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A rank ordered filter for medical image edge enhancement and detection using intuitionistic fuzzy set

Tamalika Chaira *

Centre for Biomedical Engg., Indian Institute of Technology Delhi, Hauz Khas, New Delhi 110016, India

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ABSTRACT

This paper gives a novel scheme using intuitionistic fuzzy set theory to enhance the edges of medical images. Medical images contain lots of uncertainties, as they are poorly illuminated and fuzzy/vague in nature. So, direct segmentation techniques will not produce better results. There are lots of researches on edge enhancement starting from non-fuzzy to fuzzy set, but proper enhancement (highlighting important structures) is not obtained. Enhancement of edges helps in recovering the important structures that are not visible properly. Even minute pathological blood vessels/cells are not visible properly and in that case edge enhancement will enhance these blood vessels/cells. Intuitionistic fuzzy set theory is found suitable in medical image processing as it considers more (two) uncertainties as compared to fuzzy set theory. In the processing phase, image is initially converted to intuitionistic fuzzy image and intuitionistic fuzzy entropy is used to obtain the optimum value of the parameter in the membership and non-membership functions. Then it computes the total variation of the pixels with respect to the median value of the image window (rank order filtering). This enhances the borders or the edges of the image. The resulting image is then segmented (edge detected) using standard Canny's edge detector, when simply using Canny's edge detector does not give better result. From the result it is observed that on comparing with non-fuzzy and fuzzy methods, the proposed method gives better information about the images, which is helpful to the pathologists in accurate diagnosing of diseases.

1. Introduction

In cellular imaging, it is very important to count the number of blood vessels or cells. Also, in the detection of abnormal lesions, once the boundary is enhanced, morphological features such as area, perimeter, compactness, form factor, roundness, etc. can be computed. These features are used in biomedical quantitative analysis and can be evaluated using standard edge detection techniques such as Sobel, Prewitt, Roberts, Laplacian of Gaussian [12], Canny's edge detector [4] and so on. Canny's edge detector is the most widely used and successful method. Direct applying these operators on medical images does not give accurate edges.

As medical images are poorly illuminated, edges/boundaries are fuzzy/vague in nature; direct edge detection techniques will give discontinued and broken edges. So, preprocessing is required to obtain good and clear edge images. Pre processing is the image enhancement that plays an important role in image processing. It highlights the important features or the features that are not properly visible and suppresses unwanted information that is not relevant to image processing tasks. Enhancement may be edge enhancement or contrast enhancement. Edge enhancement enhances the edges/boundaries of the image thereby suitable for edge detection where as contrast enhancement enhances the overall quality of the image. Median filtering is a good technique that preserves the boundaries and then on calculating the total variation with respect to the central pixel of the filter window, an image with enhanced boundary is obtained. The image is then edge detected using any edge detection methods.

In image processing, median filter is usually used to remove an impulse noise and restores the sharp discontinuities whereas mean filter blurs the image. Also, as median value is one of the pixels present in the window, so median filter does not create any new pixel value when it crosses an edge. Many authors [1,8] suggested modified median filter to overcome the drawbacks when the filter is prone to alter the pixels, which are undisturbed by noise. Image enhancement using both crisp and fuzzy method is suggested by many authors. When the image is considered fuzzy, fuzzy enhancement [10,11,13,14] techniques are used where each pixel is assigned membership degree. But the use of these methods on medical pathological images does not give better results.

Image edge detection followed by rank ordered filter in cellular image is suggested by Xu et al. [17]. They used Weiner filter to remove noise and computed the total variation with respect to the central pixel of the filter to enhance the edges of the nuclei cells.

* Tel.: +91 3222 264014.
E-mail addresses: tchaira@yahoo.com, ird7909@cbme.iitd.ac.in

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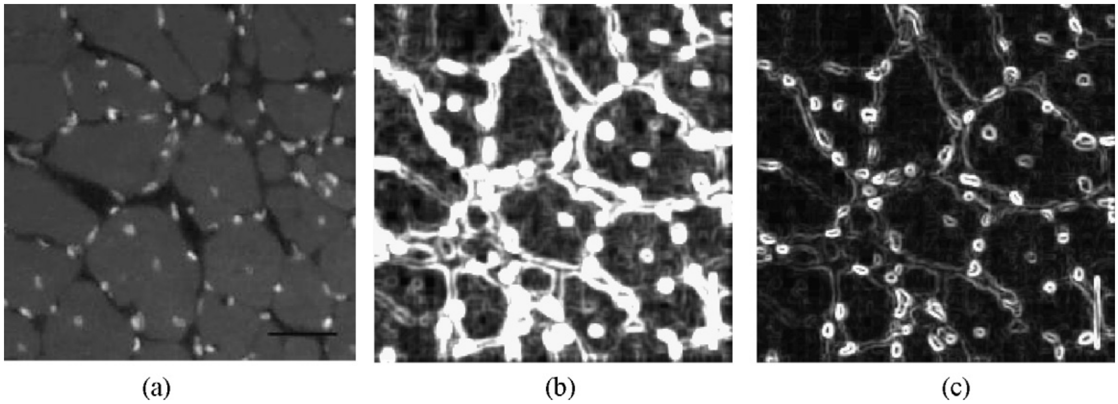

Fig. 1. (a) Original image, (b) window of size 5 × 5, (c) window of size 3 × 3.

Then edges are detected using Canny's edge detector followed by morphological operation such as 'spur' and 'clean'. The drawback in their methods is that many of the nuclei are missed i.e. proper enhancement is not done.

There is very little work using intuitionistic fuzzy set theory (IFS) introduced by Atanassov in 1986. It is a generalized form of fuzzy set theory. It takes into account two uncertainty parameters – membership degree and non-membership degree (due to the hesitation degree). Hesitation degree is the lack of knowledge or personal error that arises while defining the membership function. So, the non membership degree is not the complement of the membership degree as in the ordinary fuzzy set, rather, less than or equal to the complement of the membership degree. It gives an additional possibility to represent vague knowledge and thus makes possible to solve many real problems adequately. Intuitionistic fuzzy contrast enhancement on general images is suggested by Vlachos and Sergiadis [15] but it was not applicable to medical images. Intuitionistic fuzzy edge detection is introduced by Chaira and Ray [5]. A preliminary work on edge enhancement on medical images using intuitionistic fuzzy set theory is found in Chaira [6].

In this paper, a novel method that enhances the edges of medical image followed by edge detection using intuitionistic fuzzy set theory is suggested. Edge enhancement helps in recovering the structures in the image that are not properly visible. It initially creates an intuitionistic fuzzy image and then calculates the optimal value of the parameter in the membership and non-membership degree using intuitionistic fuzzy entropy. It then computes the total variation of the image pixel with respect to the central pixel of the median filter. This enhanced image is then edge detected for obtaining a clear boundary of the cells and also increases the accuracy while counting the number of the cells or blood vessels or segmenting abnormal lesions and so on.

The paper is organized as follows. In Section 2, the preliminaries on intuitionistic fuzzy set is presented while Section 3 details the methodology. Section 4 displays the results followed by discussion. Conclusion along with future direction is drawn in Section 5.

2. Preliminaries

A fuzzy set A in a finite set $X = \{x_1, x_2, x_3, \ldots, x_n\}$ may be represented mathematically as:

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

where the function $\mu_A(x) : X \to [0, 1]$ is the membership degree of an element x in the finite set X. Thus, automatically the non-belongingness is $1 - \mu_A(x)$.

Atanassov's [2] introduced intuitionistic fuzzy set that takes into account the membership degree, μ, and also the non membership degree, ν, of the elements of a set.

An intuitionistic fuzzy set A in a universal set X is given by:

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

where $\mu_A(x) \to [0, 1]$, $\nu_A(x) \to [0, 1]$ are the membership and non-membership degrees of an element x to the set A with the condition

$$0 \le \mu_A(x) + \nu_A(x) \le 1$$

When $\nu_A(x) = 1 - \mu_A(x)$, every x in set A becomes a fuzzy set.

The hesitation degree, $\pi_A(x)$, which arises due to lack of knowledge while defining the membership degree, for each element x in A and is given by:

$$\pi_A(x) = 1 - \mu_A(x) - \nu_A(x) \tag{1}$$

Obviously, $0 \le \pi_A(x) \le 1$.

Due to the hesitation degree, the membership values lie in an interval range.

3. Methodology

The basic requirement in intuitionistic fuzzy image processing is the computation of membership and non-membership degrees. There is a parameter, λ, present in the intuitionistic fuzzy membership functions. The optimal value of the parameter is obtained by maximizing intuitionistic fuzzy entropy.

An intuitionistic fuzzy image is written as:

$$A_{IFS} = \{x, \mu_A(g_{ij}), \nu_A(g_{ij})\}, \quad g_{ij} \in \{0, \ldots, L-1\}$$

g_{ij} is the pixel value at (i, j)th point. $i = 0, 1, 2, \ldots, N-1$, $j = 0, 1, 2, \ldots, M-1$.

Image (say A) of size $M \times N$ is initially fuzzified using the formula:

$$\mu_A(g_{ij}) = \frac{g_{ij} - g_{\min}}{g_{\max} - g_{\min}} \tag{2}$$

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

Based on the fuzzy set, the membership degree of intuitionistic fuzzy image is calculated as [15]:

$$\mu_{IFS}(g_{ij}; \lambda) = 1 - (1 - \mu_A(g_{ij}))^{\lambda} \tag{3}$$

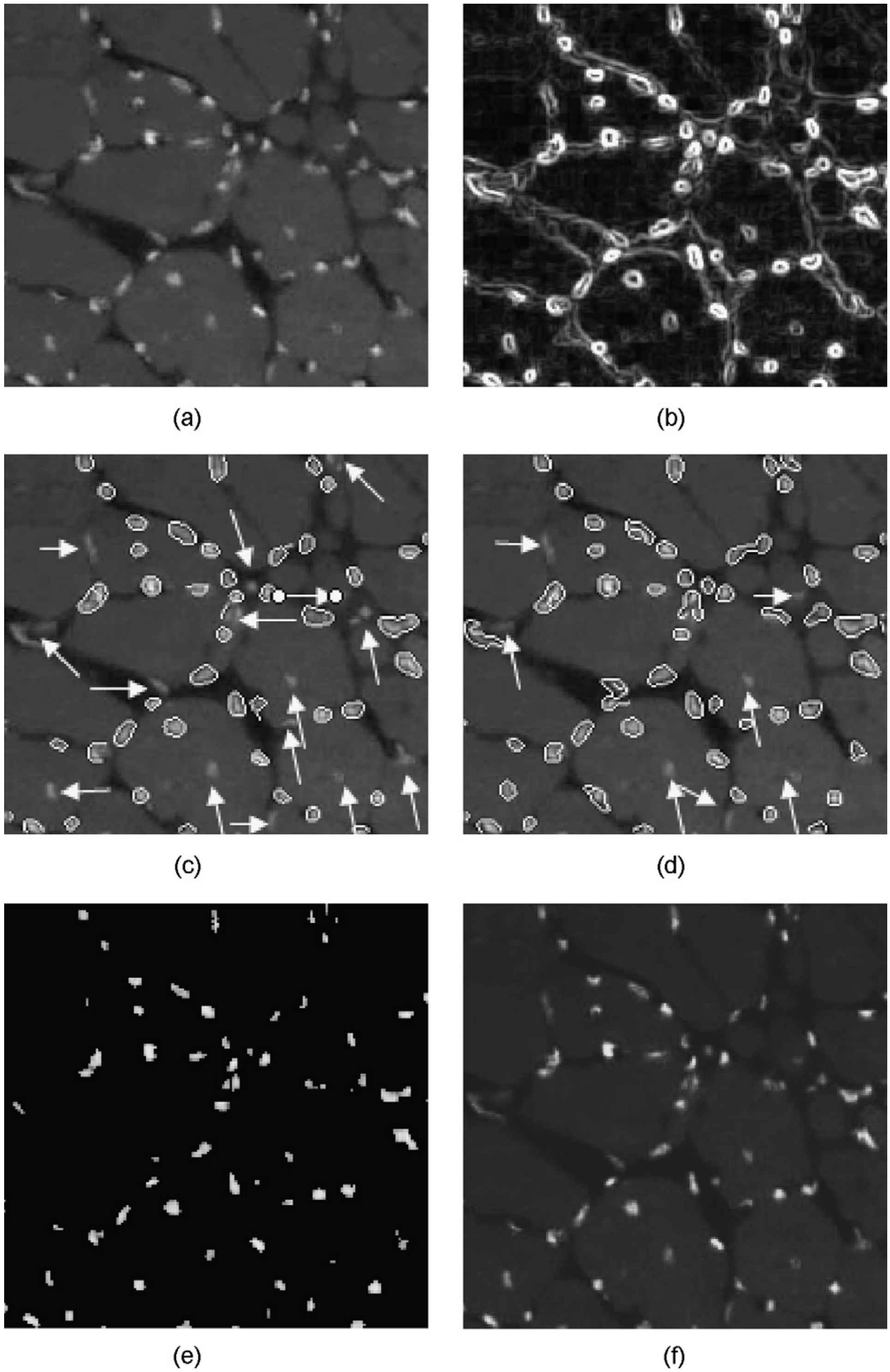

Fig. 2. (a) Nuclei image, (b) edge enhanced image using proposed method, (c) edge detected image using Xu's method, (d) edge detected image using proposed IFS method, (e) enhancement using fuzzy hyperbolization, (f) enhanced image using fuzzy NINT operator.

Using standard fuzzy negation, $\varphi(x) = (1 - x)^{(\lambda+1)}$, $\lambda \geq 0$ the non membership function is given by $\nu_{IFS}(g_{ij}; \lambda) = \varphi(\mu_{IFS}(g_{ij}; \lambda))$So

$$\begin{aligned} \nu_{IFS}(g_{ij}; \lambda) &= (1 - \mu_{IFS}(g_{ij}; \lambda))^{\lambda+1}, \lambda \geq 0 \\ &= (1 - \mu_A(g_{ij}; \lambda))^{\lambda(\lambda+1)} \end{aligned} \quad (4)$$

The hesitation degree, $\pi_{IFS}(g_{ij}; \lambda) = (1 - \mu_{IFS}(g_{ij}; \lambda) - \nu_{IFS}(g_{ij}; \lambda))$.

By varying λ parameter, different intuitionistic fuzzy sets can be obtained. As λ is not fixed for all the images, optimum value of λ is obtained using intuitionistic fuzzy entropy.

Entropy: Entropy plays an important role in image processing. De Luca and Termini [9] was the first to introduce the skeleton of non probabilistic entropy in the settings of fuzzy set theory. Since then different types of entropies are given by many authors. Authors [3,7,15,16] also suggested different entropy measures using intuitionistic fuzzy set theory. In this work, the intuitionistic

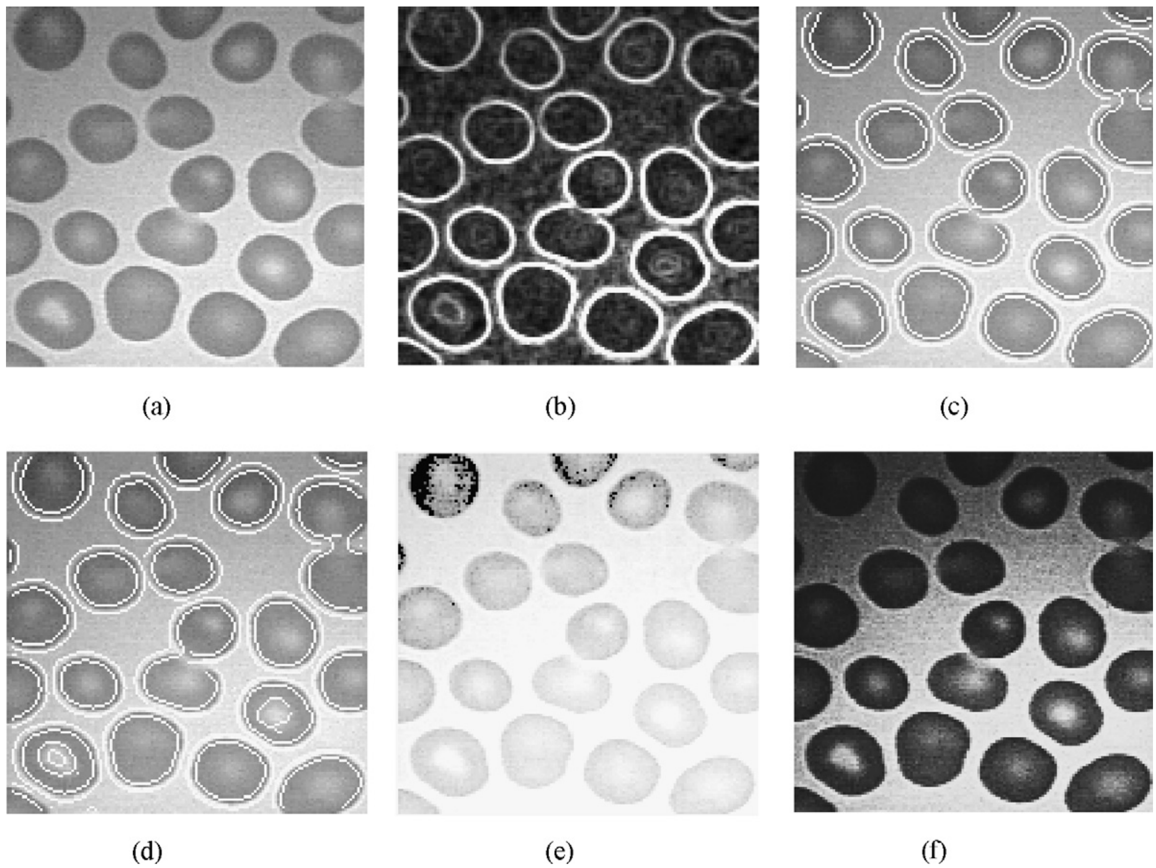

Fig. 3. (a) Blood cell image, (b) edge enhanced image using proposed method, (c) edge detected image using Xu's method, (d) edge detected image using proposed IFS method, (e) enhanced image using fuzzy hyperbolization, (f) enhanced image using fuzzy NINT operator.

fuzzy entropy (IFE) as given by Vlachos et al. is used and is written as:

$$IFE(A;\lambda)=\frac{1}{N\times M}\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}\frac{2\mu_A(g_{ij})\nu_A(g_{ij})+\pi_A^2(g_{ij})}{\pi_A^2(g_{ij})+\mu_A^2(g_{ij})+\nu_A^2(g_{ij})} \quad (5)$$

IFE is calculated [Eq. (5)] for all the λ values. The optimum value of λ that corresponds to the maximum value of the entropy values is written as:

$$\lambda_{opt}=\max(IFE(A;\lambda))$$

With the λ value known, intuitionistic fuzzy membership degrees of the pixels are computed using Eq. (3) and an intuitionistic fuzzy image is formed.

Median filter of size 3×3 is applied over the intuitionistic fuzzy image. The corresponding area of the image covered by the median filter is the image window. The median value, surrounding the current pixel $A(m, n)$ of the image window, is written as follows:

$$Z(m,n)=median\{A(m-i,n-j)\},\ (i,j)\in\phi(m,n),$$

$\phi(m, n)$ is the window. $m = 1, 2, \ldots, M; n = 1, 2, \ldots, N$.

Total variation in the 3×3 image window with respect to the median of the window is computed as:

$$I(m,n)=\sum_{i,j\in W} abs(A(i,j)-Z(m,n)) \quad (6)$$

i, j are the pixels in the 3×3 window. W is the window.

In this work, the size of the median filter and the size of the image window remain same. For each pixel position, $I(m, n)$ is computed and a new difference matrix is formed. The new matrix is an edge enhanced image.

The window size of 3×3 is chosen to obtain a good enhanced image. If the window size is increased, the enhanced image will be very blurred as shown in Fig. 1. Fig. 1(b) is the edge enhanced image using 5×5 window. Fig. 1(c) is the edge enhanced image using size 3×3.

If the difference image contains unwanted lines, the image is filtered using Gaussian filter. After filtering, image is then edge detected using standard Canny's edge detector.

4. Results and discussion

Experiment is performed on several medical images. Five sets of different types of medical images are shown below. Results are compared with Xu's non-fuzzy method [17] and two fuzzy methods such as fuzzy histogram hyperbolization [14] and fuzzy NINT operator [10]. Xu's non-fuzzy method and the proposed intuitionistic fuzzy set (IFS) method are edge enhanced methods where edges are enhanced and so these are shown together. The other two fuzzy methods–fuzzy hyperbolization and fuzzy NINT operator are the contrast enhancement methods, where the overall image is enhanced.

Fig. 2(a) is the image of nuclei. An edge enhanced image using the proposed method is shown in Fig. 2(b). In this edge enhanced image, it is observed that many unwanted lines are visible and so the difference image is filtered with Gaussian filter. From Fig. 2(c), it is observed that the number of missed nuclei is 15 and in the proposed method in Fig. 2(d), the number of missed nuclei is 7. So, the proposed method gives better information in terms of counting. Fig. 2(e) is an enhanced image using fuzzy histogram

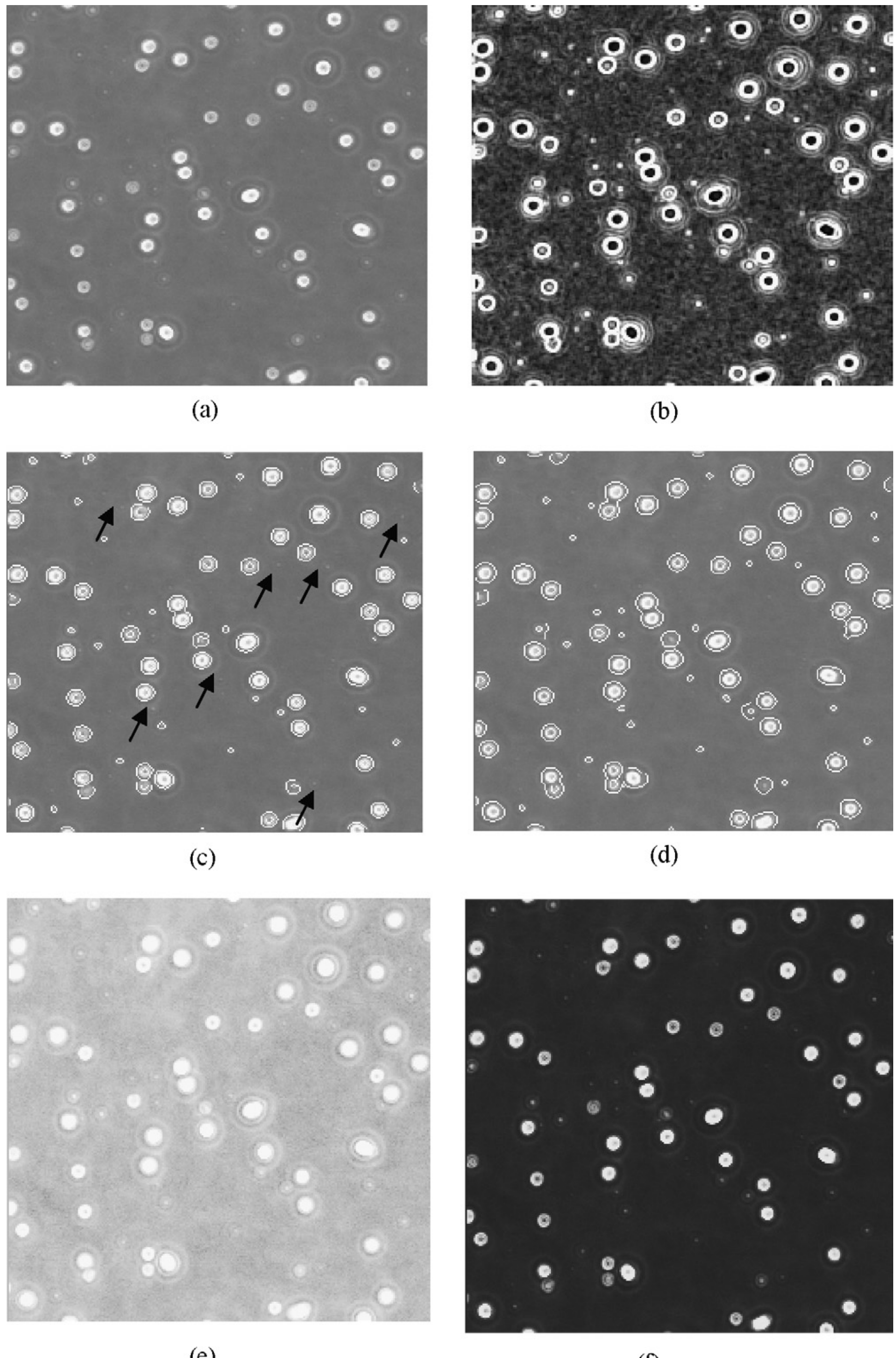

Fig. 4. (a) Live_cell_ image_1, (b) edge enhanced image using proposed method, (c) edge detected image using Xu's method, (d) edge detected image using proposed IFS method, (e) enhanced image using fuzzy hyperbolization, (f) enhanced image using fuzzy NINT operator.

hyperbolization and the number of vessels detected is similar to the proposed method. But manually counting is very difficult as the blood vessels are very small and some are like spots. Fig. 2(f) is an enhanced image using fuzzy NINT operator where the image is not properly enhanced, so blood vessel counting cannot be done.

Fig. 3(a) is a figure of a poorly illuminated blood cell image of size 160×160. Fig. 3(b) shows the edge enhanced image using the proposed method where all the edges are enhanced. Fig. 3(c) and (d) are the methods obtained using Xu's method and proposed intuitionistic fuzzy method respectively. It is observed that both the methods give similar result with clear boundary. Fig. 3(e) using fuzzy histogram hyperbolization shows that the overall image and the blood cells are very bright and Fig. 3(f) using fuzzy NINT operator shows that the upper portion of the image is almost dark.

Fig. 4(a) is an image of live cells. The edge enhanced image using the proposed method is shown in Fig. 4(b). As no unwanted lines are visible, filtering is not required. From Fig. 4(c), it is observed

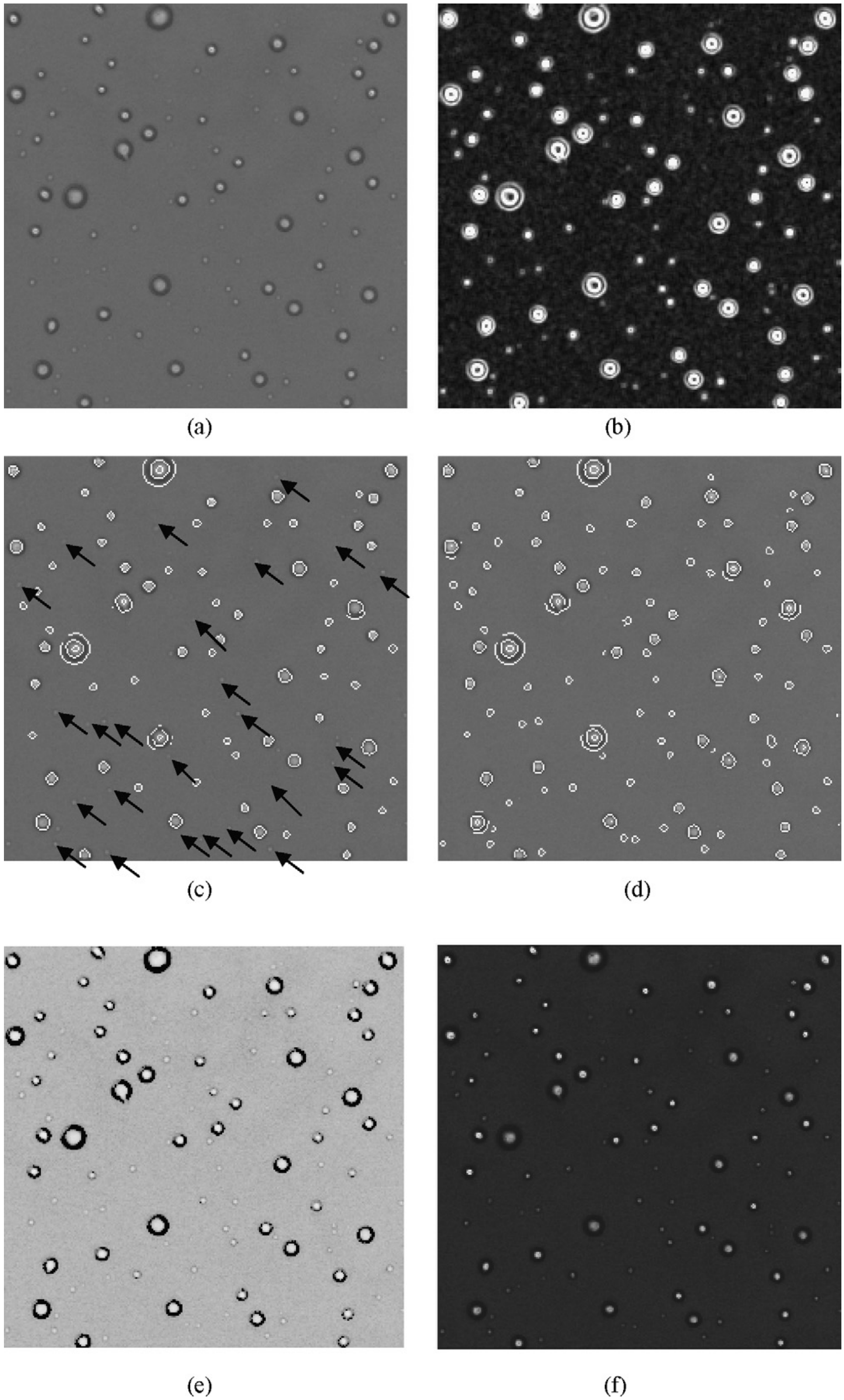

Fig. 5. (a) Live_cell_image_2, (b) edge enhanced image using proposed method, (c) edge detected image using Xu's method, (d) edge detected image using proposed IFS method, (e) enhanced image using fuzzy hyperbolization, (f) enhanced image using fuzzy NINT operator.

that the number of missed nuclei is 20 and the number of missed nuclei in the proposed IFS method in Fig. 4(d) is 13. In Fig. 4(c), the number of nuclei that are detected in the proposed IFS method but not in Xu's method is shown and this is 7. Fig. 4(e) shows the enhanced image using histogram hyperbolization but the image is so bright that the smaller cells are not visible properly and after edge detection, these smaller cells are not visible. Fig. 4(f) shows the enhanced image using fuzzy NINT operator where it is observed that the smaller cells are hardly visible and so counting of missed cells cannot be done.

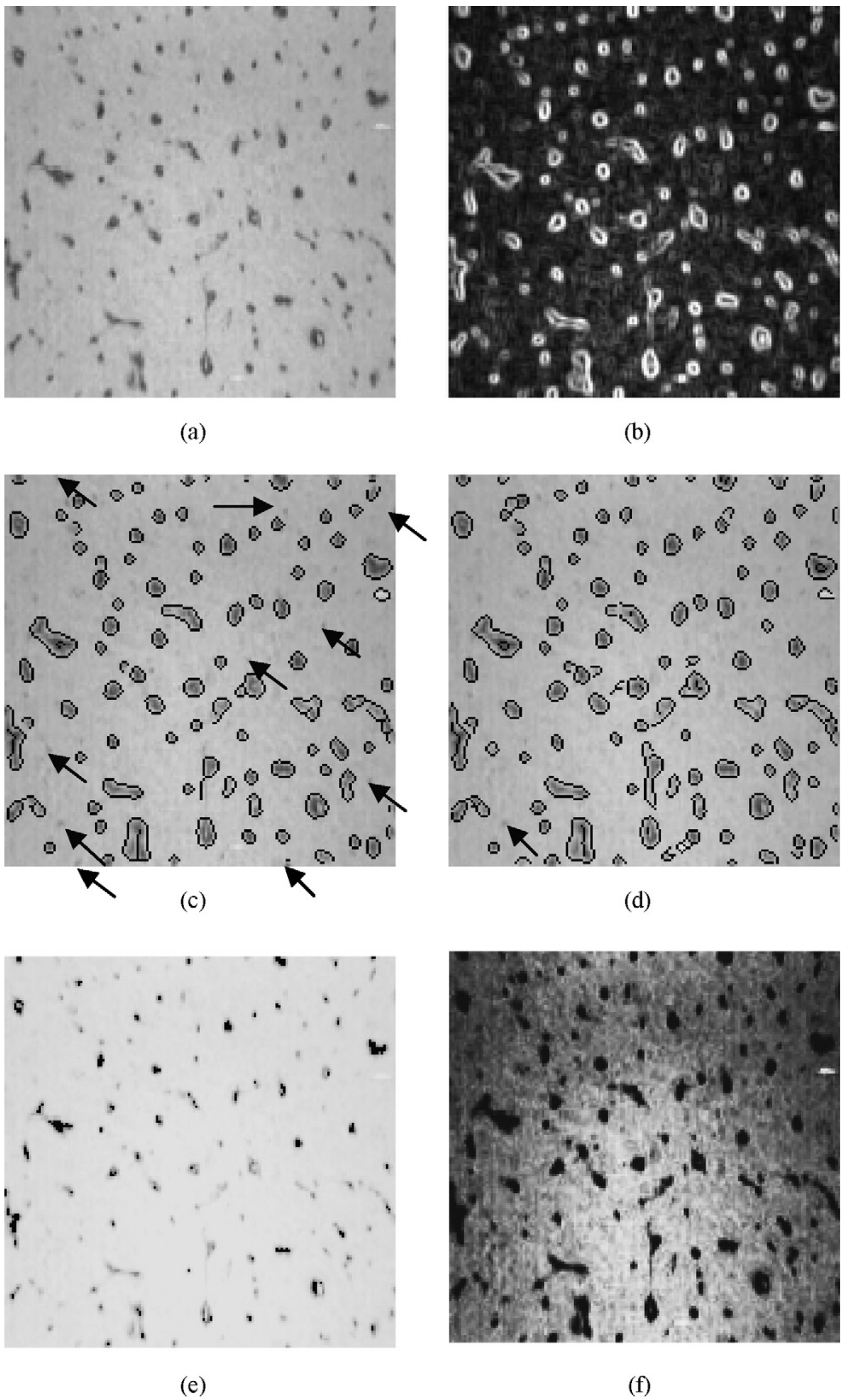

Fig. 6. (a) Blood vessel image, (b) edge enhanced image using proposed method, (c) edge detected image using Xu's method, (d) edge detected image using proposed IFS method, (e) enhanced image using fuzzy hyperbolization, (f) enhanced using fuzzy NINT operator.

Fig. 5(a) is an image of live cells. The edge enhanced image using the proposed method is shown in Fig. 5(b). As no unwanted lines are visible, filtering is not required. From Fig. 5(c), it is observed that the number of nuclei detected in Xu's method is 70 and the number of missed nuclei in is 33. The proposed method in Fig. 5(d) shows that the number of nuclei detected is 95 and number of missed nuclei is 8. The cells that are detected in the proposed method in Fig. 5(d) but not detected in the Xu's method are marked with arrow and this is 25 as shown in Fig. 5(c). The nuclei that are missed in the proposed method (which is 8 in this image) are not shown because the nuclei that are missed are not properly visible in the original image but are visible in the enhanced image shown in Fig. 5(b).

Table 1
No. of missed blood vessels in both the methods.

Images	Xu's method	Intuitionistic fuzzy method
Nuclei_image	15	7
Blood cell image	–	–
Live_cell_image_1	20	13
Live_cell_image_2	33	8
Blood_vessel	10	1

So, the number of missed nuclei is counted manually on viewing the enhanced image. Thus the total number of missed nuclei in the Xu's method is 33 and that of in the proposed IFS method is 8. To avoid congestion, the nuclei that are not detected in Xu's method but detected in the proposed method are shown, i.e. 25 nuclei are shown in Fig. 5(c). As the objective is to detect and count the cells, so the broken edges do not create any problem. So, the proposed intuitionistic fuzzy method provides more information.

Fuzzy histogram hyperbolization in Fig. 5(e) shows that the image is very bright and so the cells – both larger and smaller ones, are not enhanced properly. As the enhanced image is bright, after edge detection the smaller cells are not in picture. Fuzzy NINT operator in Fig. 5(f) shows that the enhanced cells are very small and the smaller ones in the original image are not visible properly. It becomes very difficult to count the cells. So cell counting is not done.

Fig. 6(a) is an image of blood vessel of size 160×160. The edge enhanced image using the proposed method is shown in Fig. 6(b). As no unwanted lines are visible, filtering is not required. From Fig. 6(c) and (d), it is observed that the blood vessels are circumscribed by the edges to have a clear view of the blood vessels that are missing. It is observed that the number of blood vessels not detected in Xu's method but detected in the proposed method is 9 and the number of missed blood vessel in the proposed intuitionistic fuzzy method is 1. So, total number of missed blood vessels in the Xu's method is 10 and that of in the proposed method is 1. In this figure, all the missed blood vessels are shown in both the methods. Fuzzy methods in Fig. 6(e) and (f) show the enhanced images with much lighter and darker blood vessels respectively. So it becomes very difficult to count the blood vessels.

Table 1 shows the number of missed nuclei or blood vessels in Xu's method and the proposed IFS method.

5. Conclusion

This paper provides a new approach to edge enhancement followed by edge detection of medical images using intuitionistic fuzzy set theory. It is seen that the edge enhanced results on the images are far better than the other existing methods. This will help in counting the nuclei and blood vessels in pathological images and also it may be used in segmenting vague abnormal lesions. Total variation of the pixel is calculated with respect to the central pixel after median filtering. The algorithm is tested on different types of human cell images, blood vessel images and it is observed that the proposed method gives better accuracy (better edge enhancement) in terms of blood vessel count as compared with the non-fuzzy and fuzzy approaches.

The fact that better results are obtained by using intuitionistic fuzzy set theory is that it considers more number of uncertainties, and as medical images are low contrasted with vague region/boundaries, intuitionistic fuzzy set gives better result. Fuzzy set theory may give better result, but it considers only one uncertainty parameter i.e. the membership function. When membership function is not always accurately defined due to the lack of personal error, an intuitionistic fuzzy set may help in solving the problem. From the edge enhancement method, morphological features such as area, perimeter, roundness, etc. of the cells may be computed.

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