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Original Article

Contrast enhancement of fingerprint images using intuitionistic type II fuzzy set

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Abstract

A novel contrast image enhancement of fingerprint images using intuitionistic type II fuzzy set theory is recommended in this work. The method of Hamacher T co-norm(S norm) which generates a new membership function with the help of upper and lower membership function of type II fuzzy set. The 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, as well as others. Mostly fingerprint images are poorly illuminated and hardly visible, so it is necessary to enhance the input images. The enhancement is useful for authentication and matching. The fingerprint enhancement is vital for identifying and authenticating people by matching their fingerprints with the stored one in the database. The proposed enhancement of the intuitionistic type II fuzzy set theory results showed that it is more effective, especially, very useful for forensic science operations. The experimental results were compared with non-fuzzy, fuzzy, intuitionistic fuzzy and type II fuzzy methods in which the proposed method offered better results with good quality, less noise and low blur features.

Keywords: type II fuzzy set, intuitionistic fuzzy set, Hamacher T-co-norm, fingerprint image, image enhancement

1. Introduction

The human visual system is perfectly adapted to handle uncertain information in both data and knowledge. The fundamental idea of image enhancement is to produce a new image in such a way that, - it exposes information for analysis more than the original image. The aim of image enhancement is to generate an image with higher contrast than the original image by further processing .Finger prints are fully formed at about seven months of fetus development and finger ridge configuration do not change throughout the life of an individual except due to accidents such as bruises and cuts on the finger (Babler, 1991). There are three basic fingerprint patterns: loop, whorl and arch. Finger print images have a nine- type of classification, namely, (1) arch, (2) tent arch, (3) right loop, (4) left loop, (5) double loop, (6) right pocket loop, (7) left pocket loop, (8) whorl, and (9) mixed figure. This type should be different from one person to another. Depending upon the human being, fingerprint images can present uncertainties, as the ridge and valley structure might be not clearly visible. Fingerprint images are varying in quality. So, it is required to enhance the original image to obtain a better quality image. The most common method of image enhancement techniques is histogram equalization (non-fuzzy method) (Arifin *et al.*, 2010) But this technique is not suitable for forensic science, as they are facing different types of fingerprint patterns. Therefore the fuzzy method might be more useful for such investigations. Fuzzy set (Zadeh, 1965) considers the uncertainty in form of a membership function which is the degree of belongingness of the pixel in an image. The fuzziness may present in the membership function in ordinary (Type I) fuzzy set and thus it introduced Type II fuzzy set, where the membership function is characterized by fuzzy.

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Atanassov (1986) introduced intuitionistic fuzzy set where he considered a 'hesitation degree' while defining the membership function. This hesitation is due to the lack of knowledge in defining the membership function. In the recent years, a number of researchers have used the INT operator (Hassanien *et al.*, 2003) INT is a common operator to increase the contrast of the image. The NINT operator is derived from the INT operator with some improved features. (Handmandlu *et al.*, 2003) The histogram hyperbolization (Tizhoosh *et al.*, 1995) is also used for image enhancements. Global features of fingerprint images are according to Manju *et al.* (2013) ridge orientation map, ridge frequency map, singular points and minutiae extraction. Singular point is divided into two parts. Core:-, which is the uppermost part of the curving edge, and Delta:-, which is a point where three ridge flows meet.

2. Related Works

Intuitionistic fuzzy enhancement was suggested by Vlachos *et al.* (2007) where they used intuitionistic fuzzy entropy. Enhancement using Type II fuzzy set is also suggested by Ensafi *et al.* (2005). Wu *et al.* (2005) have described an anisotropic filter (AF) and directional median filter (DMF) (Figure 1) for fingerprint image enhancement purposes. Directional median filter is used to join the broken fingerprint ridges, fill out the holes, smooth irregular ridges and remove some annoying small artifacts between ridges.

Discrete wavelet transform (DWT) and singular value decomposition (SVD) has been proposed by Bennet *et al.* (2011). Image normalization and Gabor filter techniques are used to enhance the fingerprint image according to Kim *et al.* (2002) (Figure 3). First, they have used the adaptive normalization, which is based on block processing, so input image is partitioned into sub-block with $K \times L$ size and region of interest (ROI) of the image is acquired. Second, taking a two parameter form Gabor filter for enhancing the finger print image.

Yang *et al.* (2002) proved with a novel filter design method for fingerprint image enhancement. The author has been inspired by the traditional Gabor filter (TGF) which is called the modified Gabor filter (MGF). 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.

3. Preliminaries

3.1 Definition

A fuzzy set A is a finite set $A = \{x_1, x_2, \ldots\ldots x_n\}$ may be represented mathematically as follows,

$$A = \{x, \mu_A(x) \mid x \in X\}; \text{ Where } \mu_A(x) : \mathrm{X} \to [0,1]$$

The membership function on an element *x* with the necessary condition $0 \le \mu_A(x) \le 1$

3.2 Definition

An intuitionistic fuzzy set A is a finite set X; Attanassov (1986) mathematically represented it as follows

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

where $\mu_A(x), \nu_A(x) : \mathrm{X} \to [0,1]$ are respectively. The membership and non-membership function on an element x with the necessary condition $0 \le \mu_A(x) + \nu_A(x) \le 1$; $\pi_A(x) + \mu_A(x) + \nu_A(x) = 1$. The measure of non-membership function is $1 - \mu_A(x)$.

3.3 Definition

The value of the membership function degree might include an uncertainty. If the value of membership function is given by a fuzzy set, it is type 2 fuzzy set (Chaira, 2013).

A type-2 fuzzy set may be mathematically written as:

$A_{TypeII} = \{x, \hat{\mu}_A(x) \mid x \in X\}$; Where $\hat{\mu}_A(x)$ type-2 membership function. It can be represented in terms of upper and lower membership function mathematically written as:

$$\mu^{upper} = [\mu(x)]^{\alpha}$$

$$\mu^{lower} = [\mu(x)]^{1/\alpha} \text{ ; Where } \alpha \in [0,1].$$

The membership function on an element with the necessary condition

$$A_{TypeII} = \{x, \mu_U(x), \mu_L(x) \mid x \in X\}$$

$$\mu_L(x) < \mu(x) < \mu_U(x), \ \mu \in [0,\ 1]$$

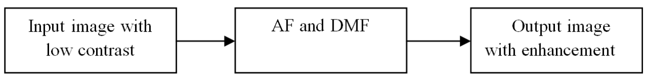

Figure 1. Fingerprint image enhancement method using directional median filter

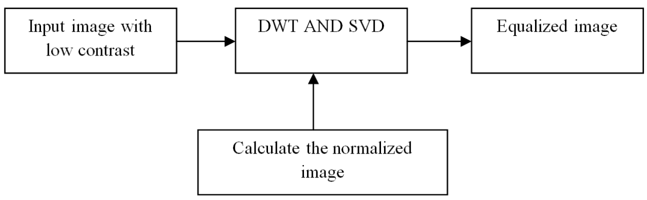

Figure 2. Fingerprint image enhancement method using discrete wavelet transform

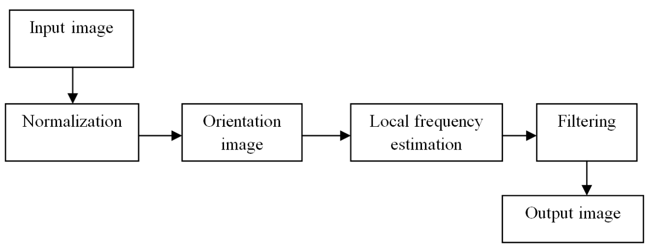

Figure 3. Block of the fingerprint image enhancement

In fuzzy set each element is mapped to by membership function $\mu_A(x) = X \to [0,1]$; where $[0,1]$ means real numbers between 0 and 1 (including 0 and 1).

4. Fuzzy T Co-Norm

A fuzzy set is an extension of classical set theory (crisp or ordinary) and contains the similar operations of classical set theory with the extension of the following operation such as the boundary, commutativity, monotonicity, and associativity; these operators are called T-norm and S-norm; (Lee, 2005). In fuzzy there are many operators (T-norm and S-norm) produced by Yager (1980), Dombi *et al.* (1982), Weber (1983) and Klir *et al.* (1988). These operators are classified into two categories:-, conditional operator and algebraic operator. The conditional operator operates with help of max and min operator whereas algebraic operator operates with purely algebraic operators. (Yager, 1980), and (Dombi, 1982) were used max or min operators with examples

i) Yager T norm =

$Yq(u,v) = 1 - \min([(1-u)^q + (1-v)^q]^{(1/q)}, 1)$ is a function with decreasing generators

$f_q(u) = (1-u)^q$, $f^{-1}(v) = 1 - v^{1/q}, q > 0$.

T-co-norm = $Y*_q(u,v) = \min([u^q + v^q]^{(1/q)}, 1)$ with increasing generators $g_q(u) = u^n$ and $g^{-1}_q(v) = v^{(1/q)}$.

ii) Hamacher, the conditional operator of T-norm and T-co-norm are given by

$$H_\gamma(u,v) = \frac{u.v}{\gamma + (1-\gamma).(u+v-u.v)}, \gamma > 0 ,$$

$$H*_\gamma(u,v) = \frac{u+v-u.v-(1-\gamma)uv}{1-(1-\gamma).uv} \text{ with}$$

T-norm and T-co-norm generator are given below

$$f_\gamma(x) = \frac{1}{\gamma}\ln\frac{\gamma+(1-\gamma).u}{u} \text{ and } f_\gamma^{-1}(y) = \frac{\gamma.e^{-\gamma.v}}{1-(1-\gamma).uv} ;$$

iii) Dombi also suggested T-norm and T-co-norm are given by

$$D(u,v) = \frac{1}{1 + \left(\left(\frac{1}{u}-1\right)^\lambda + \left(\frac{1}{v}-1\right)^\lambda\right)^{\frac{1}{\lambda}}};$$

$$D*(u,v) = \frac{1}{1 + \left(\left(\frac{1}{u}-1\right)^{-\lambda} + \left(\frac{1}{v}-1\right)^{-\lambda}\right)^{-\frac{1}{\lambda}}}$$

5. Proposed Method for Image Enhancement

The proposed method is based on window scheme where the original image is split into four windows for processing and enhancement is carried out in each window. During the processing, noise occurred when the size of the window increases. Initially the image of size *M*×*N* is fuzzified using the formula:

$$\mu_A^{fuz}(g_{ij}) = \frac{g - g_{\max}}{g_{\max} - g_{\min}}$$

where g is the gray level of the image ranges from 0 to L-1. $g_{\max}$ and $g_{\min}$ are the maximum and minimum values of the gray level of the image.

For all windows, the membership function and non-membership function is calculated using Takagi-Sugeno-Kang (TSK) type intuitionistic fuzzy set (IFS) generator and TSK type IFS generator is followed as:

$$S(\mu(g)) = \frac{(1-\mu(g))}{(1+\lambda\mu(g))}, \lambda > 0 \text{ ; Where } S(1) = 0, S(0) = 1.$$

TSK –IFS generator is a non-membership function which is written as:

$$v_A^{win}(g_{ij}) = \frac{1-\mu_A^{fuz}(g_{ij})}{1+\lambda\mu_A^{fuz}(g_{ij})}$$

TSK-IFS become as:

$$A_\lambda^{S\_IFS} = \{x, \mu_A(g_{ij}), \frac{1-\mu_A(g_{ij})}{1+\lambda.\mu_A(g_{ij})} \mid g_{ij} \in A\}$$

with the hesitation degree of the window can be written as

$$\pi_A(g_{ij}) = 1 - \mu_A(g_{ij}) - v_A^{win}(g_{ij})$$

where (g_{ij}) is the $(i,j)^{th}$ gray level of the image. The benefit of using TSK generator is to increase the value of λ. If the TSK generator decreases the membership value, it will increase the hesitation degree. It is observed that on increasing the λ value, the image enhanced will be deteriorating.

The average value of the enhanced features in each window is calculated. The modified membership value is written as:

$$\mu_A^{\text{mod}}(g_{ij}) = \mu_A(g_{ij}) - \text{mean\_window} * \pi_A(g_{ij})$$

Here, we introduce the type-2 fuzzy membership function with $\alpha = 0.8$.

The Hamacher T-co-norm of membership is introduced with the help of upper and lower membership function which can be mathematically written as:

$$\mu^{type-2}(g_{ij}) = \frac{\mu^{upper} + \mu^{lower} + (\lambda-2)\mu^{upper}.\mu^{lower}}{1-(1-\lambda)\mu^{upper}\mu^{lower}}$$

$\mu^{upper}(g_{ij})$ and $\mu^{lower}(g_{ij})$ are the upper and lower membership function of type-2 fuzzy set.

$$\mu^{upper}(g_{ij}) = [\mu_A^{fuz}(g_{ij})]^\alpha$$

$$\mu^{lower}(g_{ij}) = [\mu_A^{fuz}(g_{ij})]^{1/\alpha}$$

In this case of λ is taken as:

$$\lambda = 10 * win\_avg$$

The concept of intuitionistic fuzzy type-2 set is applied to each window:

$$\mu_A^{enh}(g_{ij}) = 2[\mu^{type-2}(g_{ij})]^2 \text{ if } \mu_A^{enh}(g_{ij}) \le 0.5$$
$$= 1 - 2[1 - \mu^{type-2}(g_{ij})]^2 \text{ if } 0.5 < \mu_A^{enh}(g_{ij}) \le 1$$

$\mu_A^{enh}(g_{ij})$ is the enhanced gray level of the window.

6. Results and Discussion

Experimental results were obtained using three different types of fingerprint images with different type of uncertainties. These images did not contain a clear vision in its ridges, valley structures and fingerprint features.

Figure 4(a) shows an image of a fingerprint with size of 125×125 with low visible features. Similarly Figure 4(b) shows the result of non-fuzzy method with more darkness and not clearly. Figure 4(c) shows the result of enhanced image using fuzzy method with not clear visible ridge and valley structures. Figure 4(d) shows the results of intuitionistic fuzzy method with clear but little blurry structures. Figure 4(e) shows the results of Type-2 fuzzy method where the image is slightly clearer than the original image. Figure 4(f) shows the result of the proposed method which is much better than the other methods.

Figure 5(a) shows an image of a latent fingerprint of sizeand is not clearly visible. Figure 5(b) shows the result of the non-fuzzy method with increased darkness. Figure 5(c) shows the result of fuzzy method without depicting the global features clearly. Figure 5(d) shows the result of intuitionistic fuzzy method which is unclear between two ridges and valley structures. Figure 5(e) shows the result of type-2 fuzzy method which is slightly clearer than the original image.Figure.5 (f) shows the results of proposed method with much better quality than previous methods.

Figure 6(a) shows an image of a fake fingerprint of size 120×120 and contains significant uncertainty.Figure 6(b) shows the results of non-fuzzy method with an image that has a large number of block mark areas. Figure 6(c) shows the result of Fuzzy method with more block mark and blurry areas. Figure 6(d) shows the results of intuitionistic fuzzy method with slightly clearer and less block mark areas. Figure 6(e) shows the result of type-2 fuzzy method with better quality by having much less black mark areas than the original image. Figure 6(f) shows the results of proposed method with better features than the methods shown before. The fingerprint image quality evaluation is very difficult because it contains a number of uncertainties and it is often poorly illuminated. The evaluation uses the linear index of fuzziness / fuzzy entropy (Handmandlu *et al.*, 2003) for

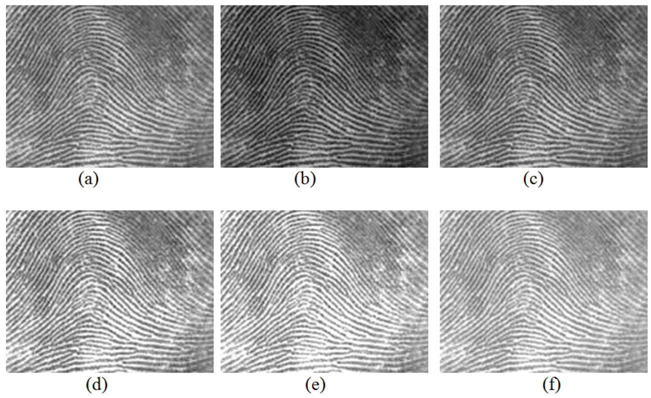

Figure 5. a) Latent fingerprint original image, b) enhanced image using non-fuzzy method, c) enhanced image using fuzzy method, d) enhanced image using intuitionistic fuzzy method, e) enhanced image type-2 fuzzy method, and f) enhanced image using proposed intuitionistic type-2 fuzzy set.

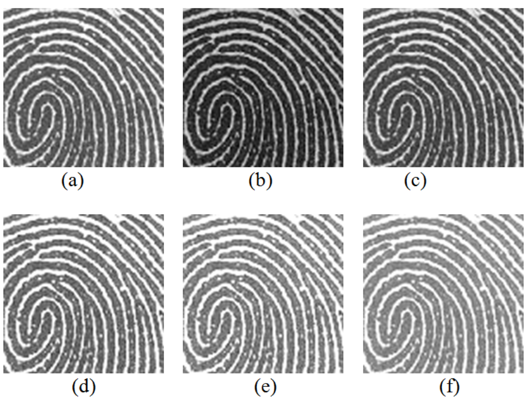

Figure 4. a) Fingerprint original image, b) enhanced image using non-fuzzy method, c) enhanced image using fuzzy method, d) enhanced image using intuitionistic fuzzy method, e) enhanced image type-2 fuzzy method, and f) enhanced image using proposed Intuitionistic type-2 fuzzy set.

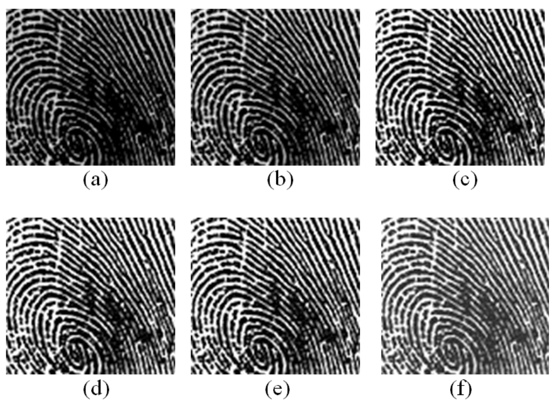

Figure 6. a) Fake fingerprint original image, b) enhanced image using non-fuzzy method, c) enhanced image using fuzzy method, d) enhanced image using intuitionistic fuzzy method, e) enhanced image type-2 fuzzy method, and f) enhanced image using proposed Intuitionistic type-2 fuzzy se

Table 1. Performance comparison using linear index of fuzziness

Image	Non-fuzzy	Fuzzy	Intuitionistic fuzzy	Type II fuzzy	Proposed Intuitionistic II fuzzy
Normal fingerprint image	0.3102	0.2092	0.1866	0.1782	0.1302
Latent fingerprint image	0.3281	0.1872	0.1222	0.1391	0.1312
Fake fingerprint image	0.2411	0.2111	0.2109	0.2712	0.1778

calculating the fuzziness in the enhanced image. The linear index of fuzziness is less than the original image and that this is the feature of enhancement. The proposed method is tested with linear index of fuzziness and it is better than the existing methods.

The linear index of fuzziness as follows:

$$\mathrm{L.I} = \frac{2}{MN}\sum\sum \min(\mu_{mn}, 1-\mu_{mn})$$

Advantages of this method provide very high accuracy and result in non - blurry images, which are standardized. It is very useful to forensic science because the image can be enhanced by the pre-processing. The proposed method is relatively easy to use. For some person it might be very intrusive, because it is related to criminal identification.

However, there are disadvantages of this method. It can make mistakes with the dryness or dirtiness of a finger's skin. Images need to be captured at 500 dots per inch (dpi), a Resolution: - of 8 bits per pixel. Therefore a 500 dpi fingerprint image at 8 bits per pixel demands a large memory space, 240 Kbytes approximately, which requires compression (a factor of 10 approximately).

7. Conclusions

This paper presented various types of fuzzy enhancement techniques that are applied on different types of fingerprint images to obtain an enhanced image with improved features. The parameter in Hamacher operator is computed from the average of the image window. From the results, it is evident that the proposed method produced an output image with better quality while comparing with other existing methods. Therefore, Takagi-Sugeno-Kang (TSK) type intuitionistic fuzzy set is more suitable for forensic science applications to perform identification and authentication with fingerprint matching process. For future study, we are aiming to use intuitionistic type-2 fuzzy set for fingerprint authentication and low false negative and increasing low false positive. MATLAB is used to implement this technique.

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