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A Comparative Analysis on Fingerprint Binarization Techniques

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***Abstract*- The robustness of a fingerprint authentication system depend on the quality of the binarized fingerprint image. Since the uniqueness of a fingerprint image is determined by the minutiae points which are extracted from a binarized fingerprint image. A very robust binarization process is therefore essential to get the correct set of minutiae points. Thresholding is an effective tool for binarization. In this paper rough set based method is compared with traditional Otsu's method for binarizing the fingerprint image. The experiments have been conducted on the fingerprint databases FVC2002 and FVC2004. The quantitative metrics such as Relative foreground Area Error (RAE), F-Measure are used to evaluate the performance of the binarization algorithm. Adaptive local threshold based on the mean is used to construct the reference image for RAE computation. The RAE, F-measure of the rough set based method is improved when compared with the Otsu's method.**

Keywords- Binarization, Fingerprint, F-Measure, Otsu, RAE, Rough Entropy, Rough Set

I. INTRODUCTION

Biometric authentication refers to verifying individuals based on their physiological and behavioral characteristics. Nowadays biometric technologies are widely used in many applications for various purposes of personal authentication. Biometric methods provide a higher level of security and are more convenient for the user than the traditional methods of personal authentication such as passwords and tokens [1]. Among all the biometrics, fingerprint is a great source for identification of individuals. Fingerprints have been used in Forensic Science for a long time for personal identification. This is because the fingerprints of an individual are unique and do not change throughout one's life. This makes them an ideal signature of a person [2], [3]. The biometric fingerprint recognition involves denoising, preprocessing, feature extraction and finally matching as shown in fig.1.

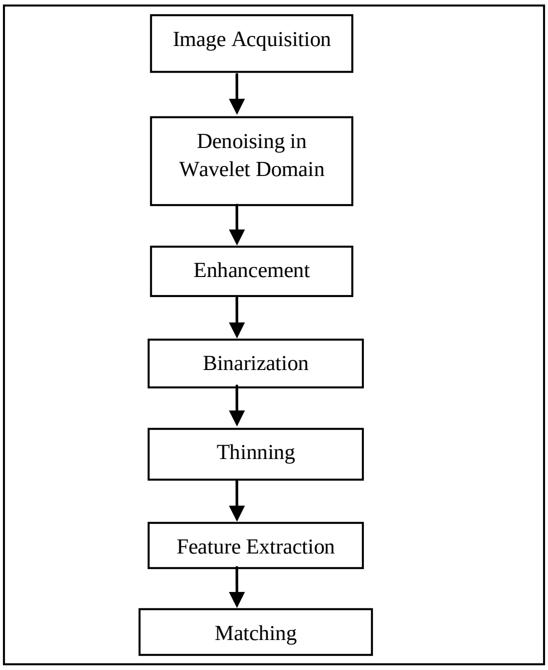

Figure 1. Process of Biometric Fingerprint Recognition

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Denoising of the fingerprint image is a vital task before further processing to get a reliable and accurate result. Fingerprint images are denoised in wavelet domain using SWT (Stationary Wavelet Transform) and universal thresholding. Then the denoised image is preprocessed (normalization, ridge orientation estimation, ridge frequency estimation) for enhancement as in [4]. Finally binarized image is constructed from the enhanced image using rough set based method and the results are compared with the results of Otsu’s method.

The operation that converts a grayscale image into a binary image is known as binarization. Binarization of fingerprint image is indispensible since the uniqueness of a fingerprint image is determined by the minutiae points which are extracted from binarized fingerprint image. The most common minutiae in the fingerprints are the terminations and the bifurcations [5]. Terminations are sudden ridge endings in a fingerprint and bifurcations are ridges that split into two new ridges as shown in fig.2.

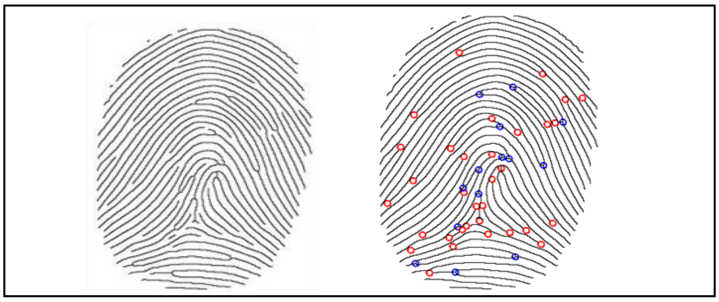

Figure 2. Fingerprint with minutiae points

In [6], they exploit the property of almost equal width of ridges and valleys for binarization. Computing the width of arbitrary shapes is a nontrivial task. So, they estimate the width using Euclidean distance transform (EDT) and provide a near-linear time algorithm for binarization. An optimum global thresholding method based on an idea of minimizing the intraclass variance of black and white pixels was proposed by Otsu [7]. A binarization technique based on an iterative application of laplacian operator and a pair of dynamic thresholds is proposed in [8]. A rough-set based approach for binarization of fingerprint image is presented in [9]. Maximization of rough entropy and minimization of roughness of the image lead to an optimum threshold for binarization. They used quad-tree decomposition for granulation.

In this paper, we compared the performance of rough set based method with traditional otsu’s for binarizing fingerprint image. The performance of the binarizaion algorithms are evaluated using RAE.

The paper is organized as follows. Section II presents the implementation of rough set for binarizing fingerprint image. Section III provides experimental results of various binarization techniques. Finally this paper concludes with some perspectives in section IV.

II. ROUGH SET BASED BINARIZATION FOR FINGERPRINT IMAGE

A. Rough Set

Rough set theory was proposed by Z. Pawlak [10] is a formal approximation of a crisp set in terms of a pair of sets which give the lower and the upper approximation of the original set. It is a mathematical tool to deal with vagueness and uncertainty. Lower approximation of a set contains elements which are certainly members of the set while upper approximation of the set includes elements which are possible members of the set.

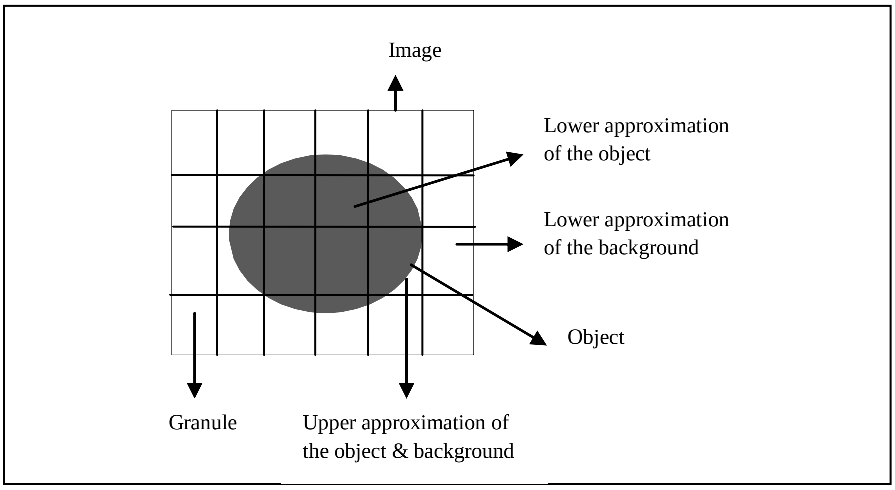

Figure 3. An example of image as a rough set

B. Granulation (Image as a Rough set)

Granulation involves decomposition of whole into parts. The image is partitioned into non-overlapping blocks of same size termed as granules. A choice of granule size can be made from gray level distribution of the image by selecting a value approximately equal to the minimum of half the width of base regions corresponding to all the peaks in the histogram. This will allow the algorithm to take into account the local information (details) of all the regions, as indicated by different peaks in the histogram, and facilitate the detection of the smallest region [11].

C. Inner and Outer approximation

Once the image is split in granules, next task is to identify each granule as either object or background. Let G be the total number of granules then problem is to classify each granule as either object or background. At this point we also need to know the dynamic range of the image. Let [0, L] be the dynamic range of the image. Our final aim is to find a threshold T, 0≤T≤L-1, so that the image could be binarized based on threshold T. Granules with pixel values less than T characterize object while granules with values greater than T characterize background. After getting this separation, object and background can be approximated by two sets as follows as described in [11].

The lower approximation of the object or background: For all blocks belonging to object (background), the blocks having pixels with same intensity values are called lower (inner) approximations of object (background).

The upper approximation of the object or background: All blocks belonging to object (background) also belong to upper approximation of the object (background).

D. Roughness of Object and background

Roughness of object and background is computed as described in [11]. The roughness of object is

$$R_o = 1 - \frac{|O_l|}{|O_u|} \tag{1}$$

Here $|O_l|$ and $|O_u|$ are cardinality of object upper approximation and lower approximation respectively. Similarly roughness of background can be defined as

$$R_b = 1 - \frac{|B_l|}{|B_u|} \tag{2}$$

Where, $|B_l|$ and $|B_u|$ are cardinality of Background upper approximation and lower approximation respectively.

Roughness is a measure of uncertainty in object or background. It can be obtained as the number of granules out of total number of granules that are certainly not the members of the object or background. Thus the value of the roughness depends on the threshold value (T) used to obtained the lower and upper approximation of the object or background.

E. Rough Entropy Measure

A measure called Rough entropy based on the concept of image granules is used as described in [11]. Rough entropy is computed from object and background roughness as

$$R_E = -\frac{e}{2}\left[R_o \log R_o + R_b \log R_b\right] \tag{3}$$

Here, is the object roughness and is the background roughness. Maximization of this Rough-entropy measure minimizes the uncertainty i.e., roughness of object and background. In other words, select

$$T = \text{argmax}\, RE_t, \tag{4}$$

as the optimum threshold for binarization.

Algorithm: Fingerprint Binarization using Rough Set
Input: **Grayscale image**
Output: **Binarized Image**

i. Represent image in the form of Granules.
ii. For a threshold value T, 0<T≤255, separate the granules into object and background.
iii. Find lower and upper approximation of object and background.
iv. Compute object and background roughness and hence find out rough entropy.
v. Repeat steps 2 to 4 for all values of T, i.e. from T=1 to 255.
vi. The value of T for which Rough entropy is maximum, is selected as a threshold for binarization.
vii. Binarize the image using optimum threshold obtained as in [9].

III. EXPERIMENTAL RESULTS

A. Dataset

The proposed method is tested on DB1 of FVC2002 and FVC2004 from Fingerprint Verification Competition (FVC) [12]. The images are resized to 256x256 for implementation and further analysis.

B. Quantitative Metrics

1) Relative foreground Area Error

The Relative foreground Area Error is used to evaluate the performance of the binarization algorithm as defined in [13].

$$\mathrm{RAE} = \begin{cases} \frac{A_R - A_T}{A_R} & \text{if } A_T < A_R \\ \frac{A_T - A_R}{A_R} & \text{if } A_T \geq A_R \end{cases} \tag{5}$$

Here A_R is the area of reference image, and A_T is the area of threshold image. For a perfect match of the segmented regions, RAE is zero, while if there is zero overlap of the object areas the penalty is the maximum one.

2) F – Measure

The F- Measure is also used to evaluate the performance of the binarization algorithm [14]. It is defined as

$$\mathrm{F-Measure} = \frac{2*\mathrm{Recall}*\mathrm{Precision}}{\mathrm{Recall}+\mathrm{Precision}} \tag{6}$$

where Precision $= \frac{TP}{Tp+FP}$, Recall $=\frac{TP}{TP+FN}$

TP, FP, FN denote True Positive, False Positive and False Negative values, respectively. The true positives are those pixels that were black in the ground truth image and are still black in the binarized image. The false positives were white in the ground truth image and black in the binarized image. The false negatives are black in the ground truth image, but white in the binarized image. A higher value of F-Measure indicates better performance.

(a) (b) (c)

Figure 4. Binarization using different methods: (a) Binarization using Rough set based method; (b) Binarization using Otsu's method; (c) Binarization using Adaptive Mean

C. Construction of reference Image

Adaptive local threshold based on mean is used to construct the reference image as in [15]. Here the image is divided into non-overlapping blocks of size m x n. Each pixel is assigned a new value (1 or 0) according to the mean intensity in a local neighborhood window as follows:

$$I_R = \begin{cases} 1 & \text{if } I_{(m,n)} \geq \mathrm{Mean} \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

Here I_R is the constructed reference image and $I_{(m,n)}$ is the grayscale image. When the intensity of the current pixel is greater than or equal to the mean intensity of the local window then it is set to 1 otherwise it is to 0.

TABLE I. PERFORMANCE RESULTS OF BINARIZATION ALGORITHMS IN TERMS OF RAE

Dataset	**Binarization Methods**	
	Otsu method	***Rough set based method***
FVC2002(DB1)	0.1788	**0.1377**
FVC2004(DB1)	0.1687	**0.1275**

Table I shows the result of RAE for binarization algorithms. The RAE is the mean Relative Foreground Area Error of the entire dataset DB1 of FVC2002 and FVC2004 respectively. Rough set based binarization algorithm gives the best result when compared with traditional Otsu's method.

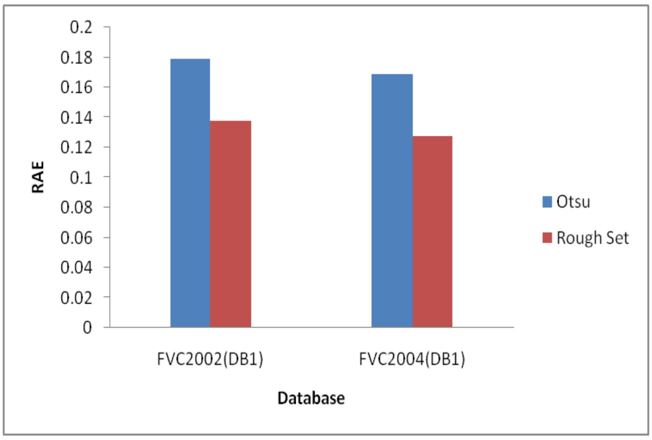

Figure 5. Comparison of RAE for different binarization methods

TABLE II. PERFORMANCE RESULTS OF BINARIZATION ALGORITHMS IN TERMS OF F - MEASURE

Dataset	**Binarization Methods**	
	Otsu method	***Rough set based method***
FVC2002(DB1)	64.0280	**65.4025**
FVC2004(DB1)	63.3034	**64.5620**

Table II shows the result of F-Measure for binarization algorithms. The F-Measure is the average of the entire dataset DB1 of FVC2002 and FVC2004 respectively. Rough set based binarization algorithm gives the best result when compared with traditional Otsu's method.

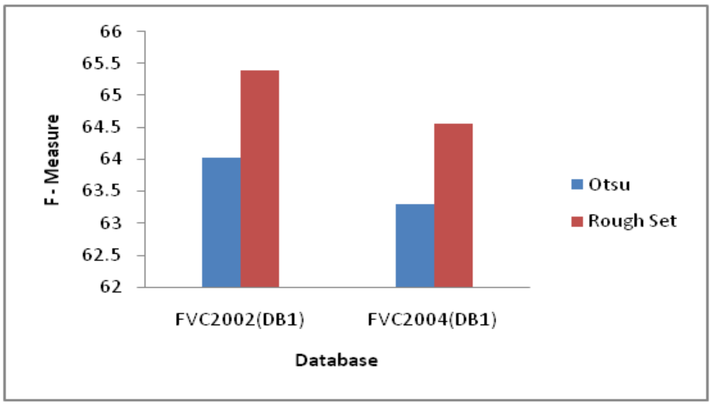

Figure 6. Comparison of F-Measure for different binarization methods

In summary, the performance of the rough set based gives the best performance when compared with traditional Otsu's method for binarizing fingerprint. Fig. 5 and Fig. 6 shows that the performance of the proposed is better than that of existing methods for fingerprint denoising.

IV. CONCLUSION

In this article, a rough set based method for binarizing fingerprint image is compared with traditional Otsu's method. The rough set based method outperforms Otsu's method in terms of RAE, F-Measure. The reference image for computing RAE is constructed using adaptive mean. In the rough set based method, Rough entropy of an image is defined using the concept of image granules. Here granules carry local information and reflect the inherent spatial relation of the image by treating pixels of a window as indiscernible or homogeneous. Based on the rough entropy measure, an optimum threshold is selected for binarization. The rough set based threshold is simple in computation and yet it is effective in binarization.

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