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Research paper



Fingerprint enhancement using modified short-time fourier transform

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Abstract

In this paper, a Modified Short-time Fourier Transform (M-STFT) fingerprint enhancement technique for non-stationary ridges has been proposed. It improves the local section of image as the fingerprint ridges fade or change with the passage of time. Freely available database (FVC2002 DB3) was used to evaluate the method. To choose the appropriate process window, various experiments on a subset of database were performed. The proposed approach based on the use of Tukey window analyses the transient data more effectively compared with other windows. The non-stationary nature of images are more efficiently enhanced using Tukey window. This scheme not only promises better fingerprint enhancement but also results in lesser computational cost than the existing methods.

Keywords: *Fingerprint Enhancement; Ridges; Window; Non-Stationary; M-STFT.*

1. Introduction

Recognition and authentication of person on the basis of biometrics has become very common now. When the individual's biometric resources are linked to authentication, the probability of fraud decreases substantially. A biometric system is mainly a pattern recognition system which is used for secure access to buildings, cellular phones, and ATMs etc. Fingerprint is one of the best technologies among all the biometric techniques and has been used for the user's authentication for a long time because of its wide recognition and dependability. Its patterns play a wide role in user authentication. Fingerprint verification should be done in such a manner is not sacrificed for image quality. In case of weak or unclear image, the enhancement of fingerprint is needed this is helpful in user recognition. Also, due to old age or wound, fingerprints are not visible and need to be enhanced with techniques which improve the accuracy of biometric system. Earlier, various researchers have used Fourier Transform for the image enhancement when the amplitude and phase is constant with time. The major drawback with frequency domain processing is that simultaneously, spatial information of the image is not made use of. In 1946, Gabor adapted the Fourier transform to analyse only a small section of the signal at a time, a procedure called windowing the signal. Gabor's adaptation, called the Short-Time Fourier Transform (STFT), STFT is very common technique used for enhancing poor quality images. This section recapitulates the literature on fingerprint and explains various enhancement techniques used for quality improvement of identification system.
Various research papers were reviewed for fingerprint enhancement. Based on the survey of research papers on fingerprint enhancement, it was observed that prior works were based on the minutiae points, singular points and many other techniques. The individuality of the fingerprint is judged by its ridge characteristics, so clear ridges play an important role in identifying individual identity. When the ridge characteristics are not correctly identified, minutiae extraction algorithms fail to extract the minutiae properly. The prior work enhanced the image quality at the cost of missing genuine minutiae and non-existence minutiae were extracted many a time. A brief overview of important contributions on fingerprint enhancement and their features are given in Table 1. Focus in this paper is to bring out a technique which is simple and less time consuming and does not miss the genuine minutiae and is, therefore, robust.
This paper is arranged as follows: Section 2 describes the proposed methodology. This consists of pre-processing of fingerprint image, proposed M-STFT scheme, the detailed description of local region in fingerprint image, ridge frequency image, the region mask, the image orientation related to coherence image and image smoothening. Further, Section 3 reports the experimental results along with discussion which gives quantitative values corresponding to proposed pseudo code and provides a comparative analysis of the results. Section 4 concludes the paper.

2. Methodology

2.1. Pre-processing of fingerprint image

In this work, database from the website of Fingerprint Verification Competition (FVC2002) freely available at http://bias.csr.unibo.it/fvc2002/download.asp has been used. This

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database contains 800 images out of which a subset containing 8 images of 10 users each is taken [16].

Table 1: Review of the Literature on Fingerprint Enhancement

Ref No	Contribution	Enhancement Technique used	Key Features
[1]	Mehtre et.al (1987)	Spatial domain enhancement	works only on grayimages; fails to give good results on low contrast images
[4]	Sherlock et. al (1994)	Directional Fast Fourier Transform	· removes desirable true minutiae gives better results compared to Mehtre et al (1987).
[15]	Yang et. al (2003)	Modified Gabor Filter (MGF)	An isotropic Gaussian filter is used to remove noise. • Higher • computational cost of the MGF.
[8]	Rahman et. al (2004)	MSR with Color Restoration algorithm	extracts the images efficiently at the cost of naturalness.
[12]	Govindraju et. al(2007)	STFT	misses genuine minutiae
[10]	Oliveira et. al (2008)	Multiscales with morphological operator	• used to find the orientation of images. • used to reconnect the broken ridges. • time consuming and complex.
[5]	Yong et. al (2010)	Principal Component Analysis	good results on binary images only.
[6]	Sawant et. al (2010)	Spatial domain technique	high computational cost.
[7]	Wang et. al (2011)	Multi-Scale Retinex (MSR)	preserves the halo effect at the cost of missing information.
[11]	Dhanabal et. al (2013)	Gabor filter	provides more security but computation time is high.
[13]	Bahgat et. al (2013)	Fast and accurate algorithm	Distortion error causes error in orientation map.
[14]	Ambadiyil et. al (2014)	create a unique ID using core point of fingerprint	missing minutiae points & difficulty in generating ID.
[2]	Sowjanya (2017)	artificial intelligence tectechniques	it enhances only gray images
[3]	Parkavi (2017)	Multimodal technique	reduced false matching and non matching rates.

To enhance images which are non-stationary in nature, a transformation is needed which can handle transient nature of image effectively. Researchers have largely used Fourier transform for this purpose. However, as the Fourier transform cannot take the inherent variation of parameters of poor quality fingerprint images existing in both space and time, the results obtained by this technique are not encouraging so far. Short-time Fourier Transform is better in such situations because here, the image is divided into small segments and Fourier transform is performed on each segment for a short period of time with a fixed window length. To evaluate the proposed method, we used freely available database http://bias.csr.unibo.it/fvc2002/download.asp. This database contains 800 images out of which we have taken a subset containing 8 images of 10 users each [16]. In this process, the dc component (mean value) of the image is calculated very effectively as discussed in [12].

The image is divided into overlapping windows assuming that fingerprint image is stationary for that specified short interval of window. The General Block diagram is shown in Fig 1 for the proposed scheme.

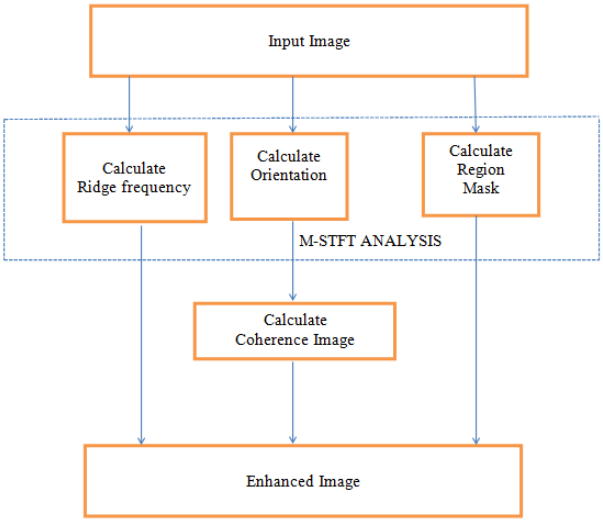


Fig. 1: General Block Diagram of Proposed Scheme.

2.2. Proposed modified-STFT (M-STFT) scheme

STFT partitions a long time signal into short segments of equal length and then computes the Fourier transform on each short segment separately. STFT provides information about time interval of the occurrence of a signal event and the corresponding frequencies. As the window size of STFT is fixed, information can only be obtained with limited precision. When a long window is used, the frequency resolution is higher and the time resolution is lower. The situation is reversed when a short window is used. To overcome this issue of compromise between time and frequency information, a different window function [17] known as Tukey window has been used in the proposed modified-STFT (M-STFT). The use of Tukey window can be used to handle image transition more effectively than STFT.

A two-dimensional Short-time Fourier Transform of an image f(t) is described as:

$$STFT_f^u(t',u) = \int \left[f(t).W(t-t')e^{-j2\pi ut} \right] dt \quad (1)$$

Where W (t-t')is the window function centered at t = t'. At each location of the window, it overlaps the pixels with the previous pixels' location to sustain the ridge continuity and limits the blocking effect, which is common with other block-processing operations. At every position, we get a single value for an orientation and the frequency of that particular region is centered at its t = t'.

Tukey Window [17] is used in the proposed work. It is also known as cosine-tapered window. It is best imagined as a cosine lobe of width (αN/2) convolved with a rectangle window of width (αN/2) N. The window ranges from the rectangle to the Hanning Window as the parameter (α varies from 1 to 0). At α =1, it becomes rectangular and at α =0, it becomes a Hanning window. The window is defined as given in Eq. (2):

$$w(n)=\begin{bmatrix} 1 & , & 0\le n\le \frac{\alpha N}{2} \\ 0.5\left[1+\cos\left[\pi\frac{n-\frac{\alpha N}{2}}{2(1-\alpha)\frac{N}{2}}\right]\right] & , & \alpha\frac{N}{2}\le n\le\frac{N}{2}\end{bmatrix} \quad (2)$$

Where α is the ratio of the total length of the cosine tapered section to the whole signal length, N is the length of window, n=0, 1, 2, 3, 4…….N-1 and w (n) is the window function.

2.3. Local region capturing

Feature is characterized into two types - local feature vector and global feature vector. Global feature vector is used to describe an entire image and cannot be seen with bare eyes, such as ridge pattern, curvature, orientation etc. Any specific location of an image describes the local feature vector which gives information about local region, for example, minutiae points. Local features are invariant in comparison to global features. However, there may be cases when two or more impressions of the same finger have indistinguishable global features but still differ from each other because they have local features (minutiae points) that are dissimilar.

The fingerprint local region, can be accessed as a surface wave (f, θ) using orientation (θ) as well as frequency (f) using Eq. (3).

$$I(x,y)=A\{\cos(2\pi f(x\cos\theta+y\sin\theta))\} \quad (3)$$

The constraints of surface wave can be achieved from the Fourier spectrum that has two impulses giving information about frequency as well as orientation component of the wave. But these methods result into errors so we converted it into polar form which contains magnitude as well as phase angle of the image. The Fourier spectrum of the fingerprint image is calculated across all frequencies and ridge orientations and ridge frequencies.

2.3.1. Ridge orientation

Assume that the orientation, E (θ) is a random variable which has the probability density function p (θ). The expected value of the orientation is calculated by performing a vector averaging according to Eq. (4).

$$E(\theta)=\frac{1}{2}\tan^{-1}\left\{\frac{\int p(\theta)\sin\theta\,d\theta}{\int p(\theta)\cos\theta\,d\theta}\right\} \quad (4)$$

The various probabilities used in this equation are given in Eq. (5), (6) and (7). The advantage of doing vector averaging is that it eliminates the noise from the images.

$$p(\theta)=\int_r p(r,\theta)dr \quad (5)$$

$$p(r)=\int_\theta p(r,\theta)\,d\theta \quad (6)$$

$$p(r,\theta)=\frac{|F(r,\theta)|^2}{\int_r\int_\theta|F(r,\theta)|^2)drd\theta} \quad (7)$$

Where F (r, θ) is the Fourier spectrum, p (r, θ) is the joint probability density function and p (θ), p (r) are the marginal density functions.

Ridge orientation is calculated with respect to the orientation of its immediate neighbourhood. It is only calculated where ridges are present and is denoted by O (x, y) of Eq. (8).

$$O(x,y)=\frac{1}{2}\left\{\frac{\tan^{-1}Sin2\theta(x,y)*f(x,y)}{Cos2\theta(x,y)*f(x,y)}\right\} \quad (8)$$

Where f (x, y) is the Gaussian smoothing kernel. Mostly, it is chosen to be 3 × 3, because it provides better results than the bigger kernel size.

2.3.2. Ridge frequency image

It is calculated like the orientation of the fingerprint image. It is assumed to be a random variable with the probability density function, p (r) as in Eq. (9).

$$F(r)=\int_r p(r)rdr \quad (9)$$

After obtaining the frequency map, process of anisotropic diffusion is applied this reduces the noise by keeping significant parts of the image intact.

2.3.3. Energy image

The energy content in the Fourier transform is much less when the area of the background of the fingerprint image is a noisy region. It indicates the energy portion of the corresponding region as shown in Eq. (10). The fingerprint region is calculated by differentiating the background of the image by thresholding the energy image, E (x, y)

$$E(x,y)=\log\left\{\int_r\int_\theta|F(r,\theta)|^2drd\theta\right\} \quad (10)$$

The region mask is obtained by thresholding, which is calculated by Otsu's optimal thresholding [18]. With the help of a region mask, we are able to determine the area where the ridges are present.

2.4. Coherence image

The block processing approaches are associated with a lack of continuity in the ridge flow at the boundaries of the block. This is more problematic in regions where area is of high curvature and is nearer to the core, and deltas have more than one dominant direction [21]. To counteract this problem, [4] used a singular point position which is obtained from the orientation. [19] suggested a map which displays the noise in the images. Our main concern, however, is on flow-orientation [19], which is more robust than a method proposed in [20]. The main focus of the coherence image is to check the correlation between the two images. The coherence related to the dispersion measure of the circular data is expressed in Eq. (11). The coherence is high when both orientation of the central block and its neighboring block resemble.

$$C(x,y)=\frac{\sum(i,j)\in W|\cos(\theta(x_o,y_o)-\theta(x_i,y_i))|}{W\times W} \quad (11)$$

Where (x_o, y_o) is the orientation of central block and (x_i, y_i) is that of the neighbouring block.

After STFT, the image is enhanced using an energy image along with image orientation. The ridge frequency of the image is calculated. With the help of energy image, the background and the fingerprint part of the image are separated. The angular coherence of the image is calculated using image orientation. Smoothening is done after calculating the ridge frequency, then the boundaries of the fingerprint-foreground region are obtained using isotropic diffusion (noise smoothening). Coherence image is calculated. After thresholding, image passes through an enhancement process by simultaneously finding an angular and a radial filter. Thus, by applying Fourier Transform, image is converted into frequency-domain. This allows one to find the frequency components present

in the image, which can be evaluated to enhance the image. The Inverse fast Fourier Transform (IFFT) converts the image back into time domain; this causes the non-stationary ridges of the image to be enhanced. This process is repeated continuously on all the images until all of the images are enhanced. The flowchart is shown in Fig. 2. The performance of the system is calculated via comparing the proposed technique with existing method using proposed pseudo code explained in Fig. 3.

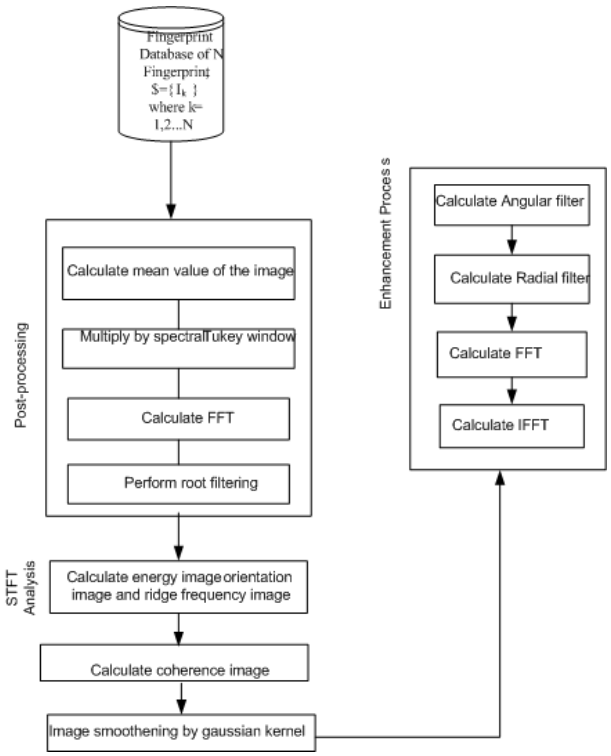


Fig. 2: Flowchart for Proposed Fingerprint Enhancement Scheme.

2.5. Enhancement of smoothened image

STFT encompasses ridge orientation image, the ridge frequency image, and the block energy stages. Ridge orientation and ridge frequency image change very gently through the image. Therefore, the orientation image is rarely calculated at full-resolution whereas ridge frequency image is calculated only once for each non-overlapping blocks of the image. STFT is liable for calculating all the intrinsic images of the fingerprint. In this process, fingerprint image is divided into analogous windows assuming that the image is stationary within the small window. Then, analysis phases are done with all the operations to implement contextual filtering. The transformed result is converted into the original image by an IFFT. Finally, the image is enhanced, and all of the other images are checked to see if they are also enhanced. Output at every stage by selecting tapering length α=0 and α=1 is shown in Fig.4, Fig.5 and Fig.6.

Proposed Pseudo Code for calculating ridge discontinuity in Fingerprint Image	
STEP 1:	Declare the images - input, $I_i(x_i,y_j)$ as well as enhanced image, $I_e(x_i,y_j)$.
STEP 2:	Perform binarization on both the images
STEP 3:	Calculate ridge discontinuity in input image, If $I_i(x_i,y_j)$ is equal to 1
STEP 4:	Calculate ridge discontinuity in input image. Calculate white pixel in input image.
STEP 5:	Repeat STEP4 same for enhanced image using proposed technique and check $I_e(x_i,y_j)$ is equal to 1.
STEP 6:	STEP 4 is again repeated for enhanced image obtained using existing method and check the ridge discontinuity in enhanced image.
STEP 7:	Calculate the ridge continuity improvement percentage in both the images. Improvement using existing method=input image - output obtained using existing approach; Improvement using proposed method=input image - output obtained using proposed approach;
STEP 8:	Tukey(proposed)enhancement percentage=(Input image -Tukey(proposed))*100; STFT(existing)enhancement percentage=(Input image- STFT(existing)) *100;
STEP 9:	Tukey (proposed) enhancement= $\frac{\text{Tukey(proposed)enhancement percentage}}{\text{Input Image}}*100$ STFT (existing) enhancement= $\frac{\text{STFT(existing)enhancement percentage}}{\text{Input Image}}*100$
STEP 10:	Overall fingerprint enhancement=Tukey (proposed) enhancement - STFT (existing) enhancement.

Fig. 3: Pseudo Code for Ridge Discontinuity of Fingerprint Image.

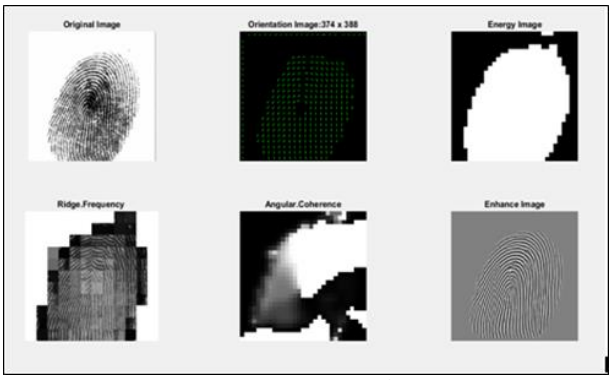


Fig. 4: M-STFT Enhancement Phases of Input Image at A=1.

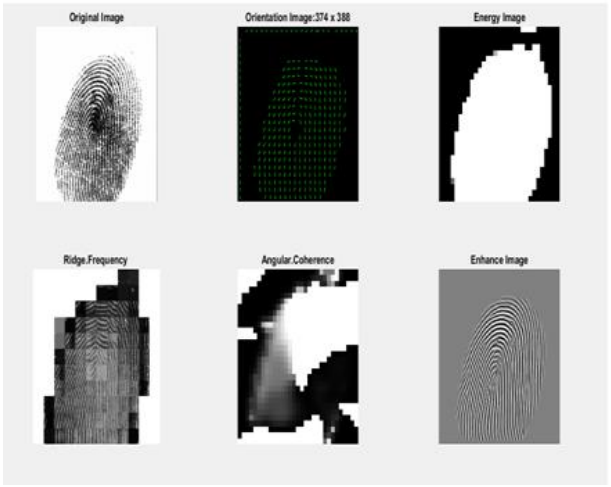


Fig. 5: M-STFT Enhancement Phases of Input Image at A=0.

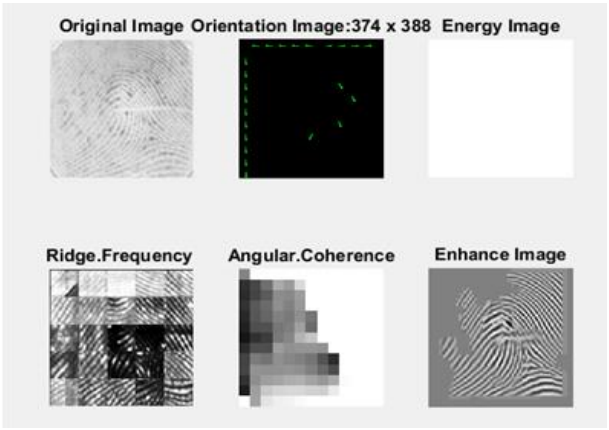


Fig. 6: M-STFT Enhancement Phases of Input Image at A=1.

3. Experimental results and discussion

Performance and validation of the proposed technique was done by comparing the results with enhancement of the non-stationary ridges using STFT [12]. The window used in our technique is different from a raised cosine window that is used in [12].

The input image is shown in 7 (a). Enhancement is done first using technique used in [12]. Fig. 7 (b) shows enhanced image using [12]. Then input image is enhanced using the proposed technique described in flowchart of Fig. 1 with tapering length α=0 (rectangular window). Fig. 7 (c) shows the enhanced image using proposed technique with α=0. Comparison of the two approaches is done according to the proposed ridge discontinuity pseudo code of Fig. 3. It was observed that on average, ridge breakage is 1.1661% times improved than as demonstrated by [12]. Various set of experiments are performed on database [16] for choosing appropriate window.

The database shows remarkable performance using proposed window in terms of recovery of poor quality images where the ridges are not present. A subset of total database is chosen for testing and validation of proposed technique where the proposed technique gives improved performance.

Similar analysis was carried out for α=1 (Hanning Window).

Fig. 8 shows the enhanced image using proposed technique in this case. Again, comparison was done with [12]. It was seen that extraction of the minutiae in Govindaraju et.al work is difficult as they have missed the genuine minutiae whereas proposed technique gives much better results in this case also. On the average, by selecting tapering length α=1, the ridge discontinuity is 6.5112% improved when compared with the method presented by [12], the existing approach.



Fig. 7: A) Input Fingerprint Image.

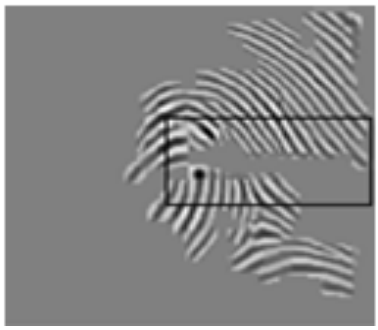


Fig. 7: B) Image Enhancement Using [12].

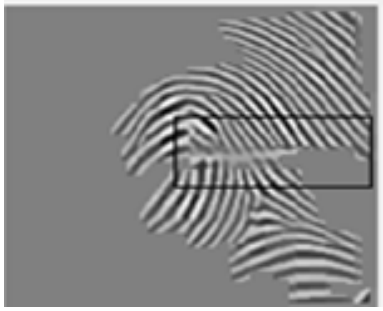


Fig. 7: C) Proposed Technique Using A=0 Shows Enhanced Recoverable Area Overlapped by Corresponding Input Image.



Fig. 8: Proposed Technique Using A=1 Shows Enhanced Recoverable Area Overlapped by Corresponding Input Image

4. Conclusion

The performance of a fingerprint feature extraction and the enhancement of the fingerprint image significantly depend upon the quality of the image. The fingerprint enhancement algorithm based on M-STFT analysis with the Tukey Window by varying tapering length 0 to 1 and the use of non-stationary filtering in the Fourier domain has been presented. This algorithm has numerous advantages over the techniques discussed in literature such as ridge orientation and the ridge frequency. The region masks of the fingerprint image are calculated simultaneously from STFT analysis.

The existing latest technique presented by Govindaraju et. al uses raised cosine window whereas the proposed technique makes use of Tukey window. Comparison with [12] shows 1.1661% improvement by the proposed method when tapering length α=0. At tapering length α=1, the proposed work shows 6.5112% improvement in recoverable images. Moreover, this technique is more suitable for poor quality images. In a nutshell, the proposed technique is more competent in enhancing genuine images than existing methods.

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