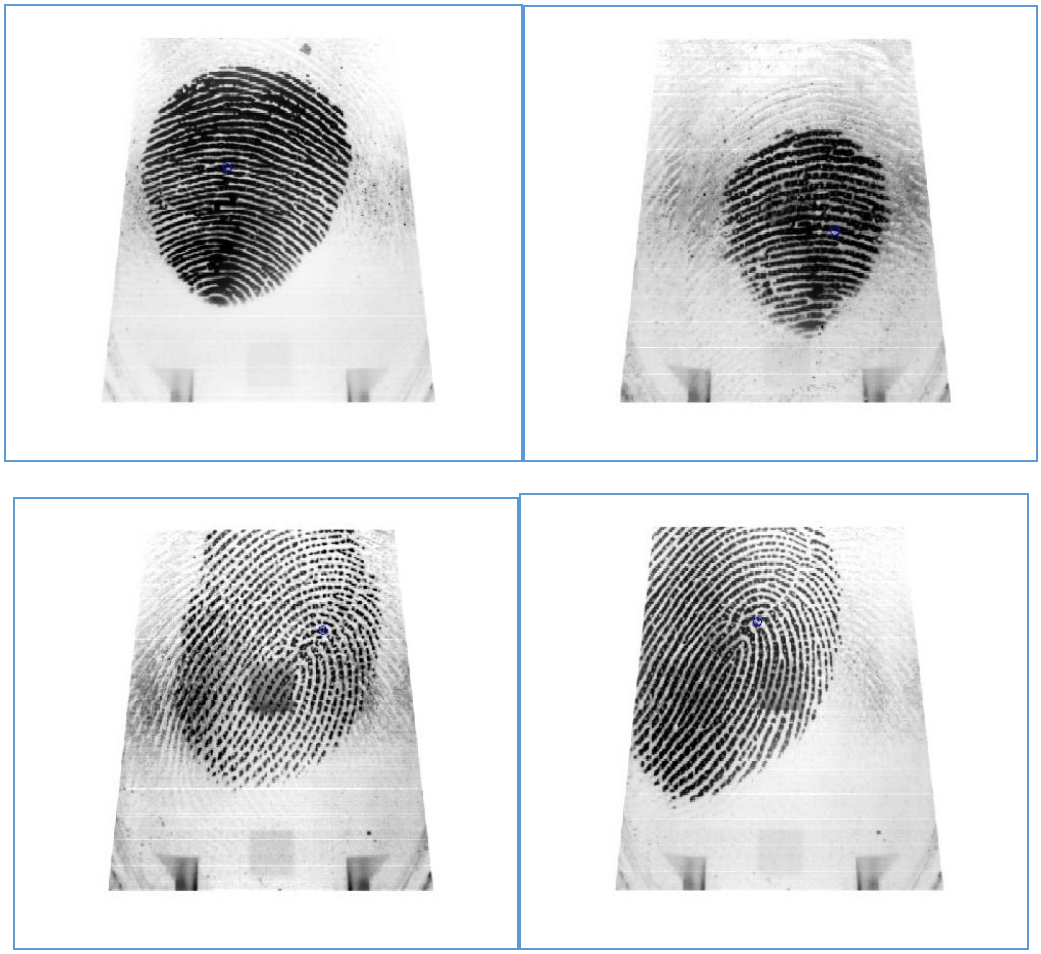


Fig. 8: The results of detection the core point. The upper images are partial fingerprint images samples which have no core point. The lower images are false location determination of core point.

Fig. 9: The results of detection the core point in left loop and right loop fingerprint image classes.

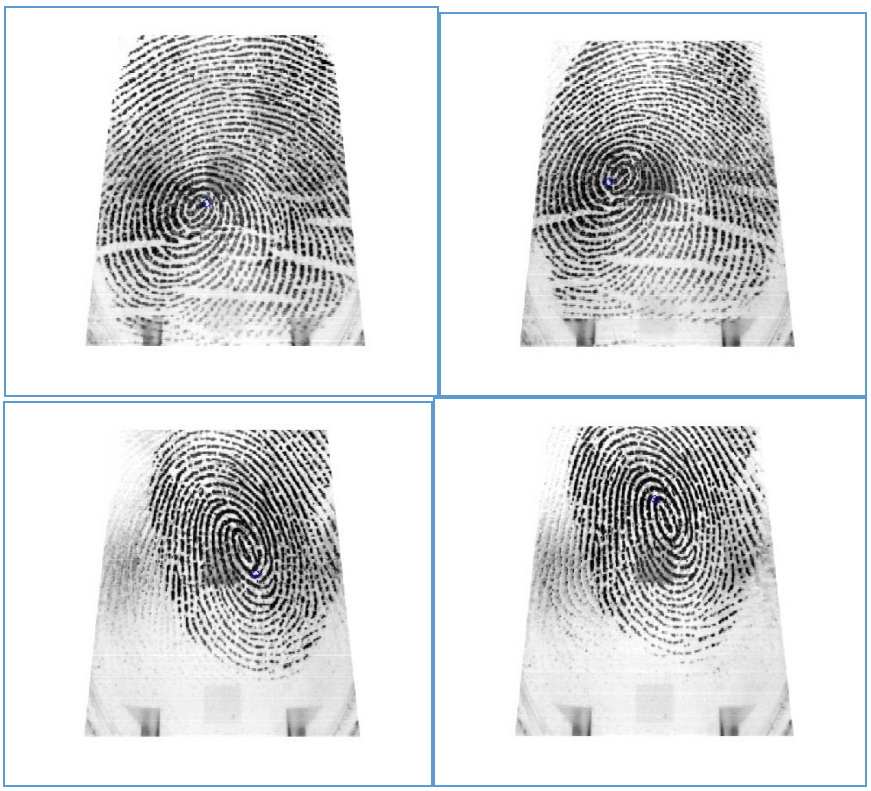


Fig. 10: The results of detection the core point in Whorl fingerprint class. The upper images are two samples from the same person, while the lower images from another person.

5.4 Matching Techniques results:

The features vectors are classified by various matching algorithms, from simple classification to more complex ones. The recognition results are illustrated in Table (1). We use the KNN algorithm for matching. We run the algorithm with different values of nearest neighbors K, and the highest recognition rate is when K=1. For a copped area of 128x128, the Wave atom has the highest recognition rate (99.5%).

Table (1): Fingerprint recognition results

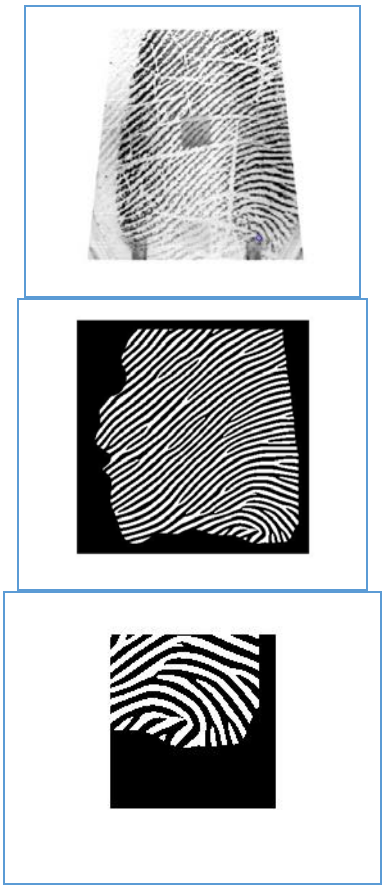
Feature Extracted By	*Fingerprint Matching Accuracy using KNN %*
Wave Atom	99.5%

5.5 Comparison with other works

In this section we will compare our work with the some others who use the multiresolution transforms as a feature extraction techniques. We use the same methodology of [27] except the size of feature vector and the feature extraction technique. They use the Curvelet transform to extract their features from the cropped fingerprint image. The comparison between their work and ours is shown in Table (2). We have a serious improvement over their work, such as we enlarge the number of fingerprint classes from 15 to 114 class, our database selection is more noisy and has more challenges than FVC2004, we use an automatic core point detection algorithm instead of the manual core point detection, we use an alignment technique to solve the problem of fingerprint image rotation. Finally we both approximately achieve the same recognition rate.

The second research we will compare our work with, is the algorithm based on Curvelet transform proposed by [28]. The comparison is shown in Table (2). To be fair with the work done in [27], we track the recognition rate of FVC2004 DB1. Although they use techniques for core point detection, and

alignment processes, their test database size is small. We have several improvement over their proposed solution, that we achieve better recognition rate with larger and noisier database



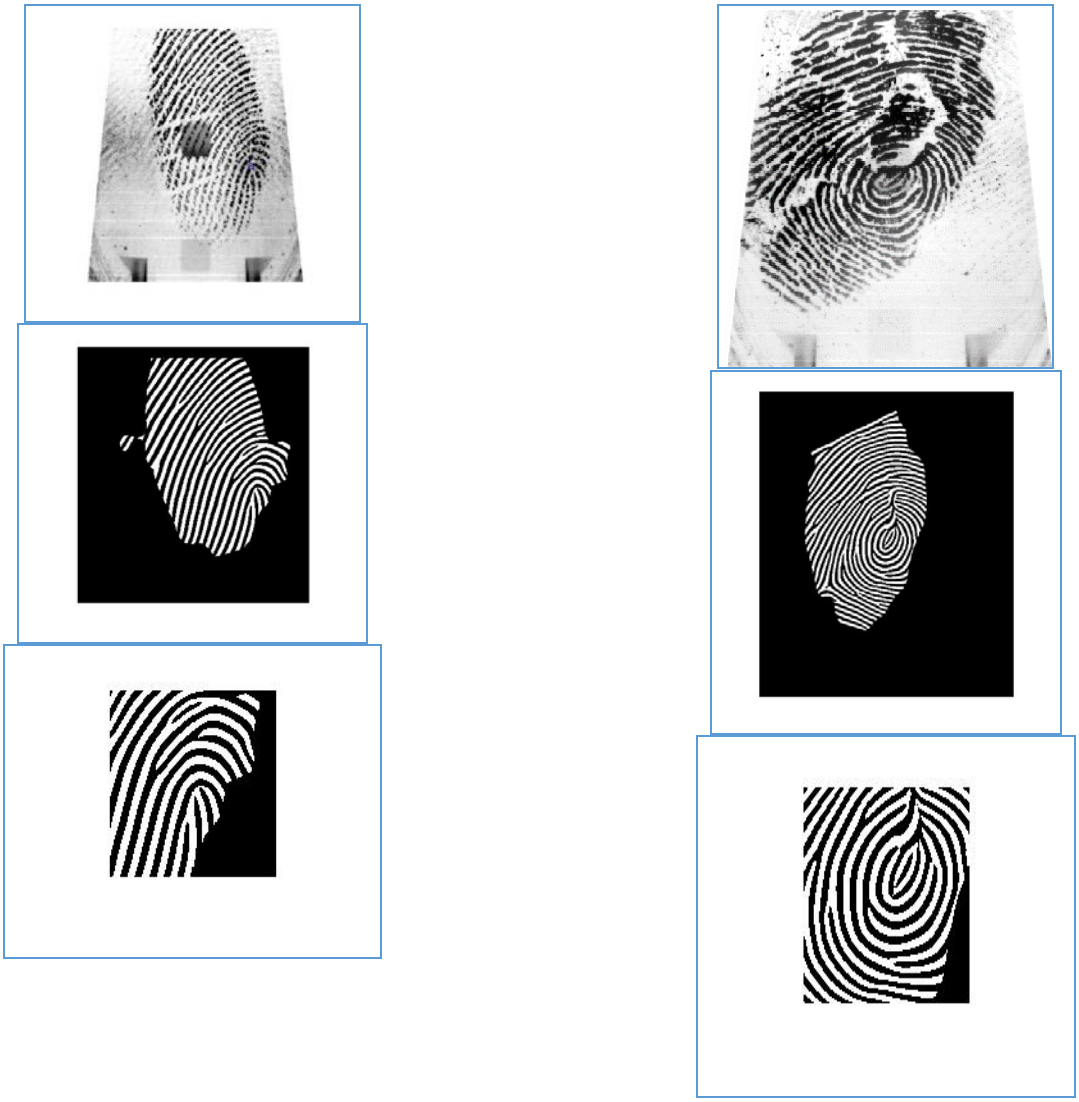


Fig. 11: The results of cropping 128x128 region around the core point. The left images are the original, the middile images are the binarization images, and the right images are the cropped regions.

Table (2): Comparison between the work done by [22] [27] [28] and ours

	The work done by [27]	**The work done by** [28]	**The work done by** [22]	**Our proposed solution**
Core point detection algorithm	Manually	Automatically	Automatically	Automatically
Alignment algorithm	Not used	Registration technique	Store 5 template with 5 different angles	Use an efficient alignment algorithm
Fingerprint Database	FVC2004 DB1	FVC2004 DB1	FVC2004 DB1	CASIA fingerprint V5
No of the fingerprint subjects	15	10	30	114
Recognition Rate	100%	88.24%	97%	99.5%

The last research we will compare our work with, is the algorithm based on Curvelet transform proposed by [22]. The comparison is shown in Table (2). We also have several improvement over their proposed solution, that we achieve better recognition rate with larger and noisier database, and faster alignment technique. On the other side, storing 5 templates for each fingerprint image, and matching each test fingerprint image with all the five templates is time consuming solution.

6. Conclusion and Future Work:

During the study and the development of this thesis, various problems has been identified, which results yield contribution to the automatic fingerprint recognition system. The following conclusions can be enumerated:

1- CASIA Fingerprint database is a very challenges database, and it needs a lot of processing steps to solve various problems. The images of the same subject have different issues: various image transition and rotations, and various bad quality images, such as creases, wounds, cuts, dryness, humidity.
2- To achieve a good recognition rate in poor quality fingerprint images, the fingerprint image have to be enhanced with a reliable techniques. Fingerprint enhancement technique based on STFT analysis is a reliable and an efficient technique which applied on CASIA database.
3- Accurate segmentation of fingerprint ridges from noisy background are necessary and important for efficiency and accuracy of subsequent enhancement and feature extraction algorithms.
4- Segmentation based on threshold value; to distinguish between the background and foreground regions; is not a good choice when it faces the humidity in fingertip issue, since it considers the humidity regions a part

of the background, and hence these part will not be processed through a complete enhancement process. Segmentation based on morphological operation is doing better in CASIA fingerprint images.

5- The displacement and rotation of fingerprint are critical issues that affect the performance of feature extraction techniques, and decrease the recognition rate.
6- Our suggested methodology is translation invariant, since we use the core point as a reference point.
7- The core point detection algorithm which is used in this thesis is robust, but it fails to detect the exact location of the core point in Whorl and double loop fingerprint types, because these types of fingerprints have two core points. So it detects one of the core point in one sample, and detect the other in the other sample. The percentage of Whorl and double loop fingerprint types is 17%.
8- Although the used algorithm of fingerprint alignment or rotation is robust, it has some drawbacks. The algorithm performs well in the images of relatively complete mask, i.e. without cuts in the image boundaries, especially if the image is cut in more than one side, such as the images of CASIA database. Another factor of limitations, that the algorithm assume that most fingerprint rotation angle is between (0-90 degree), but we found that in CASIA fingerprint images, the rotation angle is between (0-360 degree). We suggest a good solution to overcome this limitation, which will be a task for future work.
9- The segmentation process leave some small black parts in the top boundary of fingerprint image, especially in fingerprint which its upper part is lost. We solve this problem by implementing a method which can eliminate these parts.
10- In poor quality fingerprint images, especially our selected database, the cropped image of size 64x64 is not enough to extract distinctive features that can be used for identification of persons, so we cannot get a high recognition rate for this small size of fingerprint image.
11- When we increase the cropped size of fingerprint image to 128x128, the performance of recognition is increased, in spite of losing some parts of the images which contain important information about the ridge structure due to the core point location near the image boundaries.
12- We have a percentage of 22.8% of the cropped size of 128x128 fingerprint images that are considered partial images, since they have black regions, i.e. they lost their information due to the displacement problem.
13- Waveatom transform technique is proved to be an efficient, fast, and reliable feature extractor technique, and get the highest recognition rate of 99.5%.
14- We introduce an automatic fingerprint recognition system based on poor quality fingerprint images, and achieve a recognition rate of 99.5% with a very challenges database.

1. References

[1] M. Eriksson, "Biometrics Fingerprint based identity verification," *Master Thesis, UMEÅ UNIVERSITY.*, pp. 1-73, 2001.

[2] N. Jalutharia, "Fingeprint Recognitin and Analysis," *Master Thesis submitted to Thapar University, Patiala, India.*, 2010.

[3] I. Lewis, "Ever had your fingerprints taken? Meeting the challenges of 21st Century access control," *Elsevier, Biometric Technology Today*, vol. 2014, no. 5, pp. 9-11, 2014.

[4] Chaudhari and Patil, "A Study and Review on Fingerprint Image Enhancement and Minutiae Extraction," *IOSR Journal of Computer Engineering (IOSR-JCE)*, vol. 9, no. 6, pp. 53-56, 2013.

[5] S. Chikkerur, A. Cartwright and V. Govindaraju, "Fingerprint Image Enhancement Using STFT Analysis," *The Journal of Pattern Recognition, Elsevier.*, vol. 40, no. 1, pp. 198-211, 2007.

[6] L. Hong, Y. Wang and A. K. Jain, "Fingerprint image enhancement: Algorithm and performance evaluation," *IEEE Trans. Pattern Analysis Machine*, vol. 20, no. 8, p. 777–789, 1998.

[7] M. Khan, A. Khan and N. Muhammad, "Fingerprint Image Enhancement Using Principal Component Analysis (PCA) Filters," *IEEE*, 2010.

[8] C. Wu, "ADVANCED FEATURE EXTRACTION ALGORITHMS FOR AUTOMATIC FINGERPRINT RECOGNITION SYSTEMS," PHD Thesis Submitted to the faculty of the graduate school of state university of New York At Buffalo, New York , 2007.

[9] T.-Y. Jea, "Minutiae-Based Partial Fingerprint Recognition," PHD Thesis, submitted to the university at Buffalo the state university of New York, New York, 2005.

[10] C. Severance, "Anil Jain: 25 Years of Biometric Recognition," *IEEE COMPUTER SOCIETY*, pp. 8-11, 2015.

[11] Baghelani, Eshkaftaki and Ebrahimi, "A Novel Mapping for Fingerprint Image Enhancement," in *Machine Vision and Image Processing (MVIP), 2010 6th Iranian*, Isfahan, 2010.

[12] NAMBURU and PRAVEEN, "A STUDY ON FINGERPRINT IMAGE ENHANCEMENT AND MINUTIAE EXTRACTION TECHNIQUES," Master Thesis submitted to National Institute of Technology, Rourkela, 2007.

[13] Rajinikannan, Kumar and Muthuraj, "Estimating the Impact of Fingerprint Image Enhancement Algorithms for Better Minutia Detection," *International Journal of Computer Applications*, vol. 2, no. 1, pp. 36-42, 2010.

[14] Kumar and Verma, "FINGERPRINT IMAGE ENHANCEMENT AND MINUTIA MATCHING," *International Journal of Engineering Sciences & Emerging Technologies (IJESET)*, vol. 2, no. 2, pp. 37-42, 2012.

[15] Stephen, Reddy and Vasavi, "Fingerprint Image Enhancement through Particle Swarm Optimization," *International Journal of Computer Applications*, vol. 66, no. 21, pp. 34-40, 2013.

[16] Bouaziz, Draa and Chikhi, "Bat Algorithm for Fingerprint Image Enhancement," in *IEEE, Programming and Systems (ISPS), 2015 12th International Symposium on*, Algiers, 2015.

[17] Li, Busch and Yang, "A novel approach used for measuring fingerprint orientation of arch fingerprint," in *IEEE,Information and Communication Technology, Electronics and Microelectronics (MIPRO), 2014 37th International Convention on*, Opatija, 2014.

[18] Msiza, Leke-Betechuoh and Malumedzha, "Fingerprint Re-alignment: A Solution Based on the True Fingerprint Center Point," in *IEEE, 3rd International Conference on Machine Learning and Computing (ICMLC 2011)*, 2011.

[19] Wegstein, "An Automated Fingerprint Identification System," *U.S.Government Publication, U.S. Department of Commerce National Bureau of Standards,*, 1982.

[20] H. Lam, Z. Hou, W. Yau, T. Chen, J. Li and K. Sim, "Reference Point Detection for Arch Type Fingerprints," *Lecture Notes in Computer Science*, vol. 5558, pp. 666-674, 2009.

[21] Jain, Prabhakar, Hong and Pankanti, "Filterbank-Based Fingerprint Matching," *IEEE TRANSACTIONS ON IMAGE PROCESSING*, vol. 9, no. 5, pp. 846-860, 2000.

[22] H. Guesmi, H. Trichili, A. Alimi and B. Solaiman, "Curvelet Transform-Based Features Extraction For Fingerprint Identification," in *IEEE, International Conference of the Biometrics Special Interest Group (BIOSIG)*, Darmstadt , 2012.

[23] L. Liu, T. Jiang, J. Yang and C. Zhu, "Fingerprint Registration by Maximization of Mutual Information," *IEEE TRANSACTIONS ON IMAGE PROCESSING*, vol. 15, no. 5, pp. 1100-1111, 2006.

[24] K. Ito, A. Morita, T. Aoki, T. Higuchi, H. Nakajima and K. Kobayashi, "A Fingerprint Recognition Algorithm Using Phase-Based Image Matching for

Low-Quality Fingerprints," in *IEEE International Conference on Image Processing 2005*, 2005.

[25] F. Chen and J. Zhou, "A Comparative Study of Combining Multiple Features for Fingerprint Recognition," in *Emerging Techniques and Challenges for Hand-Based Biometrics (ETCHB), 2010 International Workshop on* , Istanbul, 2010.

[26] M. P. Dale and M. A. Joshi, "Fingerprint Matching Using Transform Features," in *TENCON 2008 - 2008 IEEE Region 10 Conference* , Hyderabad, 2008.

[27] T. Mandal and Q. M. Jonathan Wu, "A Small Scale Fingerprint Matching Scheme Using Digital Curvelet Transform," in Systems, Man and Cybernetics, 2008. SMC 2008. IEEE International Conference on, Singapore, 2008.

[28] N. Humaira, N. Bushra, Z. Firdous, M. Khan and M. Islam, "Curvelet Feature Based Fingerprint Recognition Using Fourier Enhancement," in IEEE,Informatics, Electronics & Vision (ICIEV), 2013 International Conference on , Dhaka, 2013.

[29] M. Omidyeganeh, A. Javadtalab, S. Ghaemmaghami and S. Shirmohammadi, "Contourlet Based Distance Measurement to Improve Fingerprint Identification Accuracy," in Instrumentation and Measurement Technology Conference (I2MTC), 2012 IEEE International, Graz, 2012.

[30] Z. HADDAD, A. BEGHDADI, A. SERIR and A. MOKRAOUI, "FINGERPRINT IDENTIFICATION USING RADON TRANSFORM," in Image Processing Theory, Tools and Applications, 2008. IPTA 2008. First Workshops on , Sousse, 2008.

[31] A. A. Mohammed, Q. M. Jonathan Wu and M. A. Sid-Ahmed, "Application of Wave Atoms Decomposition and Extreme Learning Machine for Fingerprint Classification," Springer, vol. 6112, pp. 246-255, 2010.

[32] M. Tico, E. Immonen, P. Ramo, P. Kuosmanen and J. Saarinen, "FINGERPRINT RECOGNITION USING WAVELET FEATURES," IEEE, pp. II21- II25, 2001.

[33] Jena and Dalal, "DWT Based Fingerprint Recognition Approach," International Journal of Engineering Research & Technology (IJERT), vol. 3 , no. 5, pp. 1800-1803, 2014.

[34] S. Chavan, P. Mundada and D. Pal, "Fingerprint Authentication using Gabor Filter based Matching Algorithm," in International Conference on Technologies for Sustainable Development (ICTSD-2015), Mumbai, India, 2015.

[35] Demanet and Ying, "Wave atoms and sparsity of oscillatory patterns," Elsevier, pp. 368-387, 2007.

[36] N. Otsu, "A threshold selection method from graylevel histograms," IEEE Trans. Systems, vol. 9, no. 1, p. 62–66., 1979.

[37] M. F. Fahmy and M. A. Thabet, "A Fingerprint Segmentation Technique Based on Morphological Processing," in IEEE International Symposium on Signal Processing and Information Technology , Athens, 2013.

[38] Nilsson and Bigun, "Localization of corresponding points in fingerprints by complex filtering," Elsevier, pp. 2135-2144, 2003.

Eng. Waleed Abudalal has a degree Bachelor of Computer Engineering from Islamic University of Gaza, and now he is a Master student in Computer Engineering Department in the Islamic University of Gaza. He had been working for Ministry of Finance for over two years as an oracle programmer, and for Ministry of Interior for over five years as programming department chairman.

Dr. Mohammed Ahmed Alhanjouri received Bachelor of Electrical and Communications Engineering (honor) (1998), Master of Electronics Engineering (excellent) (2002), and Ph.D. in 2006. Alhanjouri has worked at Arab Academy for Science & Technology & Maritime Transport (Alex., Egypt) from 2002 to 2006. Then he worked as Assistant Professor, with responsibility: director of projects and research center, and head of computer Engineering department at Islamic University of Gaza, Palestine. Also he worked at University of Palestine as dean of library, then as head of Software Eng. Dept. Currently, he is serving as Associate Professor, Director of Excellence and eLearning Center at Islamic University of Gaza.

His primary research interest is in the area of Artificial Intelligence. He also carries out research in many other areas such as: Advanced digital signal processing, Pattern recognition (Image and Speech), data mining, modern classification techniques (neural networks, Hidden Markov Models, Ant colony, Swarm Optimization and Genetic Algorithm).