Fingerprint Image Enhancement through Particle Swarm Optimization

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ABSTRACT

Fingerprint image enhancement is an essential preprocessing step to extract qualitative minutiae from a fingerprint image. To enhance the fingerprint image, a new parameterized transformation function is designed and the parameters in the transformation function are optimally controlled by Particle Swarm Optimization (PSO), which is one of the well known soft computing techniques. The fingerprint image enhancement algorithm, which is designed based on PSO, is implemented to remove the noise from the fingerprint image and improve the clarity of ridges. The objective of the proposed PSO based enhancement method is to maximize an objective fitness criterion in order to enhance the contrast and minutiae detail in a fingerprint image.

The efficiency of the proposed method was evaluated using NFIQ and BOZORTH3 packages of NIST Biometric Image Software (NBIS). Along with these two approaches, Robustness Index is also used for evaluating the proposed method. The results are compared with the existing techniques like Contrast Limited Adaptive Histogram Equalization (CLAHE), Wiener filter, Median filter and ABF. Various experiments were carried out on the fingerprint data sets, which are collected from “Biometrics Ideal Test (ATVS-FFp DB, CASIA-FingerprintV5”) and FVC 2002 of MSU. The proposed PSO based fingerprint enhancement image outperforms many existing image enhancement techniques.

General Terms
Fingerprint Image Enhancement, Particle Swarm Optimization, Objective criterion, Entropy, PSNR.

Keywords
Fingerprint Image Enhancement, Minutiae extraction, PSO

1. INTRODUCTION
Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling. PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles [1].

Each particle keeps track of its coordinates in the problem space which are associated with the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called *pbest*. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the neighbors of the particle. This location is called *lbest*. When a particle takes all the population as its topological neighbors, the best value is a global best and is called gbest.

The basic concept of Particle Swarm Optimization lies in accelerating each particle towards its pbest and the gbest locations, with a random weighted acceleration at each time / step [2]. In the past, several years PSO has been successfully applied in many research and application areas. It is demonstrated that PSO gets better results in a faster, cheaper way compared with other methods.

In this work Fingerprint image enhancement is considered as an optimization problem and PSO is used to solve it. Image enhancement is mainly done by maximizing the information content of the enhanced image with intensity transformation function.

For fingerprint image enhancement task, a transformation function is required which will take the intensity value of each pixel from the input fingerprint image and generate a new intensity value for the corresponding pixel to produce the enhanced fingerprint image. And to evaluate the quality of the enhanced fingerprint image automatically, an evaluation function is needed which should be effective and at the same time light weighted because it has to estimate the quality at the run time.

In the proposed methodology, a parameterized transformation function is used, which uses local and global information of the image. Here an objective criterion for measuring image enhancement is used which considers entropy and peak signal to noise ratio (PSNR). The best enhanced image was tried to achieve according to the objective criterion by optimizing the parameters used in the transformation function with the help of Particle Swarm Optimization (PSO).

2. PSO ALGORITHM
PSO is initialized with a group of random particles (solutions). The algorithm then searches for optima through a series of iterations. The particle’s fitness value is evaluated on each iteration. If it is the best value the particle has achieved, the particle stores the location of that value as pbest (particle best). The location of the best fitness value achieved by any particle during any iteration is stored as gbest (global best). Using pbest and gbest each particle moves with a certain velocity, calculated by the following equation (1).

$$V_i = wV_{i-1} + (c1 * r1 * (pbest_i - p_i)) + (c2 * r2 * (gbest - p_i)) \quad (1)$$

$$p_i = p_{i-1} + V_i \quad (2)$$

$$w = w_{max} * ((w_{max} - w_{min}/maxiterations) * np) \quad (3)$$

where V_i, Vi_{-1} are the current and previous velocities of i^{th} particle, and pi, p_{i-1} is the current and previous position of the i^{th} particle, r1 and r2 are random numbers generated in the range [0, 1], c1 and c2 are positive acceleration constants, defined as random numbers in [0 2]. And $pbest_i$ is the best solution of i^{th} individual particle over its flight path, gbest is the best particle obtained over all generations obtained.

And w is the inertia weight, w_{max} represents maximum and w_{min} represents minimum value for w and is set to two and zero respectively, which is same for all particles. And np represents no of particles.

2.1 Variants

Numerous variants of other than basic PSO algorithm are proposed in the literature [3]. For example, there are different ways to initialize the particles and velocities (e.g. start with zero velocities), how to dampen the velocity; only update pbest and gbest after the entire swarm has been updated, etc.

New and more sophisticated PSO variants are also continually being introduced in an attempt to improve optimization performance. There are certain trends in that research; one is to make a hybrid optimization method using PSO combined with other optimizers, another research trend is to try and alleviate premature convergence (that is, optimization stagnation) e.g. by reversing or perturbing the movement of the PSO particles, another approach to deal with premature convergence is the use of multiple swarms (multi-swarm optimization) and then there are also attempts at adapting the behavioral parameters of PSO during optimization. So far no researcher explored this so called PSO for fingerprint enhancement related problems.

Various filters and methodologies were used for the finger print image enhancement. Earlier the authors proposed Enhancing Fingerprint Image through Ridge Orientation with Neural Network Approach and Ternarization for Effective Minutiae Extraction [8] and Removal of False Minutiae with Fuzzy Rules from the Extracted Minutiae of Fingerprint Image. [9], so in the present work the application of PSO is experimented for the purpose of enhancing fingerprint image.

In this work the PSO basic variant is considered for enhancing the fingerprint images, thereby improving the quality of the images.

3. PROPOSED METHODOLOGY

3.1 New Transformation Function

Image enhancement, which is done on spatial domain uses a transform function that generates a new intensity value for each pixel of the MXN original image to generate the enhanced image, where M denotes the number of columns and N denotes the number of rows. In other words, local enhancement model apply transformation functions that are based on the gray-level distribution in the neighborhood of each pixel in the given image.

In image processing, the simplest statistical measures of a random variable are its mean and variance [4]. These are the reasonable parameters to be considered to design an adaptive filter because they are the quantifiers that are closely related to the appearance of an image. The mean gives the measure of average gray level in the region over which the mean is computed, and the variance gives a measure of average contrast or difference in that region.

In the traditional enhancement technique, enhancement takes place at each pixel at location (i, j) using the following transformation function [5]:

$$g(i,j) = \left[\frac{G}{\sigma(i,j)}\right][f(i,j) - m(i,j)] \quad (4)$$

where $m(i, j)$ is the mean (i, j) is the centroid and $\sigma(i, j)$ is the standard deviation, which are computed in a neighborhood centered at (i, j). Therefore, they are dependent on the local information. $f(i,j)$ and $g(i,j)$ are the gray-level intensity of pixels in the input and output image, respectively, centered at location (i, j). And lastly, G is the global mean of the image.

The traditional enhancement model mentioned in equation "(4)" is modified by including four parameters a,b,c,d to convert into a parameterized transformation function. And the resultant transformation function looks as follows:

$$g(i,j) = [((d*G))/(\sigma(i,j)+b)][f(i,j) - c*m(i,j)] + m(i,j)a \quad (5)$$

where $f(i, j)$ is the gray value of the $(i, j)^{th}$ pixel of the input fingerprint image and $g(i, j)$ is the gray value of the $(i, j)^{th}$ pixel of the enhanced fingerprint image. Four parameters are introduced in the transformation function, namely a, b, c, and d to produce large variations in the processed image. The parameters a, b, c and d are defined over the real positive numbers and their range is [0, 1]. And they are controlled by an optimization technique. $m(i, j)$ is the local mean of the $(i, j)^{th}$ pixel of the input image over a n×n window which is defined as

$$m(i,j) = \frac{1}{n \times n}\sum_{x=0}^{n-1}\sum_{y=0}^{n-1} f(x,y) \quad (6)$$

$\sigma(i, j)$ is the local standard deviation of $(i, j)^{th}$ pixel of the input fingerprint image over a n×n window and G is the global mean of the image, which are defined as:

$$\sigma(i,j) = \sqrt{\frac{1}{n \times n}\sum_{x=0}^{n}\sum_{y=0}^{n}\left(f(x,y) - m(i,j)\right)^2} \quad (7)$$

$$G = \frac{1}{M \times N}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1} f(i,j) \quad (8)$$

Comparing equation (4) to equation (5), in the transformation function (4), the values of the parameters are taken as b=0, c=1, d=1 and the term 'm(i, j)a' is taken as 0. In equation (4), value of b is not '0', and this prohibits the Not A Number (NAN) values. In the new transformation function, only a fraction of the mean is subtracted from the pixel's input gray-level intensity value because 'c' is not equal to '1', while the last term may have the effect of brightening and smoothing the image. This new transformation function broadens the spectrum of the transformation output range. This new transformation function can also be used with other optimization techniques apart from PSO. A methodology of applying 'multi transformation functions' for fingerprint image enhancement with the help of multi optimization techniques can be proposed, where this transformation function can be a part in such methodology.

3.2 Fingerprint Enhancement Using PSO

The parameters in the new transformation function are optimally controlled and changed at every step and every iteration by the optimization technique (PSO). First P numbers of particles are created. Here, in the algorithm, we have taken P = 30, for each particle, parameters a, b, c, d are initialized randomly within their range and corresponding random velocities. The parameters a, b, c, d are randomly generated within the range [0 1]. Similarly, velocities of a, b, c, d are randomly defined in the range [0 1]. The parameters c1, c2 are randomly defined in the range [0 2]. Until a termination condition is reached, for each particle, enhanced fingerprint image is generated using the Transformation function.

4 EVALUATION CRITERIA

In this present work, two objective functions are used to form a multi objective criterion in order to evaluate the rate of enhancement at each step / iteration during the enhancement process. For evaluating the quality of the fingerprint image, Entropy is considered as an important parameter in the objective function. Entropy value reveals the information content in the image. If the distribution of the intensities is uniform, then it indicates histogram is equalized and thus the entropy of the image will be more. Having considered all these factors, the fitness function, which is given in equation (9), can be a good choice for an objective criterion:

$$Fit(X) = H(g(X)) + log\left(log\left(I(g_e(X))\right)\right) * \frac{g_e(X)}{MXN} \quad (9)$$

Where, *Fit(X)* is the fitness function, *g(X)* denotes the enhanced fingerprint image (after transformation function is applied). $g_e(X)$ is the number of edge pixels as detected with the Sobel edge detector. The Sobel detector which is used in the fitness function is an automatic threshold detector [155]. $I(g_e(X))$ is the intensity of the edges detected with a Sobel edge detector that is applied to the transformed image *g(X)*[156], M and N are the number of pixels in the horizontal and vertical direction respectively of the image. Finally, *H(g(X))* measures the entropy of the enhanced image *g(X)*.

The entropy, *H*(g(i, j)) of the enhanced image *g(i, j)* is calculated based on histogram, as follows:

$$H(g(i,j) = -\sum_{i=0}^{255} e_i$$

where $e_i = h_i \log_2 h_i$ if $h_i \neq 0$ otherwise $e_i = 0$. And h_i is the probability occurrence of i^{th} intensity value of g(i, j) image.

Along with fitness function, *Fit(X)*, the PSNR is also used as objective function to form a multi objective criterion. The PSNR computes the peak signal-to-noise ratio and represents a measure of the peak error in decibels, between two images. This ratio is often used as a quality measurement between the original and a reconstructed image. PSNR is expressed as

$$PSNR = 10 * \log_{10}(b^2/MSE) \quad (10)$$

where b is the largest possible value of the signal (typically 255 or 1), and MSE in the denominator represents the cumulative squared error between the reconstructed and the original image, and is computed as follows

$$MSE = \frac{\sum i \sum j \, |f(i,j) - y(i,j)|}{N} \quad (11)$$

Where 'N' is the total number of pixels. The lower value of MSE represents the lower error in the enhanced image.

In this present work PSNR is used as an objective function. To calculate PSNR, two images must be given but here only input image is given for enhancement. So after generating enhanced image in the 1st step / iteration then that image is considered as the 2nd image. The input image is fixed at one side and at each step / iteration the enhanced images is considered as the second image. The usage of PSNR as objective function to evaluate the quality at each step / iteration is as follows.

During the enhancement process at each step / iteration i, PSNR is calculated between enhanced image and input image and the value is stored. Again after enhancement in the next step / iteration i+1, the PSNR value is computed between new enhanced image and input image. The PSNR value at iteration i and i+1 are compared and the one with the lowest PSNR value must be selected. This is because more the image is enhanced then more the Mean Square Error (MSE) between enhanced image and input Image. And if the MSE value is high then the PSNR value will be less.

During the fingerprint image enhancement process, at each step / iteration while a fingerprint image is enhanced, after applying the transformation function, both *Fit(X)* value and PSNR value are calculated. The best enhanced image is selected based on the better values of these two objective functions.

5 PSO-BASED IMAGE ENHANCEMENT ALGORITHMS

Step 1: Create P number of particles of d dimensions.

Step 2: For each particle, initialize parameters a,b,c,d randomly within their range and corresponding random velocities.

At each iteration, repeat until a termination condition (no. of iterations) is reached.

Step 3: For each particle, generate enhanced fingerprint image using equation (5) and calculate objective function value (entropy and PSNR) using equations (9), (10)

Step 4: Set *pbest* as best solution of i^{th} particle achieved so far based on the fitness value.

Step 5: Now, check if fitness value of enhanced fingerprint image of i^{th} particle is greater than *pbest* value, then set update *pbest* value with fitness value of i^{th} particle.

Step 6: Set *gbest* as the global best solution achieved so far among all generation.

Step 7: Check if fitness value of enhanced fingerprint image of i^{th} particle is greater than *gbest* value, then set *gbest* value with fitness value of i^{th} particle.

Step 8: For each particle, update the velocity using the equation(1) and update the position using the equation (2).

5.1 Control Parameters

In this work, the following combinations of the control parameters are used for running PSO based enhancement.

The number of particles *np* considered is 30. Dimension of particles is four since the parameters need to be tuned are 4. Range of particles is the positive real numbers. And parameters *a, b, c* and *d* are the parameters defined over the real positive numbers and their range is [0, 1]. Parameters *c1, c2* are positive acceleration constants, given a random number in [0, 2]. These parameters are fixed for each particle throughout its life. And *r1* and *r2* are random numbers in [0,1] and varies for each component of the particles in every generation.And w_{max} and w_{min} represents maximum & minimum value for inertia weight, *w* and is set to two and zero respectively, which is same for all particles.

6. EXPERIMENTAL RESULTS

The aim of the experimental results section is to illustrate the results of the PSO based enhancement algorithm and to assess how well it performs comparing with the other existing enhancement techniques.

6.1 Fingerprint Database used:

Databases used for experiments:

We have used databases collected from two major sources.

- ATVS-FakeFingerprint Database (ATVS-FFp DB) [6]

- FVC 2002 from MSU [7]

The ATVS-FakeFingerprint Database (ATVS-FFp DB), which was collected from Biometrics Ideal Test (BIT) and made available at http://biometrics.idealtest.org/ is exhaustively used for various experiments in the present work. This database is a very much suitable to simulate latent fingerprints at crime location.

A database of real and fake fingerprints was specifically created for each of the two scenarios namely: i) with a cooperative user, and ii) without the cooperation of the user. And the fingerprints were captured using three different sensors each belonging to one of the main technologies existing in the market: two flat (optical and capacitive), and one sweep sensor.

Here these fake fingerprint images are considered as if they are gathered from the crime location. It is quite obvious that fingerprints that are gathered from the crime location are of very poor quality. So in this work those fake fingerprints are taken as the input to the proposed fingerprint image enhancement through PSO. The advantage with this database is that the corresponding real fingerprints are also available. So the enhanced fake fingerprint's quality can be compared with the respective original fingerprint to evaluate the rate of enhancement achieved through the proposed method.

6.2 Validation of the present work

The proposed enhancement method has been validated through the following three approaches

- Evaluating the improvement in the quality before and after enhancement using NFIQ of NBIS [15]
- Calculating Robustness Index
- Verification performance using BZORTH3 of NBIS [14]

6.2.1 Evaluation of improvement in Quality using NFIQ package of NBIS Software:

The NIST Fingerprint Image Quality (NFIQ) package of NIST Biometric Image Software (NBIS) [15] is used in the experiments to evaluate the quality of the fingerprint images before and after applying proposed enhancement technique. This tool labels the samples from '1' being the highest and '5' the lowest.

It can be observed from the table 1 and graphs that after applying the PSO Image Enhancement Algorithm, even the quality of poor fake images (input image) are also increased. Many experiments were carried out to test the efficacy of the proposed method. In table 1 the results are presented only for 32 sample fingerprint images because of the space constraint. Independent graphs have been plotted for the optical, capacitive and thermal scanners with 250 images for each as input.

Table 1: NFIQ quality labels: Before and after enhancement

Image (fake database of ATVS-FFp)	File Name of the database	Type of Scanner	NFIQ - Quality label before enhancement	NFIQ - Quality label after enhancement (PSO)
u01_f_fc_li_01	U01-	Capaciti	5	5
u01_f_ft_rm_04	U01-	Therma	5	5
u02_f_fo_li_03	U02-	Optical	5	4
u02_f_ft_ri_01	U02-	Therma	3	2
u03_f_fc_rm_0	U03-	Capaciti	5	4
u03_f_ft_lm_04	U03-	Therma	3	3
u04_f_fc_li_02	U04-	Capaciti	5	4
u04_f_fo_rm_0	U04-	Optical	5	4
u05_f_fc_ri_03	U05-	Capaciti	5	5
u05_f_ft_rm_01	U05-	Therma	3	2
u06_f_fc_rm_0	U06-	Capaciti	5	5
u06_f_fo_ri_04	U06-	Optical	5	4
u07_f_fc_li_01	U07-	Capaciti	5	4
u07_f_ft_li_01	U07-	Therma	3	3
u08_f_fc_lm_04	U08-	Capaciti	5	5
u08_f_ft_ri_04	U08-	Therma	3	3
u09_f_fo_rm_0	U09-	Optical	4	3
u09_f_ft_ri_03	U09-	Therma	5	4
u10_f_fc_lm_04	U10-	Capaciti	5	4
u10_f_ft_ri_02	U10-	Therma	5	4
u11_f_fc_lm_02	U11-	Capaciti	5	5
u11_f_fo_li_04	U11-	Optical	3	2
u12_f_fc_rm_0	U12-	Capaciti	5	4
u12_f_ft_rm_02	U12-	Therma	4	4
u13_f_fo_rm_0	U13-	Optical	3	3
u13_f_ft_lm_04	U13-	Therma	5	4
u15_f_fc_ri_04	U15-	Capaciti	5	4
u15_f_fo_ri_03	U15-	Optical	3	3
u16_f_fc_ri_04	U16-	Capaciti	5	5
u16_f_ft_rm_03	U16-	Therma	5	4
u17_f_fo_lm_0	U17-	Optical	2	2
u17_f_ft_lm_04	U17-	Therma	2	2

Independent graphs have been plotted for the optical, capacitive and thermal scanners with 250 images for each as input. It can be observed from the graphs in figures 1 to 5 that after applying the proposed PSO based enhancement technique, the quality of the fingerprints are improved. A very important point to be noted here is that only image enhancement technique is applied to remove noise from the fingerprint image. The typical fingerprint filtering techniques can be applied on these enhanced fingerprints to get the optimal enhancement results.

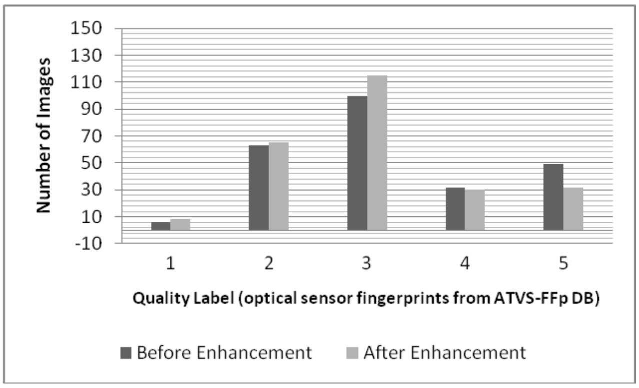

Fig 1: NFIQ quality: before and after enhancement (Optical sensor fingerprints)

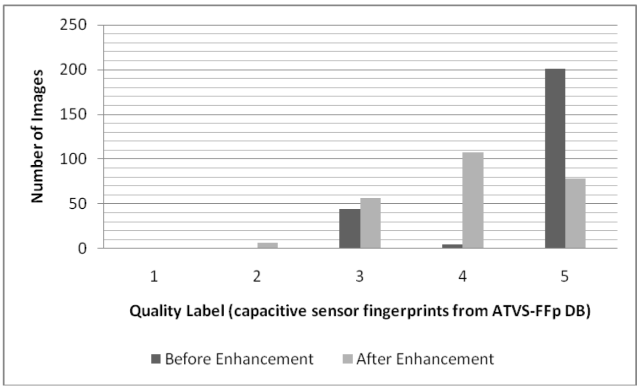

Fig 2: NFIQ quality : before and after enhancement (capacitive sensor fingerprints)

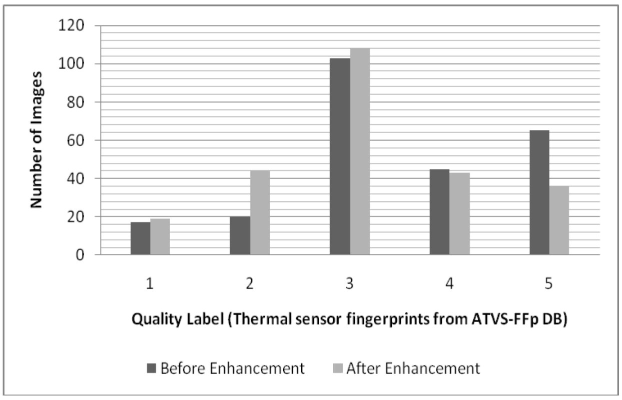

Fig 3: NFIQ quality: before and after enhancement (thermal sensor fingerprints)

Validation and performance of the proposed methodology and the associated algorithms is an important criteria without which the efficacy of the present work cannot be established.

6.2.2 Evaluation using Robustness Index

The efficiency of the proposed enhancement method is alo validated using Robustness Index (R.I). Two tests are carried out on ATVS-FFp DB fake database [6] in calculating R.I. In first test the R.I is calculated between unenhanced poor quality fingerprint and corresponding real (original) fingerprint image. In second test, after enhancement, the Robustness Index (R.I) is calculated between enhanced fake fingerprint image and corresponding real fingerprint image.

The formula that is used to calculate Robustness Index (*RI*) of a Fingerprint image is

$$RI = p / u + v - p \tag{12}$$

within a tolerance bound of 18 pixels and 30 degrees, respectively.

Where '*p'* is the number of paired minutiae and ($u + v - p$) represents the total union count of minutiae detected in both the images.

The tolerance bound is taken higher than the normal case because the R.I calculation is done between poor quality fake fingerprints and corresponding real fingerprints. So it may be a reasonable consideration. While calculating R.I, first the false minutiae are removed from the extracted minutiae [8].

A low *RI* value indicates large variance in the number of minutiae detected in two images and hence reflects poor image quality. The results that are presented in the graph show the improvement in R.I after performing enhancement.

The results of the proposed techniques were compared with some of the existing techniques such as Median Filter [11], Weiner Filter [12], Contrast Limited Adaptive Histogram Equalization (CLAHE)[10], adaptive bilateral filter (ABF) [13] to establish the effectivity while enhancing image. The graph in the figure 4 presents the improvement in the fingerprint image quality after applying various enhancement techniques and proposed enhancement technique. For effective results analysis the results of the same sample set of 32 fingerprints from fake database of ATVS-FFp DB are presented.

From these experimental results, it can be observed that the quality of the fingerprints, Robustness Index and performance of the verification system are improved when the proposed enhancement algorithm is applied to the input fake fingerprint images. It can be observed that in the present work only image enhancement is done to remove noise from the fingerprint image but further fingerprint image enhancement techniques need to be applied for more enhancement. But these results demonstrate that quality of fingerprint and verification performance can be increased even by eliminating noise from the fingerprint image. Initially in the present work, the enhancement is evaluated through verification performance using a newly developed authentication system, "fingerprint authentication system using traditional Euclidian distance and SVD algorithm"[16]. But because Bozorth3 is a standard matching system of reputed international organization, NIST, the final results are verified using Bozorth3 of NBIS. Through lot of experiments were carried out on huge fingerprint datasets of CASIA Version5 and FVC 2002 to evaluate the proposed enhancement technique, the results that were obtained with FVC 2002 database are presented in this paper.

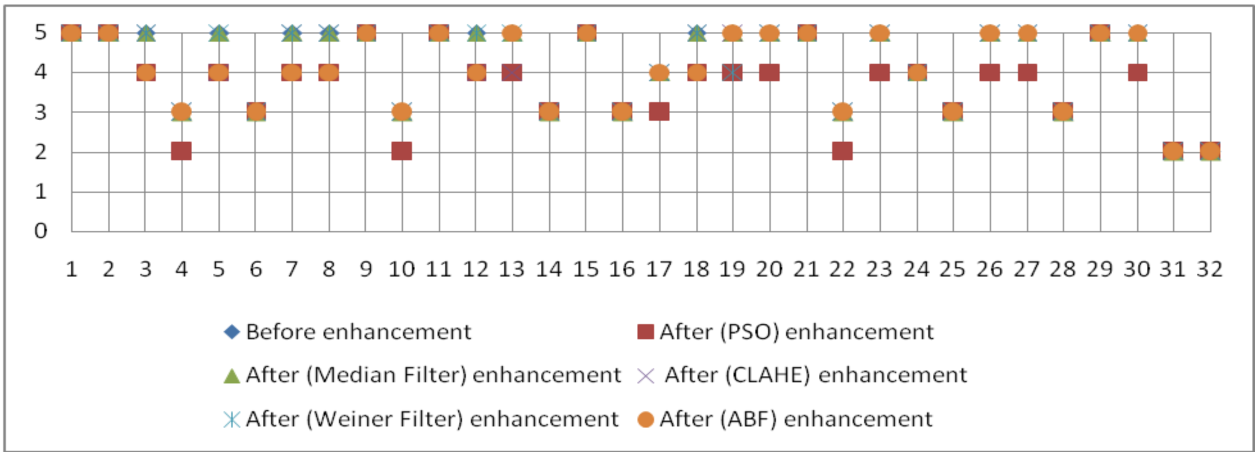

Figure 4: NFIQ Quality labels of the fingerprint image comparitive results of proposed & other existing techniques

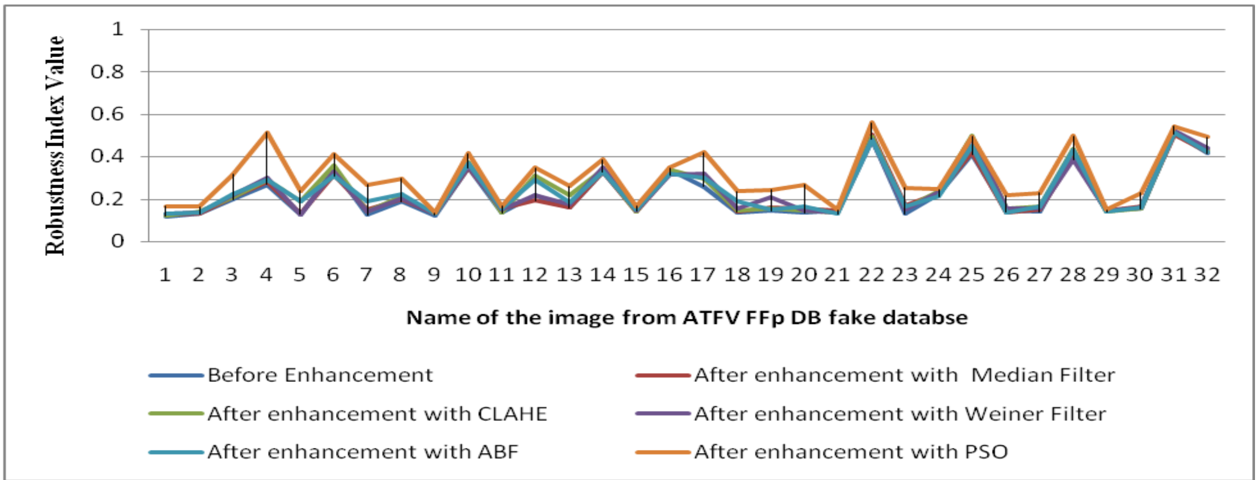

Figure 5: Comparative results: Robustness Index values (Before & after enhancment)

6.2.3 Evaluation through verification performance:

Lot of effort had been invested in evaluating the efficacy of the proposed enhancement technique in terms of verification performance. Before concluding this paper, the experimental finding with respect to the verification performance on the standard fingerprint dataset, collected from FVC 2002 of MSU [7] are presented.

The effectiveness of the proposed enhancement technique is also evaluated using BOZORTH3 of NBIS. BOZORTH3, a fingerprint matching system, which is the second export controlled package of NBIS. BOZORTH3 is a fingerprint matching system. It uses the minutiae detected by MINDTCT (a minutiae detection system of NBIS) to determine if two fingerprints are from the same person, same finger. It can analyze two fingers at a time or run in a batch mode comparing a single finger (probe) against a large database of fingerprints (gallery). The BOZORTH3 matcher uses only the location (x,y) and orientation (theta) of the minutia points to match the fingerprints. The matcher is rotation and translation invariant. [14] For these experiments the database DB3_A of FVC 2002 is used, which contains total of 800 fingerprints (100 fingers, 8 images each). The total number of genuine and impostor matching attempts are 2800 and 4950 respectively. The NIST's open source software, BOZORTH3, (available at http://fingerprint.nist.gov) is used for the purpose of feature extraction and matching. The overall matching performance is measured by the receiver operating characteristic (ROC) curve that plots the genuine acceptance rate (GAR) against the false acceptance rate (FAR) at different operating points (matching score-thresholds)

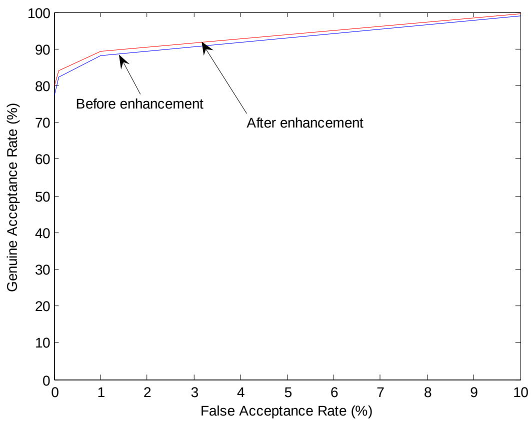

Figure 6: ROC graph: Before and after enhancement

After applying the proposed enhancement technique, even the verification performance has been increased. These results are very encouraging because just by removing noise through the application of proposed image enhancement technique (without applying any typical fingerprint enhancement filtering techniques), the quality of fingerprint images are increased such that the verification performance is also improved.

7. CONCLUSION AND FUTURE WORK

So Particle Swarm Optimization (PSO) is used to control and change the parameters optimally in the new transformation function for fingerprint image enhancement. The proposed methodology had been effectively implemented to improve the quality of the image and the clarity of ridges. This proposed PSO based image enhancement method may be improved in several ways. Few more new transformation functions are designed by the researcher and are applied with some of the latest optimization techniques for the purpose of fingerprint image enhancement. Once after the proposed enhancement process is completed then some fingerprint filtering techniques can be applied to further increase the quality that leads towards the qualitative extraction of minutiae.

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