A Review Study on Fingerprint Image Enhancement Techniques

D. Ezhilmaran
School of Advanced Sciences
VIT University
Vellore, India.
ezhilmaran.d@vit.ac.in

M. Adhiyaman
School of Advanced Sciences
VIT University
Vellore, India.
adhiyaman.m@vit.ac.in

Abstract—Image enhancement techniques have become more popular among the researchers as it is widely been used in security and medical applications. There have been different image enhancement technique approaches and filters were developed to enhancement the fingerprint images. While analysis a few accesses are established in spatial domain, frequency domain and fuzzy model. These techniques are based on local ridge frequency and orientation. This survey research paper was aimed to analyze these techniques, its effectiveness on fingerprint image enhancement. The study has considered and discussed various available methods and techniques that have been used in the previous research studies and also provides the direction for further research on fingerprint image applications.

Keywords-Fingerprint image; Enhancement; Filters; Fuzzy Model.

I. INTRODUCTION

Finger print identification is one of the very few techniques employed in Forensic science to aid criminal investigations in daily life, providing access control in financial security, Visa related services and so on. Finger print is an image, actually, an impression of the friction ridges of all or any part of the human finger. Basically, a finger print image can be taken by pressing the finger against a hard surfaced device which is sensitive. Moreover, these images are barely of good quality and need to be enhanced to obtain a better version of the original image [1]. Image enhancement process is commonly used to improve the quality of original images by using different methods. i.e. Image Segmentation, Image Extraction, Image Filtering etc., Much of the research studies have used the above methods to improve the quality of the raw (fingerprint) image with various techniques (discussed in the following sections).

A fingerprint image is having the following features by which, it can be enhanced using appropriate techniques. Ridge Orientation Map is the local direction of the ridge valley which is used for classification, verification and filtering purposes, whereas Ridge Frequency Map is only used for image filtering purposes. Registration and classification can be done on the basis of Singular points in the fingerprint image, where core represents the uppermost part of curving edge and Delta represents' the point where three ridge flows meet. Automatic Fingerprint Identification System (AFIS) uses the minutiae features of fingerprint such as ridge endings and bifurcation [2].

Ridge and valley structure

Finger print

II. FINGERPRINT IMAGE ENHANCEMENT

Though, there is no well defined theory for image enhancement, much of the research activities were carried out by reducing noises, increasing the contrast in gray scale images. Moreover, the viewer can decide on the image quality with his/her own aspects [3]. Basically, two types of images can be considered for image enhancement process.

A. Gray Level Image

This type of image forms a sinusoidal-shaped plane with ridges and valleys of the fingerprint image, which has a well defined frequency and orientation [4].

B. Binary Ridge Image

Binary images are also called bi-level or two-level. This means that each pixel is stored as a single bit i.e. a 0 or 1. Where 0 refers to black and 1 refers to white. Minutiae extraction algorithm is used to obtain the binary ridge image from a gray level fingerprint image. Image enhancement techniques are categorized into two domains.

Spatial Domain refers to the image plane itself, and approaches in this category are based on direct manipulation of pixel in an image

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

Where $f(x, y)$ the input image is $g(x, y)$ is the processed image and T is an operator on f .

Frequency Domain processing techniques are based on modifying the Fourier transform of an image.

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

Where $\Im^{-1}$ is the IDFT, $F(u,v)$ is the DFT of the input image, $F(u,v), H(u,v)$ is the filter function and $g(x, y)$ is the filtered output image.

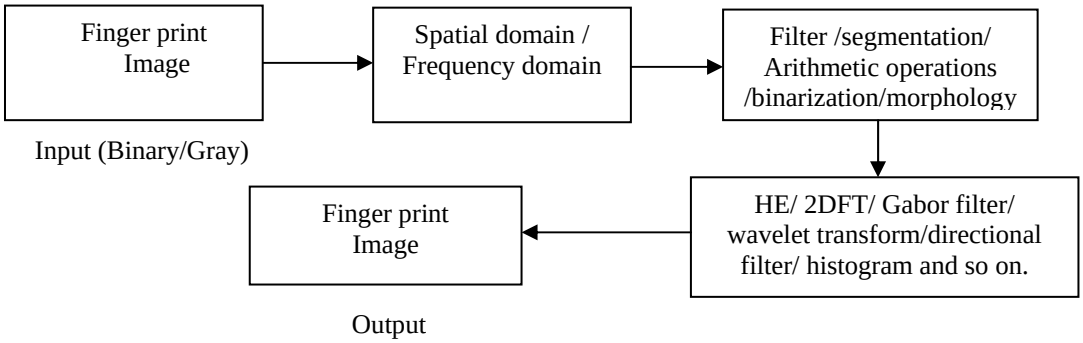

Figure1: Stages of image enhancement process

III. IMAGE ENHANCEMENT USING DIFFERENT TECHNIQUES

A. Histogram Equalization

$$k = \sum_{i=n}^{j} \frac{N_i}{T}$$

Where the sum Σ counts the number of pixels in the image with brightness equal to (or) less than 'j' and T is the total number of pixels.

This approach is aimed to adjust the image intensities by enhancing image contrast and re-assigning the intensity values of pixels to produce an image with uniform intensity distribution value.

- S Greenberg et al. [5] have proposed the following techniques 1.Local histogram equalization, Winer filtering and image binarization 2.Unique anisotropic filter for direct grayscale enhancement. While comparing with other methods, these two techniques have showed significant improvement in the minutiae detection process in terms of either efficiency or time required.

B. Directional Filter

In this technique, the image is divided into eight parts, based on orientation of the ridge structure and implementing the type of band pass filter used to remove the noise from image and reconstructed.

- Haohong Wu et al. [6] have described an anisotropic filter and Directional Median Filter (DMF) for fingerprint image enhancement purposes. Directional median filter is used to join the split fingerprint

ridges, fill out the holes, smooth irregular ridges and remove some annoying small artifacts between ridges. The end results were better than Gaussian-distributed.

- Md.A.U.Khan et al. [7] have described a method called decimation- free directional filter. This method takes the resultant image of Directional Filter Bank (DFB) as an input, since the non-uniform illumination of the original fingerprint image is removed by DFB. The final image is generated by this algorithm on block by block basis by picking and grouping the one that offers highest energy.
- J.Strom Bartunek et al. [8] have proposed directional filter and binarization based method for finger print image enhancement. This technique identifies the required place in the given fingerprint image automatically. By using frequency analysis, the directional filter is designed on the basis of identified local areas of the image. Directional filter and binarization was tested on many fingerprint image taken from the different data bases. The proposed technique experimental result shows a good ability to tune itself for each finger print image.
- Dinesh Kumar Misra et al. [9] have proposed a system of energy minimization principal for fingerprint image enhancement. On this, filter based image enhancement design is proposed, where two distinct filters were used to enhance the image in Fourier domain. One is used to enhance the ridge frequencies and another one to design the ridge direction. Energy minimization principle produces an enhanced image with good quality by selecting certain image features i.e. frequencies and directions, which could minimize the energy function. The proposed method helps to identify the smoothness of feature and the directional filters identify the intensities of image features that measure the energy function required to enhance the fingerprint image. The results explore that it reduces error rates when compared with other techniques.

C. 2D Fourier Transform

$$F(u,v) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)\exp[-j2\pi(ux+vy)]dxdy$$

It is a technique where the input image is transformed from spatial domain to frequency domain. The following steps are involved in this technique: Normalization, Segmentation, Orientation image estimation, 2D Fourier transformation, Butterworth filter, Inverse 2D Fourier transform and reconstruction.

- B.G.Sherlock et al. [10] have described non-stationary directional Fourier filter for finger print image enhancement, where Directional filter is used for finger print smoothing and for orientation matching with local ridge orientation. Threshold value has been used to remove unwanted information from the smoothed version image of directional filter. Experimental result of this technique is significantly better than of AFIS in terms of speed and accuracy.
- Sharat S. Chikkerur et al. [11] have proposed new approaches of Short Time Fourier Transform (STFT) for finger print image enhancement. STFT is used to analyze the non-stationary signals of the fingerprint. This algorithm evaluates all the peculiar features of the fingerprint image such as foreground mask, local ridge orientation and local frequency orientation. This algorithm has done well experimental study in compared with other methods.
- C.Nandini et al. [12] in their work, they have introduced hybrid type of Fingerprint image enhancement where Discrete Fourier Transform (DFT) based adaptive regularized constraint total least-squares de - convolution is performed followed by Discrete Wavelet Transform (DWT) based maximum a posteriori estimator [13]. The proposed approach is tested on standard Bio lab FVC 2002 data sets. Also the Fatal Acceptance Rate (FAR) False Reject Rate (FRR) of the system has been considerably reduced employing the proposed procedures for removing the false minutiae by unifying terminations and bifurcations and aligning the two fingerprints for matching the minutiae pairs. Experimental results on standard datasets show that the proposed method of restoration has provided better improved representation of fingerprint for extraction of the minutiae points which operates iteratively and switches between the two different domains DWT and DFT. This restoration algorithm shows a well convergence. Thus the overall system has shown an increased rate of recognition accuracy of the system especially when the fingerprints are degraded.

D. Gabor Filter

$$g(x,y,\phi,T) = \exp\left(-\left[\frac{x_\phi^2}{\sigma_x^2}+\frac{y_\phi^2}{\sigma_y^2}\right]\right)\cos\left(\frac{2\pi x_\phi}{T}\right)$$

Here,

$$x_\phi = x\cos\phi + y\sin\phi$$

$$y_\phi = -x\sin\phi + y\cos\phi$$

Where ϕ is the orientation of the derived Gabor filter and T the period of the sinusoidal plane wave.

In this technique is used to remove the noise and preserve the ridge structure.

- L. Hong et al. [14] have a proposed to enhance the finger print image using one type of feature i.e. Image extraction module. When the applied estimated local ridge orientation and frequency, the input finger print image get good quality of ridge and valley structure. In each pixel applied the Gabor filter. The image is judged based on extracted minutiae feature and online verification system. In this author carried out the same, above performances in this proposed algorithm
- Byung- Gyn Kim et al. [15] Image normalization and Gabor filter techniques are used to enhance the finger print image. Here two methods are used to enhance the finger print image. Firstly used in adaptive normalization, it's based on block processing, so input image is partitioned into sub-block with K*L size and Region of Interest (ROI) of the image is acquired. Secondly taking a two parameter form Gabor filter for enhance the finger print image. This algorithm is compare with NIST and significant improvement in the experiment.
- Jianwei Yang et al. [16] have done by the novel filter design method for fingerprint image enhancement. The author has inspired from Traditional Gabor Filter (TGF), is called the Modified Gabor filter (MGF). The MGF has been used for fingerprint enhancement. The modification of the TGF can make the MGF more accurate in preserving the fingerprint image topography. A new scheme of adaptive parameter selection for the MGF is discussed. This scheme leads to the image-independent advantage in the MGF. Experimental results shows can reduce the FRR of a fingerprint matcher by approximately 2% at a FAR of 0.01%.
- Xue Jun-Tao et al. [17] have described an enhancement algorithm based on edge filter and Gabor filter. It's used to solve the different type of finger print images. Here three methods are used to enhance the finger print image enhancement. First one is gray-based algorithms purpose of enhance the edge and segmentation of the image. Secondly a multi level block size method is needed to extract the orientation field from segmented fingerprint image. Finally, Gabor filter is used to fulfill the enhancement of the fingerprint image. This explained algorithm is better than normal Gabor filter. So it is useful for the subsequent research, such as classification, feature exaction and identification.

E. LPD (Laplacian-Based Pyramidal Decomposition)

Laplacian-based pyramidal decomposition techniques are depends on quality of the input image from original image and to increase the recognition rate to ensure low error rate.

- H. Fronthaler et al. [18] have planned to enhance the quality, and improve the recognition of the finger print image. In this method, processing decompose the original fingerprint image into 3 smaller images, corresponding to different frequency bands. The continue process contextual Filtering is performed using these pyramid levels and 1D Gaussians, where the corresponding filtering directions are derived from the frequency-adapted structure tensor. It is continuous on spatial domain approach avoiding block artifacts while conserving the biometric signal well. It does thereby not suffer from blocking artifacts. Both absolute frequency and orientation it's used to enhance this method. The results on the 4FVC2004 databases are favorable to the suggested enhancement method.

F. Fuzzy Approaches

A fuzzy set A in a finite set $X = \{x_1 x_2 ..., x_n\}$ may be represented mathematically as:

$$A = \{(x, \mu_A(x) \mid x \in X\}$$

Where, the function $\mu_A(x) : X \rightarrow [0\ 1]$ is measure of degree of belongingness or membership function on an element x in the finite set X and the measure of non-belongingness is $1 - \mu_A(x)$.

There are some fuzzy inference techniques, such as Mamdani, Sugeno and Tsukamoto for fingerprint image enhancement.

1. Mamdani are used to the choice of T-Norm and T-Conorm operators can be max-min and max-product [19] 2. Sugeno fuzzy inference are used to polynomial (degree 0 and 1) equations and finally calculating weighted average [20] 3.Tsukamoto are used to fuzzy rules, while the enhancement process of Fuzzification and Defuzzification and finally calculated the weighted average. A Tsukamoto fuzzy model aggregate each rule's output by the method of weighted average and thus avoids the time-consuming process of Defuzzification [21].

- Vijay Kumar Sagar et al. **[**22] have proposed a method of fuzzy- neuro technology in automated fingerprint recognition for the extraction of fingerprint feature is called minutiae. The results showed that on average, the fuzzy neural approach is a better alternative. The hybrid fuzzy and neural network model performs the minutiae extraction in two stages, a fuzzy front-end and a neural back-end. By such a separation, designing and training of the neural Networks can be done in isolation. In addition, other

neural networks can be investigated and used instead of the back-propagation networks. To conclude, using the fuzzy neural hybrid model, fingerprint minutiae extraction is more accurate since fewer false minutiae are identified and more true minutiae identified.

- D.Bennet et al. [23] in this paper Discrete Wavelet Transform and singular value decomposition (SVD) has been proposed. This technique is compared with three other techniques namely, conventional image equalization technique, general histogram equalization and local histogram equalization. A significant contrast between ridge and valley of the best, medium, Poor images are to extract quality images rate using fuzzy measures. So many methods are implemented and to compare the outputs of the SVD, DWT and Fuzzy Measures method is more accurate contrast enhancement compare to Otsu method. After the results analysis is conclude that the proposed approach presents a higher performance for a large number of tested images.
- K.Sirinivasan et al. [24] have proposed an efficient and robust fingerprint image enhancement using fuzzy based filtering. In this work fully aimed to removing noise as well as for improving the luminosity of the ridges. The fuzzy filter values are evaluated and supervised. The probability of gray level values is measured according to input image pixel. This proposed filter techniques method are implemented in MATLAB. The proposed algorithm is used to improve the transparency of ridge and valley structure of the input image. Proposed technique has solved the problem of narrow and wide gray range images better than another technique. This algorithm tested with different type of fingerprint images and the result has shown that the quality of the generated images was very high with less noise.
- Roil Bansal et al. [25] have applying Type-2 fuzzy logic to fingerprint image enhancement when the input is pre-processed by the Hong's algorithm. In this paper were implementing in MATLAB versions 7.3.0 on the windows XP operating system. More than 50 input images are first input to an implementation of the Hong's algorithm, to enhance them. For comparison of results, quality is observed at three points: 1. initially, with the image which is not enhanced. 2. When the image is passed through Hong's algorithm and then type-1 Fuzzification is applied. 3. When type-2 Fuzzification is applied on the image after it has been passed through the Hong's algorithm. The proposed algorithm experimental result shows measured the fuzzy quality visually and quantitatively to note the effective.

G. Latent Fingerprint Enhancement Technique.

Latent Fingerprint Image Quality (LFIQ) that can be useful to reject the Latents which cannot be successfully identified the "lights-out" mode.

- Soweon yoon et al.[26] have proposed new fingerprint image enhancement technique is called the latent, which is requires manually marked Region Of Interest (ROI) and one of the fingerprint feature is called singular points. The main theme of algorithm is novel orientation field estimation algorithm, which fits orientation field model to coarse orientation field estimation from skeleton outputted by a commercial fingerprint SDK. The experimental results on latent fingerprint enhancement database shows matching accuracy was significantly improved better than other methods.

H. Combined Methods.

The following study shows combined in many techniques; these techniques all are fully used to enhance the fingerprint image.

- Choudhary et al.[27] the frequency and spatial domain filtering, local orientation estimation, local frequency estimation and morphological methods are used to adaptively improve the clarity of ridge and furrow structure of input fingerprint image. The randomly selecting 100 fingerprint images without repetition from database DB-finger, purpose of testing for this algorithm. The experimental result shows improve the quality of fingerprint images.
- I.G. Babatunde et al. **[**28] have described a new and improved version is called the sub-models of an existing mathematical algorithm for fingerprint image enhancement. This new version include different type of mathematical model for fingerprint image segmentation, normalization, ridge orientation estimation, ridge frequency estimation, Gabor filter, binarization and thinning. MATLAB and WINDOWS HOME BASIC OPERATING SYSTEM are used to implementing in this technique. This method result shows significant improvement over the original versions and necessity of each level of the enhancement.
- Tanaya Mandal et al. [29] have proposed a method is called Digital Curvelet Transform for fingerprint image enhancement based on feature extraction. Enhanced fingerprint images act as the feature-set for a K-nearest neighbor classifier extracted to the Curvelet coefficient. The method is checked on a small database of 120 images. This method is also compared with Wavelet-based technique. It's better than small scale fingerprint recognition system.

- Andelija et al. [30] have proposed an adaptive filter in frequency domain for fingerprint image enhancement. To achieve this algorithm the query images is first normalized to have desired mean and variance. The image is divided into non-overlapping blocks using subsequent process. For dominant ridge orientation is determined for each block. The dominant ridge directions are the smoothed and subsequently the block-direction is formed and estimate the average ridge distance. Here two different types of filters are used and compared. The main purpose of this method is enhancement process should increase the contrast between ridge and valley and remove the noise in image. The experimental result is better than AFIS accuracy.
- Sepasian et al. [31] have proposed a three- step procedure for the fingerprint enhancement using Contrast Limited Adaptive Histogram Equalization (CLAHE) together with clip limit, standard deviation and sliding neighborhood as the stages while processing of the fingerprint images. During the process in this method following three stages, one is applied the contrast to the small tiles and eliminate the artificially, induced boundaries existing in the fingerprint image. The second step is distinct array is decomposed and computing the standard deviation of the matrix to remove the image background. In final step is neighborhood processing, it's used to thinning. This paper fully investigated in simulation only.

IV. ISSUES AND CHALLENGES ON FINGERPRINT IMAGE ENHANCEMENT

- Factor that will affect / impact finger print capture process.
- One of the open issues in fingerprint verification is the lack of robustness against image quality degradation.
- Poor quality images result in spurious and missed features, thus degrading the performance of the overall system.
- Recent issue in fingerprint recognition is the use of multiple sensors, either for sensor fusion or for sensor interoperability.
- Another recent issue in fingerprint recognition is the use of multiple sensors, either for sensor fusion or for sensor interoperability.
- Recent studies have shown the vulnerability of fingerprint systems to fake fingerprints. Surprisingly, fake biometric input to the sensor is shown to be quite successful.

V. DIRECTIONS FOR FURTHER RESEARCH

Though, Image enhancement techniques have been used in many applications such as Medical, Security and more, security is one of the primary research objectives for enhancing the original image. In the recent years, fingerprint registration have become more popular in identifying a person; be it on banking applications, Prisons, Bio-metric identity cards and so on. Therefore, developing strategies and algorithms for fingerprint enhancement, which could support more real-time applications would be an ideal choice for conducting the future research

VI. CONCLUSION

Analyses of fingerprint image enhancement techniques are exhausted by spatial domain, frequency domain and fuzzy model so far. Spatial domain, in particularly, Gabor filter enhancement techniques are used in so many researchers, because of time consuming and parameter selection such as ridge centre frequency, radial bandwidth and central orientation, feel necessity for is factual system. Very few work succeeded in image enhancement features namely ridge orientation, ridge frequency and singular points and also fuzzy in depth intuitionistic fuzzy. Fingerprint image enhancement techniques for this purpose such as segmentation, filtering, binarization and morphology. In final conclusion, histogram equalization enhancement technique result is shows good quality better than other technique.

REFERENCES

[1] Dines kumar Misra, Dr.S.P.Tripathi,Dipak Misra, "A review report on fingerprint image enhancement technique,"volume 2,Issue 2, pp224-230, March-April 2013
[2] M.Manju,V.Kavitha, "Survey on fingerprint image enhancement techniques," international journal of computer application, volume 62.No.4,January 2013.
[3] Rafael C.Gonzalez Richard E.woods, "Digital image processing," Second edition,Prentice Hall ,2007.
[4] Purneet Kaur , Jaspreet Kaur , "A review report on fingerprint image enhancement with different methods," International journal of modern engineering research, vol.3,Issue.4,pp-2424-2428, Jul-Aug.2013.
[5] S.Greenberg, M.Aladjem, D.Kogan, and I.Dimitrov,"Fingerprint image enhancement using filtering techniques," International conference on pattern recognition, Vol. 3, pp. 326–329,2000.
[6] Chaohong Wu, Zhixin Shi and Venu Govindaraju, "Finger print image enhancement method using directional median filter," Elsevier Science, pp. 250-256, 2004.
[7] Mohd. A.U.Khan, M. Khalid Khan, M.Aurangzeb Khan, "Fingerprint image enhancementusing decimation-free directional filter bank,"Information technology journal, Vol. 4, no. 1,pp.16-20, 2005.
[8] J.Strom Bartunek, M. Nilsson, J. Nordberg and I.Claesson, "Adaptive fingerprint binarization by frequency domain analysis,"IEEE transaction,pp.598-602,2006.
[9] Dinesh Kumar Misra, Dr.S.P.Tripathi, "Fingerprint image enhancement based on energy minimisation principle," International Journal Of Computer Science And Communication, Vol.3, no.1, pp.165-170, 2012.

[10] B.G.Sherlock, D.M.Munro, and K.Millard,"Algorithm for enhancing fingerprint images,"Electronics letters,Vol.28, no.18, pp.1720-1721,1994.
[11] Sharat S. Chikkerur, Alexander N. Cartwright and Venu Govindaraju, "Fingerprint image enhancement using STFT Analsis" ,Pattern recognition,Vol.40,pp.198-211,2007.
[12] C.Nandini,C.N.Ravikumar, "Improved fingerprint image representation for recognition," International journal of computer science and information technology, MIT Publication, Vol. 01, no.2, pp.59-64, 2011.
[13] S.M. Mabubur Rahman, M.Omair Ahmed, M.N.S. Swamy, "Improved image restoration using wavelet-based de noising and fourier–based de convolution," IEEE Xplore, pp 249-252, 2008.
[14] L. Hong, Y. Wan, A. Jain, "Fingerprint image enhancement: algorithm and performance evaluation," IEEE trans. Pattern analysis & machine intelligence, Vol. 20, no.8, pp.777-789, 1998.
[15] Byung-Gyu Kim, Han-Ju Kim and Dong-Jo Park, "New enhancement algorithm for fingerprint images,"IEEE proceedings, Vol.4651,no.2, pp. 1051-1055, 2002.
[16] J.Yang, L.Liu, T.Jiang, Yong Fan, "An improved method for extraction of fingerprint features," In: Proc. 2nd ICIG, SPIE, Vol. 4875, no.1, pp. 552–558, 2003.
[17] Xue Jun-tao, Liu Jie & Liu Zheng-guang, "Anenhancement algorithm for low quality fingerprint image based on edge filter and gabor filter," Proc. Of SPIE, Vol. 7383,2009.
[18] H. Fronthaler, K. Kollreider and J. Bigun, "Pyramid based image enhancement of fingerprints," Halmstad University, SE-30118, Sweden,2007.
[19] E.H.Mamdani and S.Assilian, "Application of fuzzy algorithms for control of simple dynamic plant," Proceedings of. IEEE vol. 121, pp.1585-1588.1974.
[20] M.Sugeno, and G.T. Kang, "Structure identification of fuzzy model, Fuzzy sets and systems," Vol. 28, pp. 15-33,1988.
[21] Y.Tsukamoto, "An approach to fuzzy reasoning method," In Madan M. Gupta, Rammohan K. Ragade and R. Yager Edts.Advances in fuzzy set theory and applications, North-Holland, Amsterdam, pp. 137-149,1979.
[22] Vijay Kumar Sagar and Koh Jit Beng Alex, "Hybrid fuzzy logic and neural network model for fingerprint minutiae extraction,"IEEE Transaction, 7803, pp.3255-3259, 1999.
[23] D.Bennet and Dr.S.Arumuga Perumal,"Fingerprint: DWT, SVD based enhancement and significant contrast for ridges and valleys using fuzzy measures,"Journal of computer science and engineering, Vol. 6, no.1, pp.36-42, 2011.
[24] K. Srinivasan, C. Chandrasekar, "An efficient fuzzy based filtering technique for fingerprint image enhancement," International journal of computational intelligence and informatics, vol.1:No.1,pp.48-57, Apirl-June 2011.
[25] Roil Bansal,Payal Arora,Malvika Gaur,Priti Sehgal,PunamBedi "Finger print image enhancement using type-2 fuzzy set," proceeding of the sixth international conference on Fuzzy system and knowledge discovery,IEEE, DOI 10.1109/FSKD.396,2009.
[26] Soweon Yoon, Jianjiang Feng and Anil K. Jain, "On latent fingerprint enhancement," Michigan State University, MI 48824, USA,2010.
[27] J.Choudhary, Dr.S.Sharma, J.S.Verma, "A new framework for improving low quality fingerprint images," international journal of computer technology and application. Vol.2, no.6, pp.1859 -1866,2011.
[28] I.G.Babatunde, A.O.Charles, A.B.Kayode and O.Olatubosun, "Fingerprint image enhancement: segmentation to thinning," International journal of advanced computer science and application.,Vol.3,no.1, pp.15-24,2012.
[29] Tanaya Mandal and Q. M. Jonathan Wu, "A small scale fingerprint matching scheme using digital curvelet transform,"IEEE Conf. on SMC, pp.1534-1538,2008.
[30] Andelija M. Raicevic and Brankica M. Popovic, "An effective and robust fingerprint enhancement by adaptive filtering in frequency domain," FACTA Universities conference,Vol.22,No.1,pp.91-104,2009.
[31] M. Sepasian, W. Balachandran and C. Mares, "Image enhancement for fingerprint minutiae- based algorithms using CLAHE, standard deviation analysis and sliding neighborhood," Proceedings of the World Congress on Engineering and Computer Science San Francisco,USA,October22-24,2008.