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Oily Fingerprint Image Enhancement Using Fuzzy Morphology

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Abstract:The quality of fingerprint image greatly affects the performance of minutiae extraction and the process of matching in fingerprint identification system. In order to improve the performance of the fingerprint identification system, a fuzzy morphology technique is proposed in this paper to enhancement oily fingerprint images. Experimental results, using the DB_ITS_2009 database [15] indicated that the proposed method did enhance the quality of fingerprint image. The new proposed method increased the fingerprint identification rate from 82% to 96% when compared withan adaptive pre-processing method based on binary image morphology.

Keywords:*Oily fingerprint image; fuzzy Morphology; Fuzzy Dilation; Fuzzy Erosion;Image enhancement.*

1. Introduction

Fingerprint identification is the most widely used biometrics technologies and is used in criminal investigations, commercial applications, etc. With such a wide variety of uses for the technology, the demographics and environment conditions that it is used in are just as diverse. However, the identification performance of such system is very sensitive to the quality of the captured fingerprint image. Fingerprint image enhancement is useful in improving the performance of fingerprint identification systems [7, 8, 14].

Various factors can affect the quality of fingerprint images such as dryness/wetness conditions, non-uniform and inconsistent contact, permanent cuts, etc. Many of these factors cannot be avoided. Therefore, enhancement of the quality and validity of the captured fingerprint image is necessary and meaningful. Many papers in biometric literature address the problem of enhancement fingerprint image quality. But these methods still have some problems and can't be suitable for all the condition [1].

Eun-Kyung Yun et al. [2] proposed an adaptive pre-processing method. The method works through image quality characteristic analysis by extractingfeatures from fingerprint images and enhances the images according to their characteristics. Experimental results indicated that the proposed method improved the performance of the fingerprint identification significantly.

Hong, Lin, Wan, and Jain [3] introduced a fast fingerprint enhancement algorithm that adaptively improved the clarity of ridge and valley structures of input fingerprint images based on the estimated local ridge orientation and frequency. The main steps of the algorithm included the normalization, local orientation estimation, local frequency estimation, region mask estimation, and Filtering.

Selvi and George [4] proposed a fuzzy based filtering technique and adaptive thresholding method which wasdesigned to identify the noisy pixels area and enhancedit.The method wasapplied in four stages. The first stage was thepre-processing which cropped the original database images into specified size. The second stage wasthe fuzzy filtering step which replacedthe central pixel in the window of the image by that one which maximizedthe sum of similarities among all its neighbours. The third stage was theadaptive thresholding step which determined the threshold value where it wasapplicable to use with an image having different types of noises. A different threshold value wasselected for each type of noise. The last stage wasthe morphological operation step where two operations were performed, the dilation process and the erosion process, which were used to eliminate all pixels in regions that were too small to contain the structuring image.

The paper is organized as follows: section 2 presents the rational of using fuzzy logic, section 3 presents a brief introduction to Mathematical Morphology, section 4 presents a fuzzy Morphology, section 5 presents the new proposed fingerprint image enhancement system that enhancement oily fingerprint image. Section6 presents the experimental results using the DB_ITS_2009 database [15].

2. Fuzzy logic

Fuzzy logic is a form of many-valued logic or probabilistic logic. It deals with approximate (rather than fixed and exact) reasoning. It has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false [5].

Linguistic variables are used to express fuzzy rules, which facilitate the construct of rule-based fuzzy systems. A linguistic variable can be defined as a variable whose values are words or sentences. For example, a linguistic variable such as age may have a value such as young, very young, old, very old rather than 30, 36, 18 etc. However, theadvantage of linguistic variables is that they can be modifiedvia hedges (fuzzy unary operators) [5].

Fuzzy inference system is a method that interprets the values in the input vectors and based on user defined rules, assigns values to the output vector. Using a GUI editors and viewers in the fuzzy logic toolbox of Matlab, we can build the rules set, define membership functions and analyze the behavior of a fuzzy inference system. The editors and viewers are used to edit and view the membership functions and rules for fuzzy inference system [6].

3. MathematicalMorphology

The Mathematical Morphology (MM) is a theory that has been used for image processing. MM is based on concepts of geometry, algebra, topology and set theory which was created originally to characterize physical and structural properties of different materials. Currently the MM has become a solid mathematical theory based on the powerful tools for Digital Image Processing. The central idea of this theory is to analyse geometric structures in an image whichoverlap with small patterns located in different parts of it, called structuring elements (SE). The MM allows enhancing areas, edge detection, analyzing structure and segment regions, among others. Based on solid theoretical foundations, the MM has achieved excellent results in deploying fast and simple algorithmsfor segmentation of structures. Nevertheless, in images of high texture and vague edges, a new approach is indispensable[9].

The MM has been applied successfully to a large number of image processing problems. However, MM does not allow a complete representation of the uncertainties in images with high texture or a high degree of uncertainty in structural components. Different extensions have been made for binary MM withgrayscale images. One of these extensions is the Fuzzy Mathematical Morphology (FMM) [9].

An essential part of any mathematical morphology operation is the structural element used toprobe the image. A typical structural element matrix is smaller than an image matrix in size. The center pixel of the structuring element which is called the origin,does define the pixel being processed. The pixels in the structuring elements which are 1's defines the neighborhood of the origin of the structuring element. A structuring element is a special mask filter that enhances an input image[10].

4. Fuzzy Morphology

According to Bloch and Maitre[11], Kaufmann in 1988 was thefirst tocombine the mathematical morphology and fuzzy logic. Kaufmann proposed the α-cut approach for further fuzzy set operations. A fuzzy set that contains all elements with a membership value of $\alpha > 0$is called the α-cutset. The membership function is cut horizontally at a finite number of α-levels between 0 and 1. For each α-level of the parameter, the model is run to determine the minimum and maximum possible values of the output. This information is then directly used to construct the corresponding fuzziness (membership function) of the output which is used as a measure of uncertainty. Based on this fact, a fuzzy set maximum and minimum operation can be defined over α-cut [10].

α-cut provide an appropriate way of combining a fuzzy set and a crisp set. Given a fuzzy set $\mu(x)$ where x is an element of the universe of discourse X and assigning membership degrees from the interval [0,1] to each element of X, then the α-cut of $\mu(x)$ for $0 \leq \alpha \leq 1$ is the set of all $x \in X$ with membership degree of at least α[10]. That is

$$\mu_\alpha = \{x \mid \mu(x) \geq \alpha\}.$$

Using the definition of α-cut fuzzy set, other operations are easily derived from the crisp counterparts. For example, the union operation of two fuzzy sets$\mu(x)$ and $v(x)$ is defined as

$$[\mu U v](x) = \max\, [\mu(x), v(x)]$$

which implies that

$$(\mu U v)_\alpha = \mu_\alpha U v_\alpha.$$

The Minkowski addition of two crisp sets A and B that belong to X can be defined as

$$A \oplus B = \{\alpha \in A \mid \tau_\alpha(B) \ \cap A \neq \emptyset\},$$

where $\tau_\alpha(X) = \{y \mid y = x - \alpha,\ x \in X\}$, $\tau\alpha(X)$ is called the translate B.

Moreover if Aand B are given graphically, the shapeof A is 'dilated' by the shape of set B.As a dualoperation, the Minkowski subtraction of a set B from aset A ($A \ominus B$) can be defined similarly. Now only elements of Abelong to the result set if their corresponding translateB completely belongs to A, that is

$$A \ominus B = \{\alpha \in A \mid \tau_\alpha(B) \subseteq A\}$$

This operation presents the 'eroding' shape of Aby the shape of B. By using these ideas we can definethe erosion and dilation operations over α-cut. Tocomprehend this, we have to fuzzify the image pixels tocreate a fuzzy set image. Using this fuzzyset image, we will define anα-cut from that fuzzy setimage as a threshold value. So the image f(x,y) willbe defined as $g_\alpha(x)$. By using this definition, thescale of a grayscale image would be selected over thethreshold α.

If we define a structuring elementmask, for instance, a 3x3 fuzzified weighted mask$\mu_\alpha(x)$ over the α-cut, then the definition of a 2-D α-cut Bloch and Maitre dilation and erosion with the help of the Minkowski addition and subtraction [10] can be as follows:

$$[g(x) \oplus \mu (x)]_{\alpha}(x)=\sup\min[g(x-y),\mu(x)]$$

Where$y\in X$ forDilation.

$$[g(x) \ominus \mu (x)]_{\alpha}(x)=\inf \max[1-g(x-y),\mu(x)]$$

Where $y\in X$forErosion.

Figure 1 shows the fuzzy dilation which takes two pieces of fuzzified data as input wherethe first is the image which is to be dilated and the second is set of coordinate points known as structuring element (ES). The fuzzy dilation determines the precise effect of the dilation on the input image.

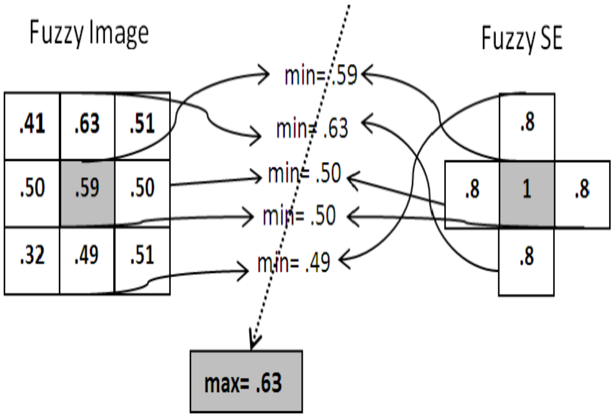

Figure 1. Figural representation of fuzzy morphology formula (Dilation)[10]

Fuzzy dilation process presented in figure 1is very important to gradually enlarge the boundaries of regions of foreground pixels. Thus areas of foreground pixels grow in size while holes within those regions become smaller. This process will fill up the ridges whichhave some white pixels in the rides.

The structuring element is a probe that scans the image and alters the pixels based on its content. The task of the structuring element is to alter the input image in a certain way by taking into account local information.

Atypical structuring element consists of few fuzzified pixels that are connected to each other as shown in table 1[11].

The performance of fuzzy morphological operation mainly depends on the size of the structuring element.The fuzzy structuring element itself is a function or image, which has greater capability to affect the image through size [11].

Structuring element is selected as a3x3 mask matrix to cover the whole image boundaries. Generally, in image processing odd sized mask shows apixel values neighbouring pixels. As the size of the mask increases, the detailed results of the operations decrease. For this reason it is better to have a small odd sized structuring element mask for better performance. The values used inside the structuring element are the pixel values. These pixel values are randomly selected values so that a user can define different elements for the mask[11]. Table 1 shows the fuzzy structuring element used in this paper.

Table 1. Structuring Element Mask

0.3	0.8	0.3
0.8	1	0.8
0.3	0.8	0.3

5. The Proposed Method

Figure 2 shows the flowchart forthe new proposed fingerprint enhancementmethod. The method ismade offivesteps. The steps are as follows:

1. Input animageto alow pass filter to smooth the image. Then employ a fuzzy morphology dilation on the smoothed image and lastly perform the intersection operation between the original image and dilated image.
2. Employ fuzzy morphologyerosion on the original image.
3. Come up with the inverse of the dilated image.
4. Take the intersection operation between the output of second step and third step.
5. Perform the union operation between the output of first step and fourthstep to display results.

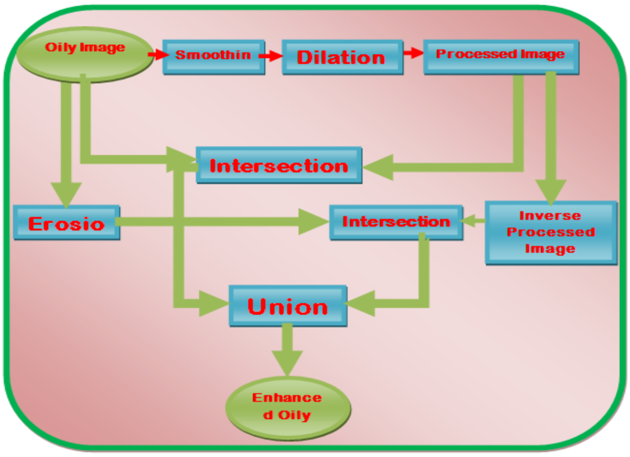

Figure 2. The flowchart of the proposed method

Finally, performance evolution is conducted to measure the quality of the enhanced image compared with previous studies using feature similarity index metric (FSIM) [12] which will be covered in section 4.

Smoothing is applied to reduce noise in an image and to decrease the disparity between pixel values by using winner filter [13].
Figure3 showsa smoothed fingerprint image.

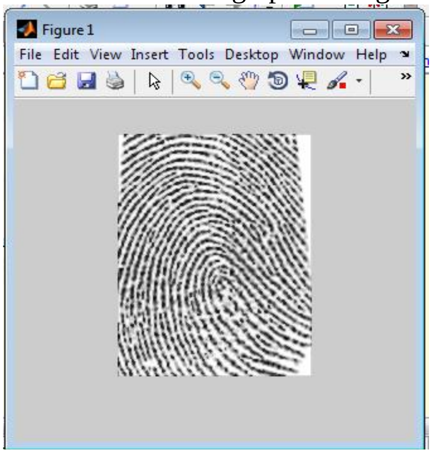

Figure3.A smoothed image

Fuzzy mathematical morphology is the extension of grayscale morphological operations to fuzzy sets. Fuzzy morphological operations are more sensitive to details within an image allowing to fine tune standard morphology operations. The basic fuzzy morphological operations are dilation and erosion. Fuzzy erosions and dilations produce results identical to the nonlinear minimum and maximum. Opening and closing morphology operations are a sequential combination of dilation and erosion. Figures 4 and 7shows an examples of a dilated and erosion fingerprint image using fuzzy morphology, respectively.

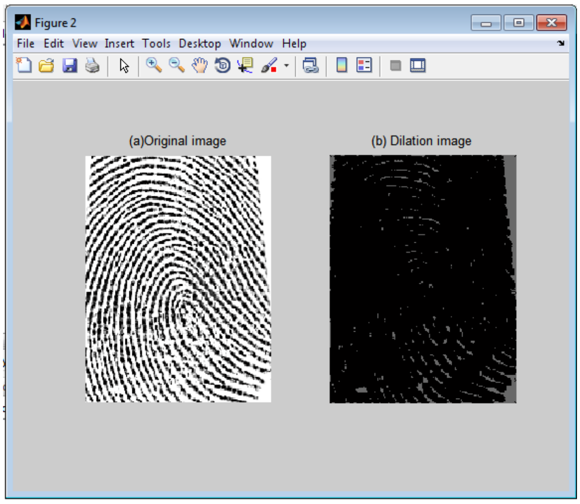

Figure4. Fuzzy dilated image

Fuzzy dilation and erosion operations aredual operations. Dilation is applied on smoothing fingerprint image, where erosion is applied on oily image (input image). Input images need to be fuzzified thenboth the α-cut dilation equation to dilatethe images and the α-cut erosion equation to erosion the images are applied. Fuzzification is applied totransfer animage back to grayscale image.

Forimage fuzzification, the use of membership functionsis required. The selection of a membership function depends on theapplication. In image processing, heuristic membership functions are widely used to define certain properties (such as lightness or darkness of a pixel value). S-function is a prominent heuristic membership function used in image processing applications. The shape of S-function depends on three parameters a, b, and c. The parameters a, b and c are specified to ensure the membership function maximizes the information contained in the image. In this paper, theS-membership function is used where the parameters a, b, and c are defined as follows:

$$\mu(x) = \begin{cases} 0 & x<a, \\ 2\,[(x-a)/(c-a)]2 & a<x<b, \\ 1-2\,[(x-c)/(c-a)]2 & b<x<c, \\ 1 & x>c, \end{cases}$$

where, b is any value between a and c. Figure 5shows a normalized S-membership function plot for a = Xmin = 50, c = Xmax = 250.

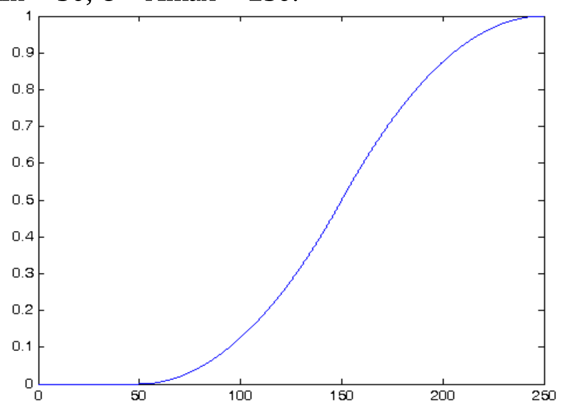

Figure 5. S-membership functions

The membership function μ = 1 represents the maximum brightness of an image. This paper used theS-membership function to improve the quality of an image.
Fuzzy dilation is applied by probe the structuring element to scan the whole image and replace the center pixel in each probe of structuring element with pixel that satisfy the following formula:

$$[g(x) \oplus \mu(x)]_{\alpha}(x)=\text{supmin}[g(x-y),\mu(x)]$$

wherey∈ X for dilation.

Inverse of image is obtained from dilated image using mathematical function which is the subtraction operation between the maximum value in the image and the image pixels as shown in figure 6.

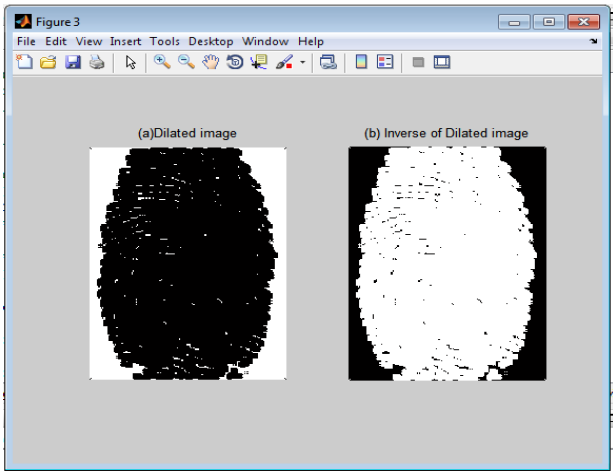

Figure 6. The inverse of dilated image

Fuzzy erosion is applied by probe the structuring element to scan the whole image and replace the center pixel in each probe of structuring element with pixel that satisfy the following formula:

$$[g(x) \ominus \mu(x)]_{\alpha}(x)=\inf\max[1-g(x-y),\mu(x)]$$

where $y \in X$ for erosion.

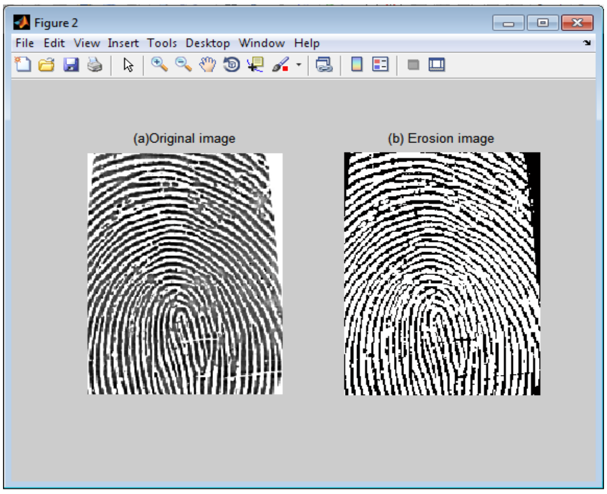

Figure7.Fuzzy erosion fingerprint image

The logical operations intersection and union are usedto extracts the intersection and union of black pixels, as shownin figure2. Figure 8 shows the intersection betweenthe erosion image and the inverse of the dilated image.

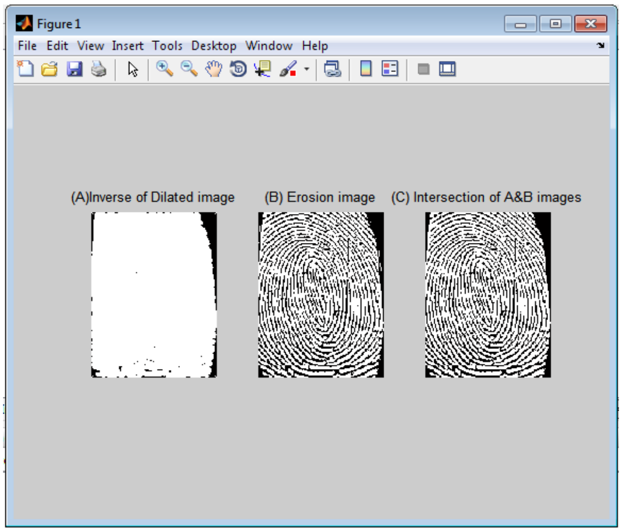

Figure8. Intersection operation

Finally, we performthe union operation between the two intersection operations presented in figure2. By the end of the operation the valleys are enhanced as shown in figure9.

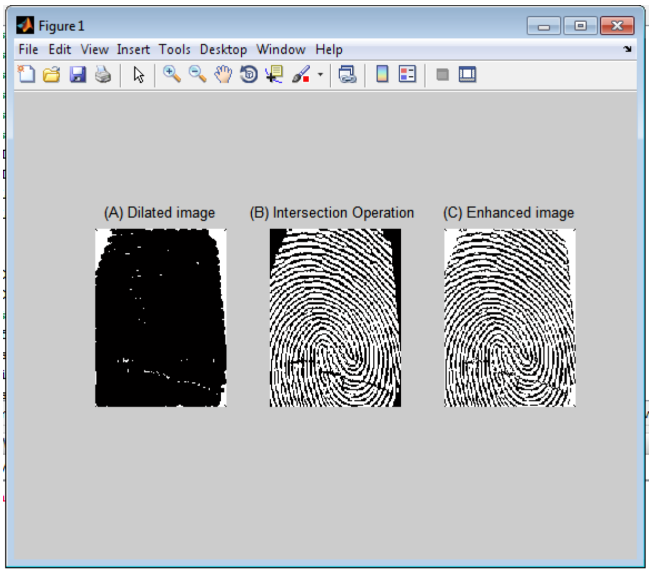

Figure9.Enhanced image

6. Experimental Results

The proposed method was testedusing the DB_ITS_2009 database [15]. The database was taken with great caution because of the image quality considerations. The DB_ITS_2009 databasewas taken using an optical sensor U.are.U 4000B fingerprint reader with the specifications: 512 dpi, USB 2.0, flat fingerprint and uncompressed. This database has 1704 fingerprint images of size 154x208 pixels. The details are as follows: The fingerprint images are classified into three types the finger conditions (dry, neutral and oily). Each type of finger condition consists of 568 fingerprint images sourced from 71 different fingers. Each of these fingerprint images was taken eight times for the three conditions above. As a result, 3x71x8=1074 fingerprint images were obtained. To obtain dry fingerprint images, hair-dryer was used to completely dry the fingertip. Likewise, in order to get oily fingerprint images,smeared baby-oil on the fingertips before the image was taken [15].

Image smoothing is done using Winner filter, then fuzzy morphology operations are performed. A greyscale image is fuzzified with the use of the S-fuzzy membership functions. Then a fuzzy structuring element is traversed on the whole image to process dilation and erosion operations.

The logical operations, union and intersection, are done using mathematical function as well as inverse of dilated image.Figure 9 showsan example of an enhanced image through the proposed method.

The Feature Similarity index (FSIM) is appliedto evaluate the performanceof the proposed method. The FSIM[12]is an image quality assessment (IQA) metric, whichuses computational models to measure the image quality consistently with subjective evaluations. The FSIM is a full reference IQA which is based on the fact that human visual system (HVS) understands an image mainly according to its low-level features. Specifically, the following low-level features:the phase congruency (PC) and thegradient magnitude (GM), which represent the complementary aspects of the image visual quality. The phase congruency (PC), which is a dimensionless measure of the significance of a local structure, is used as the primary feature in FSIM. Considering that PC is contrast invariant while the contrast information does affect HVS' perception of image quality, and the image gradient magnitude (GM) is employed as the secondary feature in FSIM.

The computation of FSIM index consists of two stages. In the first stage, the local similarity map is computed, and then in the second stage, the similarity map is pooled into a single similarity score, as in the following equation:

$$FSIM = \frac{\sum_{x \in \Omega} S_L(x).PC_m(X)}{\sum_{x \in \Omega} PC_m(X)}$$

Where

Ω means the whole image spatial domain.

SL is the similarity between two images

PC is Phase congruency

The proposed oilyfingerprint enhancement method using fuzzy morphology gives high FSIM when compared to the existing enhancement method byEun-Kyung Yun et al. [2] that uses adaptive pre-processing method based on binary morphology image processing.TheFSIM forthe existing method and the proposed method are described in tables 2 and 3, respectively.

Table 2. Samples of FSIM values for Eun-Kyung Yun et al. method [2]

Finger# / Person #	1	2	3	4	5	6
1.	0.5616	0.5807	0.5616	0.5829	0.5928	0.5967
2.	0.6084	0.6082	0.6122	0.5884	0.5925	0.5924
3.	0.6013	0.6030	0.5938	0.5997	0.5925	0.6033
4.	0.5900	0.6087	0.5857	0.5990	0.6244	0.6060
5.	0.5538	0.5442	0.5723	0.5713	0.5361	0.5759
6.	0.5928	0.5755	0.5792	0.5942	0.5827	0.5716
7.	0.5983	0.6157	0.6174	0.6167	0.6164	0.6166
8.	0.6002	0.5917	0.6112	0.6033	0.5707	0.6020
9.	0.6247	0.6163	0.6151	0.6163	0.6190	0.6085
10.	0.6024	0.6161	0.6303	0.6291	0.6112	0.6234
11.	0.6035	0.5904	0.6008	0.5939	0.6059	0.5908
12.	0.5878	0.5875	0.5806	0.5857	0.5881	0.5887
13.	0.6191	0.6084	0.6064	0.6134	0.6168	0.6176
14.	0.5442	0.5477	0.5465	0.5352	0.5523	0.5580
15.	0.5684	0.5610	0.5629	0.5760	0.5667	0.5732
16.	0.5986	0.5891	0.5959	0.5923	0.5856	0.5877
17.	0.5872	0.5632	0.5776	0.5876	0.5798	0.6004
18.	0.5800	0.5985	0.6130	0.6094	0.6275	0.5957
19.	0.5714	0.5710	0.5801	0.5891	0.5806	0.5816
20.	0.5470	0.5575	0.5599	0.5876	0.5768	0.5550

Figure10 shows the comparison between Eun-Kyung Yun et al. [2] method and the new proposed method.Eun-Kyung Yun et al. method isan adaptive pre-processing method whichis based on binary image morphology. The proposed method is based on fuzzy morphology, where the image has more information than the binary image morphology. The figure shows that the proposed method enhanced the quality of fingerprint image and increased the fingerprint identification rate from 82% to 96%.

From table 2, table 3, and figure 10, it is clear that the proposed method has performing better than the Eun-Kyung Yun et al. method. The FSIM difference between the proposed method and Eun-Kyung Yun et al. method is 14.2308% (calculated only for table 2, and table 3). Therefore, the values of FSIM for the proposed method as in table3 is higher than the values of FSIM for the Eun-Kyung Yun et al. method as in table2. The new proposed method has an FSIM value of about 96% as an identification rate and Eun-Kyung Yun et al. method has an FSIM value of about 82%as an identification rate.

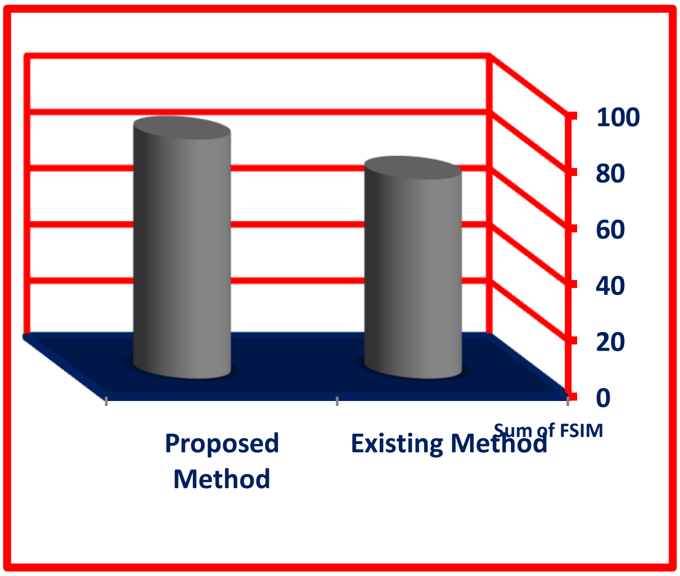

Figure10. Comparison of existing method and proposed method

Table 3. Samples of FSIM values for proposed method

Finger# / Person #	1	2	3	4	5	6
1.	0.7291	0.6977	0.7291	0.7038	0.6884	0.7126
2.	0.7201	0.7192	0.7137	0.6996	0.6969	0.6977
3.	0.7032	0.7084	0.7042	0.7091	0.7157	0.7092
4.	0.7356	0.7179	0.7466	0.7393	0.7339	0.7344
5.	0.6561	0.6531	0.6599	0.6716	0.6498	0.6836
6.	0.6983	0.6689	0.6769	0.6784	0.6902	0.6859
7.	0.7064	0.6978	0.7300	0.7203	0.7101	0.7239
8.	0.7551	0.7550	0.7484	0.7443	0.7273	0.7198
9.	0.7323	0.7086	0.7234	0.7232	0.7179	0.7298
10.	0.7181	0.7314	0.7348	0.7343	0.7251	0.7163
11.	0.7224	0.7087	0.7011	0.6993	0.7033	0.6781
12.	0.7173	0.7129	0.7222	0.7221	0.7241	0.7246
13.	0.7325	0.7497	0.7368	0.7435	0.7459	0.7384
14.	0.6684	0.6898	0.6778	0.6806	0.6876	0.6904
15.	0.6473	0.6726	0.6626	0.6763	0.6718	0.6744
16.	0.7455	0.7348	0.7380	0.7562	0.7493	0.7489
17.	0.7188	0.6813	0.6952	0.6989	0.7213	0.7342
18.	0.6763	0.6522	0.6957	0.7039	0.7060	0.6929
19.	0.6589	0.6677	0.6659	0.6712	0.6831	0.6846
20.	0.7228	0.7454	0.7358	0.7236	0.7345	0.7459

7. Conclusion

The performance of fingerprint identification system relies heavily on the image quality. Hence, good quality images make the system performance more robust. However, it is usually very difficult to obtain good quality images. To overcome this problem, image enhancement is needed.

In this paper, we have proposeda fuzzy morphology method to enhance oily fingerprint images. The method applied is as follow: smoothing with low pass filter then fuzzy dilation and erosion.Fuzzy dilation is applied on smoothingthe fingerprint image and fuzzy erosion is applied on oily image (the input image). Both operations are done byfuzzifying the input image using theS-Membership function. The α-cut dilationor erosionis applied, then defuzzificationis performed which is the inverse of fuzzification.

Using logical operation to extract the union and intersection of black pixels from processed images, as well inverse of dilated image to get lost information in image. This way, the valleys of oily fingerprint images are enhanced. The result obtained using the proposed method is better than the result from using conventional methods. The performanceevaluation wasperformed using FSIM. The new proposed method has an FSIM value of about 96%as an identification rate and Eun-Kyung Yun et al. method has an FSIM value of about 82%as an identification rate which uses adaptive pre-processing method based on binary morphology image processing.

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