Title: Contrast Enhancement of Fingerprint Images using intuitionistic Type II Fuzzy Set

Author(s): D. Ezhilmaran and M. Adhiyaman

Authors Affiliation:

Dr. D. Ezhilmaran,
Assistant professor(senior),
School of Advanced Sciences,
VIT University,
Vellore-632014,
Tamil Nadu, India
E-mail: ezhilmaran.d@vit.ac.in

M. Adhiyaman (Corresponding author)
Research Scholar,
School of Advanced Sciences,
VIT University,
Vellore-632014,
Tamil Nadu, India
E-mail: adhiyaman.m@vit.ac.in
Contrast Enhancement of Fingerprint Images Using intuitionistic Type II Fuzzy Set

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 fingerprint 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 which are studied from literature. 

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

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 such that, it exposes information for analysis more than original image. The aim of image enhancement is to generate an image with higher contrast than the original image by giving a 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, arch, Tent arch, right loop, left loop, double loop, right pocket loop, left pocket loop, whorl and mixed figure. This type of fingerprint images should be varying one person to another. Depending upon the human being, fingerprint images have present lot of uncertainties, so ridge and valley structure are not clearly visible. Fingerprint images are varying in quality. So, it is required to enhance the original image to obtain better quality image. The most common method of image enhancement techniques is histogram equalization (non fuzzy method) (Arifin et al., 2010) But it’s not suitable for forensic science, because they are facing different type of fingerprint patterns so; fuzzy method may be useful for investigation. Fuzzy set (Zadeh, 1965) considers the uncertainty in the form of the 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. Atanassov (1986) refer introduced intuitionistic fuzzy set where he considered ‘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, lot of researchers have used INT operator (Hassanien et al., 2003) INT is a common operator to increase the contrast of the image. NINT operator is derived from INT operator with some improved features. (Handmandlu et al., 2003) The Histogram hyperbolization (Tizhoosh et al., 1995) is also used for image enhancement. The global features of fingerprint images are Manju et al. (2013) Ridge orientation map, Ridge frequency map, singular points and minutiae extraction. Singular point is divided into two parts. Core: It is the uppermost part of the curving edge and Delta: It’s 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) 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).

(Kim et al., 2002) Image normalization and Gabor filter techniques are used to enhance the fingerprint image. Here two methods are used to enhance the fingerprint image. First, they have used the adaptive normalization, it’s 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. Secondly, taking a two parameter form Gabor filter for enhancing the fingerprint image.
Yang et al. (2002) proved with a novel filter design method for fingerprint image enhancement. The author has inspired from 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 $A = \{x_1, x_2, \ldots, x_n\}$ may be represented mathematically as follows,

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

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

3.2 Definition

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

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

Where $\mu_A(x), \nu_A(x) : X \rightarrow [0,1]$ are respectively. The membership and non-membership function on an element $x$ with the necessary condition

$$0 \leq \mu_A(x) + \nu_A(x) \leq 1; \pi_A(x) = \mu_A(x) + \nu_A(x) = 1 \; . \text{The measure of non-membership function is} \; 1 - \mu_A(x).$$
3.3 Definition

The value of membership function degree might include 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:

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

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

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

The membership function on an element \( x \) with the necessary condition

\[ A_{\text{TypeII}} = \{(x, \mu_u(x), \mu_l(x)) \mid x \in X\} \]

\[ \mu_l(x) < \mu(x) < \mu_u(x), \mu \in [0, 1] \]

In fuzzy set each element is mapped to \([0,1]\) by membership function

\[ \mu_A(x) = X \rightarrow [0,1] \]; 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), Klir et al. (1988), Dombi et al. (1982) and Weber (1983). 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, Hamacher and Dombi were used max or min operators with examples

i) Yager T norm = $Y_q(u,v) = 1 - \min\left(\left((1-u)^q + (1-v)^q\right)\left(1/q\right), 1\right)$ is a function with decreasing generators

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

T-co-norm = $Y^*(u,v) = \min\left(\left(u^q + v^q\right)\left(1/q\right), 1\right)$ with increasing generators $g_q(u) = u^q$ and

$$g_q^{-1}(v) = v^{1/q}.$$ 

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

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

$$H^*_y(u,v) = \frac{u + v - u.v - (1-y)uv}{1 - (1-y)uv}$$

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

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

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

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

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

5. Proposed Method for Image Enhancement

The proposed method is based on window scheme where the original image is split into 4 windows for processing and enhancement is carried out in each window. During the
processing, lot of noise occurred when the size of the window increases. Initially the image of size $M \times N$ is fuzzified using the formula:

$$\mu_{ij}^{\text{fz}}(g) = \frac{g - g_{\text{max}}}{g_{\text{max}} - g_{\text{min}}}$$

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

For all window, 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 non-membership function which is written as:

$$\nu_{ij}^{\text{win}}(g) = \frac{1 - \mu_{ij}^{\text{fz}}(g)}{1 + \lambda \mu_{ij}^{\text{fz}}(g)}$$

TSK-IFS become as:

$$A_{\lambda}^{S, IFS} = \{x, \mu_{A}(g), \frac{1 - \mu_{A}(g)}{1 + \lambda \mu_{A}(g)} | g \in A\}$$

With the hesitation degree of the window can be written as

$$\pi_{ij}(g) = 1 - \mu_{ij}(g) - \nu_{ij}^{\text{win}}(g)$$

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

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

$$\mu^\text{mod} \left(g_{ij} \right) = \mu_A \left(g_{ij} \right) - \text{mean}_\text{window} \star \pi_A (g_{ij})$$

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:

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

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

$$\mu^{\text{upper}} \left(g_{ij} \right) = \left[\mu^{\text{fuzz}} A \left(g_{ij} \right)\right]^\alpha$$

$$\mu^{\text{lower}} \left(g_{ij} \right) = \left[\mu^{\text{fuzz}} A \left(g_{ij} \right)\right]^\frac{1}{\alpha}$$

In this case of $\lambda$ is taken as:

$$\lambda = 10 * \text{win}_\text{avg}$$

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

$$\mu^{\text{enh}} A \left(g_{ij} \right) = 2[\mu^{\text{type-}2} \left(g_{ij} \right)]^2 \text{ if } \mu^{\text{enh}} A \left(g_{ij} \right) \leq 0$$

$$= 1 - 2[1 - \mu^{\text{type-}2} \left(g_{ij} \right)]^2 \text{ if } 0.5 < \mu^{\text{enh}} A \left(g_{ij} \right) \leq 1$$

$\mu^{\text{enh}} A \left(g_{ij} \right)$ 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 1 (a) shows an image of a fingerprint with size of $125 \times 125$ with low visible features. Similarly figure 1 (b) shows the result of Non-fuzzy method with more darkness and not clear. Figure 1 (c) shows the result of Enhanced image using fuzzy method with not clearly visible in ridge and valley structure. Figure 1 (d) shows the result of Intuitionistic fuzzy method with clear but little bit blurry. Figure 1 (e) shows the result of Type-2 fuzzy method is little bit clear than the original image. Figure 1 (f) shows the result of the proposed method which is much better than the other methods.

Figure 2 (a) shows an image of a latent fingerprint of size $110 \times 110$ and is not visible clearly. Figure 2 (b) shows the result of non-fuzzy method with increased darkness. Figure 2 (c) Shows the result of fuzzy method without depicting the global features clearly. Figure 2 (d) shows the result of Intuitionistic fuzzy method which is unclear in between two ridges and valley structure. Figure 2 (e) shows the result of Type-2 fuzzy method which is little bit clear than original image. Figure 2 (f) Shows the result of proposed method with much better quality than existing methods.

Figure 3 (a) shows an image of a fake fingerprint of size $120 \times 120$ and contains lot of uncertainty. Figure 3 (b) shows the result of Non-fuzzy method with an image that has lot of block mark areas. Figure 3 (c) shows the result of Fuzzy method with more block mark and blurry areas. Figure 3 (d) shows the result of intuitionistic fuzzy method with little bit clear and less block mark areas. Figure 3 (e) shows the result of Type-2 fuzzy method with better
quality by having much less black mark areas than the original image. Figure 3 (f) shows the result of proposed method with better features than the existing methods.

The fingerprint image quality evaluation is very difficult because it contains a lot of uncertainty and poorly illuminated. The evaluation uses the linear index of fuzziness / fuzzy entropy (Handmandlu et al., 2003) for calculating the fuzziness in 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 method.

The linear index of fuzziness as follows:

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

Advantages of this method provide very high accuracy and result with non blurry image which is standardized. It is very useful to forensic science department because image enhanced by the pre-processing. Proposed method is very easy to use. For some people it is very intrusive, because is still related to criminal identification. It can make mistakes with the dryness or dirty of the finger’s skin. Image captured at 500 dots per inch (dpi). Resolution: 8 bits per pixel. A 500 dpi fingerprint image at 8 bits per pixel demands a large memory space, 240 Kbytes approximately, compression is required (a factor of 10 approximately). These three points are the disadvantages of this method.

7. Conclusion

This paper is presented with various types of fuzzy enhancement techniques that are applied on different type of fingerprint images to obtain the 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 the 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.

References


Dombi, J. 1982. A general class of fuzzy operators, A De Morgan’s class of fuzzy operators and fuzziness induced by fuzzy operators, Fuzzy Sets and Systems, 8, pp 149-163.


Fig. 1: 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, f) Enhanced image using proposed Intuitionistic type-2 fuzzy set.
Latent fingerprint images:

Fake fingerprint images:

### TABLE 1
PERFORMANCE COMPARISON USING LINEAR INDEX OF FUZZINESS

<table>
<thead>
<tr>
<th>Image</th>
<th>Non-fuzzy</th>
<th>Fuzzy</th>
<th>Intuitionistic fuzzy</th>
<th>Type II fuzzy</th>
<th>Proposed Intuitionistic II fuzzy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal fingerprint image</td>
<td>0.3102</td>
<td>0.2092</td>
<td>0.1866</td>
<td>0.1782</td>
<td>0.1302</td>
</tr>
<tr>
<td>Latent fingerprint image</td>
<td>0.3281</td>
<td>0.1872</td>
<td>0.1222</td>
<td>0.1391</td>
<td>0.1312</td>
</tr>
<tr>
<td>Fake fingerprint image</td>
<td>0.2411</td>
<td>0.2111</td>
<td>0.2109</td>
<td>0.2712</td>
<td>0.1778</td>
</tr>
</tbody>
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