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Review paper

Applications of Neutrosophic Logic in Image Processing: A Survey

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Abstract

Background and Objectives: Images and videos play significant roles in our lives. Moreover, there are considerable improvements in computer data collection systems; therefore, anyone is able to acquire much many images or videos, whereas he/she cannot process them manually. Images and videos have become attractive since depicting and digital processing of these kinds of data became possible. Since indeterminacy surrounded the world, including images and videos of that; imprecision is needed to interpret this world.
Methods: Neutosophic logic, which is from philosophy and is also included of logic, set theory and probability/statistics, is able to depict this imprecision. As a result, advanced image processing can be defined by translation of image processing into neutrosophic domain. In this paper, first of all, a general introduction about image/video processing (segmentation, noise reduction and image retrieval) and uncertainty is stated. Then, definitions of fuzzy sets, intuitionistic fuzzy sets and neutrosophic sets are expressed. In the following, applications of neutrosophic domain in image and video processing such as segmentation, noise reduction and image retrieval are introduced.
Results: Although, neutrosophic is used for image restoration and segmentation; input images are usually medical images or gray level natural images. The remarkable point is that there are few researches that focuse on image restoration or segmentation using neutrosophic and consider color images. Therefore, color image restoration and segmentation in neutrosophic domain is novel to be done.
Conclusion: Neutrosophic usage in image retrieval brings out an improvement in average recall and precision measure compared to earlier methods. Considering different textures and shapes can extend usages of neutrosophic space in image retrieval applications.

Introduction

Image and video processing is the most common processing technique which is used in medical images, remote sensing images, videos from security cameras and natural videos [1]-[4]. Image processing is important in different systems of information achievement. The word image processing actually stands for a set of technique which can change an image with the purpose of improving that (making it better in terms of quality, storage space, etc) or extracting some information from that.

Neutrosophic set which is from neutrosophic theory, brings out some studies of neutralities from origin, nature and scope of neutralities points of view.

Neutosophic is applied into image and video processing applications with the purpose of giving a powerful tool which can help describing image containing uncertain information; it is done by separating the problem into three subsets: true, false and indeterminacy.

In the following, some image processing applications such as image segmentation, noise reduction and image retrieval are described.

Image segmentation can be nominated as a very important issue in image processing and pattern recognition problems; it is also a difficult task.

Image segmentation is a significant part of work in applications such as medical imaging, object recognition, robot vision and so on [5]-[7]. It actually means dividing an image into various regions while each region is itself homogeneous but two adjacent regions are not similar [8]. Segmentation is noticeable for machine learning and computer vision researches. Abundant applications which are extending, are dependent to careful and efficient segmentation mechanism [9]. Of course, you can see review papers [10] and [11] for more study on image and frame segmentation using deep learning.

Images and videos are mostly affected by noise. Noise may occur during capturing, transmission and etc. Therefore, it seems significant to remove the mentioned noises from images and videos [12]. Image restoration is about recovering an original scene from damaged scenes. Image restoration can be used in some fields such as astronomical imaging, motion picture restoration, defence, printing and investigation applications and medical imaging [13].

A system which is used for image retrieval, is applied to search a large database of images with the purpose of retrieving images from that. In such systems, the goal is to retrieve images corresponding to the user's request from a large image database [14].

Fuzzy set theory was initially introduced by Zadeh (1995) in [15] to consider uncertainty in database. Fuzzy sets show acceptance, rejection and uncertainty parts using single-valued membership function in [0,1]. Yet, they cannot depict indetermination individually. As a result, Smarandache (1998) introduced netrosophic logic and sets in [16]. Neutrosophic is an extended family of attractive mathematics theories along with a review on fuzzy concepts.

Single valued neutrosophic include membership function values of truth, false and indeterminacy for each attribute. These three functions are independent; in other words, one function is not affected by another one. To discuss the neutrosophic application in image processing, firstly, fuzzy sets, intuitive fuzzy and neutosophic are explained. You can see [17]-[20] for more study.

Fuzzy Sets

First attempt towards fuzzy sets was [15]. Zadeh described uncertainty to define membership in these sets and assigned values rated in [0,1] for these sets.

Assume that *U* is a universal set. A subset *A* in which membershsip of each member *uϵU* is presented as a function f_A: $U \rightarrow [0,1]$. $f(u) \in [0,1]$ is degree of belonging *u* to *A*. As much as f_A is nearer to 1 for each member in *U*, its grade of membership is more and the statement *uϵA* is more correct. Also, as much as f_A is nearer to zero for each member in *U*, its grade of membership is less and the statement *uϵA* is more incorrect [15]. Fig. 1 depicts an example of membership functions definitions; it shows membership functions of the linguistic importance weight [21].

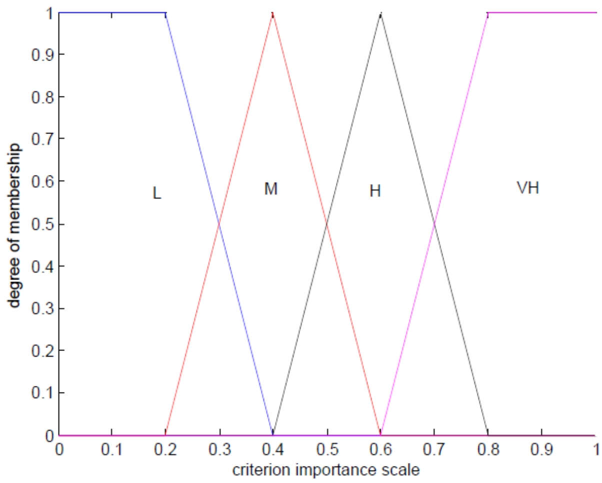


Fig. 1: Membership functions defined for linguistic importance weight [21]. L: Low importance, M: Moderate importance, H: High importance, VH: Very High importance.

In [22], an example of fuzzy applications in image processing is shown.

This study proposed an advanced image segmentation algorithm which considered patch-weighted distance and fuzzy clustering; this algorithm was stated in two steps: First, patch-weighted distance was used to retrieve the pixel correlation between adjacent pixels and second, the pixel correlation is applied to put down the effect of neighborhood information in fuzzy algorithms which leads to robustness enhancement.

Intuitionistic fuzzy sets

An intuitionistic fuzzy set for a universal Set *A* which assigns two values "membership" and "non-membership" degrees to each member *uϵU* is considered as a function f_A: $U \rightarrow [0,1] \times [0,1]$ so that $f_A(u) = (\mu_A(u), v_A(u))$ and $0 \le \mu_A(u) + v_A(u) \le 1$ for each *uϵU*. Here, $\mu_A(u)$ is membership function and $v_A(u)$ is non-membership function; both functions are fuzzy; therefore, intuitionistic fuzzy sets are called as two dimensional fuzzy sets. $\pi_A(u) = 1 - \mu A(u) - \nu A(u)$ is called the hesitancy for membership degree for u in A [20]. Fig. 2 shows an example of intuitionistic fuzzy set which depicts membership and non-membership functions [23].

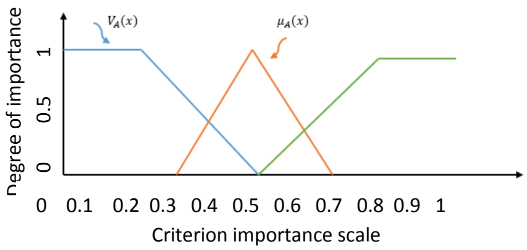


Fig. 2: Intuitionistic fuzzy set [23].

Neutrosophic Set

The concept neutrosophic was initially introduced in 1998 by Smarandache [16].

This set not only define membership and non-membership, but also they give attention to indeterminacy. The term neutrosophy means having neutral thinking.

Three functions T_A (truth membership function), I_A (indeterminacy membership function) and F_A (falsity membership function) are defined to create a neutrosophic set (A) in U. For each member $u \in U$, values $T_A(u)$, $I_A(u)$ and $F_A(u)$ are subsets of standard or non-standard real numbers in [0,1].

$$T_A: U \to [^-0, 1^+]$$

$$I_A: U \to [^-0, 1^+]$$

$$F_A: U \to [^-0, 1^+]$$

There is no limit on summation of $T_A(u)$, $I_A(u)$ and $F_A(u)$; So:

$$0 \le (u) + sup I_A(u) + sup F_A(u) \le 3$$

Since neutrosophic set considers inconsistency and uncertainty for for real life problems, many applications such as ones related to optimization, use this concept. These applications are: image segmentation [24], image retrieval [25], image noise reduction [26], data envelopment analysis [27], [28], linear programming with nonlinear method [29], linear programming with triangular neutrosophic [30], multi-attribute decision making (MADM) problem [31], optimal path selection [32], [33] and etc.

Authors presented an abstraction of advantages and disadvantages of uncertainty algorithms in [34].

A. *Neutrosophic Image Segmentation*

Applications of neutrosophic image segmentation are divided into two categories based on whether deep neural network is used or not:

- **Applying neutrosophic for image segmentation using deep neural networks**

In [35], authors combined deep convolution neural network and neutrosophic; it once applied deep convolution neural networks for MRI images. Then, it used sets T, I and F in neutrosophic domain to update network's weights. Finally, it reused deep convolution neural network with new weights for images.

Authors assumed layer number as l-1, m^{th} input feature as $x^{l-1}(m)$ and the filter's weight $W^l(m,n)$ which connects n^{th} feature of the output layer to the m^{th} feature of the input layer. $x^l(n)$ in the l^{th} convolution layer is as (1):

$$x^l(n) = f(\textstyle\sum_m (x^{l-1}(m) * W^l(m,n) + b^l(n))) \quad (1)$$

where $b^l(n)$ stands for bias, $*$ represents convolution operation and f is a nonlinear sigmoid function which is acquired by (2).

$$f(x) = \frac{1}{1+e^x} \quad (2)$$

In the pooling layer l, $x^l(n)$ is determined using (3).

$$x^l(n) = pool(x^{l-1}(n)) \quad (3)$$

$pool(.)$ represents a sampling function. During the training phase, we have:

$$T_m(i) = \overline{S_m(i)} \quad (4)$$

$$I_m(i) = S_m^h(i) - S_m^l(i) \quad (5)$$

$$F_m(i) = S_m^l(i) \quad (6)$$

where $\overline{S_m(i)}$, $S_m^h(i)$ and $S_m^l(i)$ are the average value, highest value and lowest value of the sample batch i for the m^{th} model.

Authors of [36] started by strictly defining both pixel and feature attributes. Then, fuzzy C-means clustering is applied on pixel's intensity value. In the following, deep convolution neural network with SVM classifier is used. Finally, the acquired result will be evaluated.

Authors brought forward the following pseudo code to get to final result.

1. Obtain the data included in an image.
2. Fix the cluster numbers
3. Apply center initialization algorithm to initialize the cluster centers.
4. Determine partition matrix.
5. Update centers of the clusters.
6. Apply classifiers DCNN and SVM; the image features and classification will be acquired.

Repeat step 4 to 6 until the stop criterion is reached: Absolute difference between vectors of cluster prototypes at previous iteration and the ones at present iteration is smaller than a predefined threshold named ε.

In [37], authors added high resolution to the above research. Authors have researched on medical image segmentation for brain tumor diagnosis and introduced the objective function for FCM approach as (7):

$$Jm = \sum_{i=1}^{Cl} \sum_{k=1}^{N} u_{ik}^{m} \|im_k - v_i\|^2, \qquad 1 < m < \infty \tag{7}$$

In [38], combination of neutrosophic and deep convolution neural network is done based on [35].

Survey [39] gives a fully study on image segmentation using combination of neutrosophic and deep convolution neural network. In [40] worked on semi-automatic video object segmentation; mask is determined on the first frame, an object in video is separated from background. Here, semantic one-shot video object segmentation is done. Authors proposed a new framework in [41] for object segmentation with identification used for unsupervised automatic video object segmentation. These authors believe that this field can be studied more and more; because it is a new concept; the mention algorithm is as follow:

- Initialize an empty list of trackers $tr\_list \leftarrow \emptyset$
- For frames *T = 0, 1, …,M* do
  - *D*← Detect objects in T with threshold θ_1
  - TR← Update trackers in tr_list with threshold θ_2
  - DM,TRM ← Match masks in D with masks in TR
  - Use DM to re-initialize trackers in tr_list
  - Initialize an empty set of new targets DN← ∅
  - For x ∈ D \ DM do
    - If salient(label(x)) then
      - Add x to DN
      - Initialize a new tracker tr with x
      - Append tr to tr_list
    - End if
  - End for
  - Output masks DM ∪DN∪ (TR \ TRM)
- End for

Fig. 3 illustrates usage of deep neural networks for image segmentation.

- **Applying neutrosophic for image segmentation without using deep neural networks**

In [43], authors transformed the image into neutrosophic domain; as a result, three membership degree sets would be defined as *T* (truth), *I* (indeterminacy) and *F* (falsity) using (8)-(12).

$$t(i,j) = \frac{\overline{g(i,j)} - \overline{g}_{min}}{\overline{g}_{max} - \overline{g}_{min}} \tag{8}$$

$$i(i,j) = \frac{\delta(i,j) - \delta_{min}}{\delta_{max} - \delta_{min}} \tag{9}$$

$$f(i,j) = 1 - t(i,j) \tag{10}$$

$$\overline{g(i,j)} = \frac{1}{w \times w} \sum_{m=i-w/2}^{i+w/2} \sum_{n=j-w/2}^{j+w/2} g(m,n) \tag{11}$$

$$\delta(i,j) = abs\left(g(i,j) - \overline{g(i,j)}\right) \tag{12}$$

where $g(i,j)$, $\overline{g(i,j)}$ and $\delta(i,j)$ are the intensity of the pixel at coordinates (i,j), the local average of intensities and the absolute difference between $g(i,j)$ and $\overline{g(i,j)}$.

Entropy is defined in neutrosophic and is used to evaluate unreliability. Two operators α-mean and β-enhancement are applied to decrease set's unreliability. At the end, γ-means clustering is applied for segmentation.

As described above, clustering is used for segmentation. Authors applied neutrosophic for clustering in [44]. The important idea was the way neutrosophic was used to find border and outside data points which were actually challenging points considered in clustering problems. In the beginning, data indeterminacy was defined in neutrosophic domain (indeterminate set) based on data expansion feature. Data points in outspread regions will be given less indeterminacy value and vice versa. In second step, clustering is done for each data point based on distance from cluster center. Here you can see the algorithm:

Input: A set of multi-dimension data points.

Output: Cluster labels for each data point.

- Initialize T and F sets in neutrosophic domain randomly.
- Initialize parameters c, $w1$, $w2$, Eps, K and m.

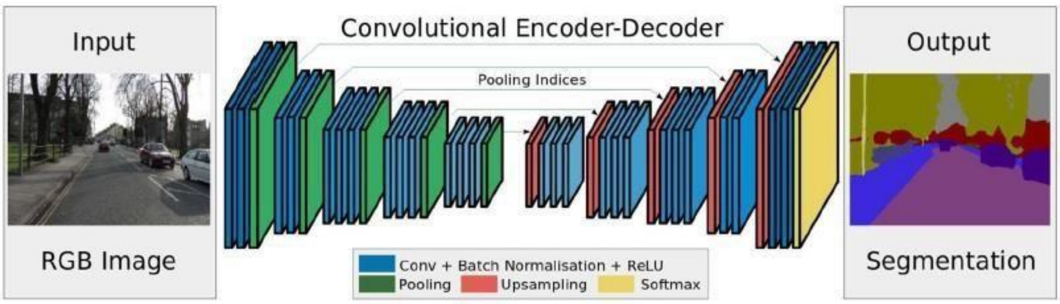


Fig. 3: SegNet architecture [42].

$$S_{C_j}(A_i, A^*) = \frac{w_k\left[T_{C_j}(A_i)T_{C_j}(A^*)+I_{C_j}(A_i)I_{C_j}(A^*)+F_{C_j}(A_i)F_{C_j}(A^*)\right]}{\sqrt{w_k\left(T_{C_j}{}^2(A_i)+I_{C_j}{}^2(A_i)+F_{C_j}{}^2(A_i)\right)}\sqrt{w_k\left(T_{C_j}{}^2(A^*)+I_{C_j}{}^2(A^*)+F_{C_j}{}^2(A^*)\right)}} \quad (15)$$

- while $|T^{(k)} - T^{(k-1)}| < \varepsilon$ do
  - Update T_{ij}, F_i and C_i (determinate cluster).
- If T_{ij} and T_{ik} (first and second memberships) are between t and $(1-t)$, data point belongs to border cluster, else, it belongs to a cluster with maximum membership for data point *i* to this cluster.
- End.

Most researches related to medical image processing includes mammogram images or MRI images. Some researches in this field are as follow:

Authors of [45] introduced a method which applied TOPSIS to optimize image's edge and decrease indeterminacy using developed operators α-mean and β-enhancement. It defined neutrosophic memberships the same as [43] using (8) to (10).

Authors introduced a novel method in [46], which considered people defected by diabetic macular edema (DME). They gathered images of optical coherence tomography (OCT) retina of those people and aimed to segment region which were either fluid-filled or cyst regions. This method was consisted of four key contributions:

1. Define *I* and *T* (*T* is defined using a novel $\lambda - correction$ method).
2. Perform segmentation using graph shortest-path; it does in neutrosophic domain. So, it causes the inner limiting membrane (ILM) and the retinal pigment epithelium (RPE) separate as interested regions from outer plexiform layer (OPL) and inner segment myeloid (ISM) as middle layers. It is done by the help of an edge weights definition.
3. Present a cost function to perform cluster-based fluid/cyst segmentation in interested region; it estimates the cluster numbers, automatically.
4. Ignore both subminiature regions and the regions which are placed between middle layers to get to the final fluid regions.

They introduced the below algorithm to find number of clusters, automatically.

1. Compute the average (μ) and standard deviation (σ) related to the normal distribution defined for pixel intensities which are between *OPL* and *ISM*.
2. The histogram is found for pixels which are between *ILM* and *OPL* regions.
3. Consider the interval $[\mu - \sigma, \mu + \sigma]$ for intensity and count pixel numbers (*A*) in that interval.
4. Highlight the minimum and maximum of *A* for all *OCT* images, individually and name it as A_{min} and A_{max}.
5. Map the *A* acquired from each *OCT* image to compute *K* (apply (13), (14):

$$A_1 = 1 - \frac{A - A_{min}}{A_{max} - A_{min}} \quad (13)$$

$$K = round((Kmax - Kmin)A_1 + Kmin) \quad (14)$$

Researchers of [47] firstly translated medical image into neutrosophic domain. Then, they introduced a similarity measure and use thresholds to segment the images. In that paper, the whole kinds of medical images were considered and there was no constraints on a special kind of that. Yet, color images were not considered there. Equation (15) considers the ideal A^* and computes the score of A_i due to A^*.

In [48], neutrosophic was applied as a vital tool to remove uncertainty from ultra sound images.

Authors in [49] presented a survey on neutrosophic applications for image processing. Authors of [50] combined two capable methods neutrosophic sets and expert maximum fuzzy-sure entropy to determine edges for brain tumor diagnosis; they named it as NS- EXFSE1. They had used a threshold to convert MRI images into binary ones. Fig. 4 shows the result of segmentation without using deep neural network.

(a)

(b)

Fig. 4: Image segmentation using neutrosophic without considering deep neural network. (a) Original Lena image. (b) Segmentation result [51].

In [52], different high pass (*HP*) filter types are applied to define *I* subset and low pass (*LP*) filter types to define

T subset in order to achieve accurate boundary detection and segmentation for dermoscopy images. Results show that there is a superiority for using an unsharp filter and an average filter which are applied for implementing the *I* subset and the *T* subset, respectively. The unsharp filter with size 3×3 was represented as:

-1/16	-2/16	-1/16
-2/16	12/16	-2/16
-1/16	-2/16	-1/16

They also represented the unsharp filter with size 5×5.

-1/32	0	-2/32	0	-1/32
0	-1/32	-2/32	-1/32	0
-2/32	-2/32	24/32	-2/32	-2/32
0	-1/32	-2/32	-1/32	0
-1/32	0	-2/32	0	-1/32

In the following, by the use of above masks, *I* could be determined for each pixel in the neutrosophic domain.

Equation (16) was applied to introduce the average filter:

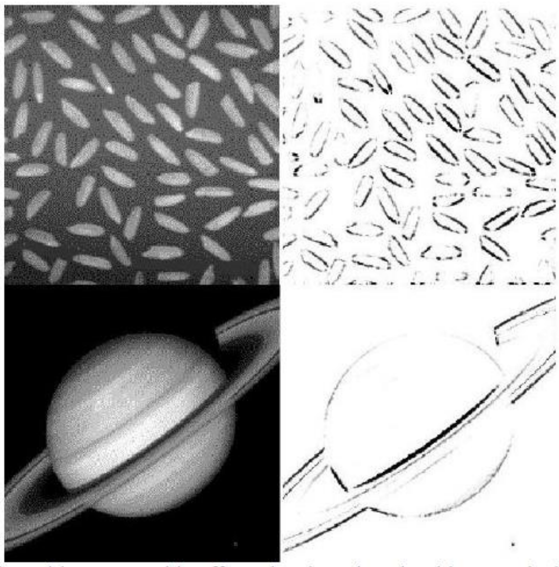


Fig 5: Edge detection with neutrosophic offset edge detection algorithm [57]. On the left, the original images appear, on the right, images of objects with detected edges appear.

$$T_{local_{average}}(l,m) = \frac{1}{s \times s} \sum_{a=m-s/2}^{m+s/2} \sum_{b=l-s/2}^{l+s/2} V(a,b) \quad (16)$$

where *V(a,b)* is the filtered image and *s* is the filter size.

Authors introduced an approach in [53] to identify lumen boundary, which applied neutrosophic c-means (NCM). This approach considered the intravascular optical coherence tomography image and applied indeterminacy and neutrosophic theory to define clusters; it aimed to find the boundaries. Their approach had two steps: preprocessing and applying NCM for lumen detection.

Authors in [54] proposed a weight function using neutrosophic. This method improved the efficiency of non-local means (NLM) filter to eliminate speckle noise in ultrasound (US) images.

Researchers highlighted the details and used the guided filters in [55] to overcome the problem of weak edges. The guided filter they introduced is as follows:

$$q_i = a_k l_i + b_k, \qquad \forall i \in \omega_k \quad (17)$$

where (a_k, b_k) are linear coefficients, constant in window ω_k. *k* is the center of ω_k and *r* is the radius of ω_k. This local linear model guaranteed that only if *I* had an edge, q would have an edge, too; since ∇q = $a*\nabla I$.

Authors in [56] proposed a marker based water based method to segment dental X-ray images. Here, there is algorithm which was introduced by the authors:

1. Preprocessing
2. Converting the image into neutrosophic set and take the true
3. Gradient calculation
4. Watershed segmentation from markers
5. ROI extraction using morphological operation

In [57], edge detection is depicted with neutrosophic offset edge detection algorithm; which you can see in Fig. 5.

Authors in [58] transformed the image into a neutrosophic domain. Then, they proposed a combined fuzzy c-means (*FCM*) algorithm which was based on particle swarm optimization (*PSO*). They aimed to acquire better global search. Finally, they applied the proposed algorithm to the neutrosophic image segmentation. The results showed that this method deleted image noise more efficiently rather than the FCM method. Moreover, it provided a clearer area boundary. Here, you can see the *PSO-FCM* algorithm:

1. Receive the image which is considered as input data.
2. Propose the transformed image; which is an image in neutrosophic domain and is done using (8)–(12).
3. Perform the α-mean operation.
4. Perform the image enhancement operation.
5. Calculate En_I (entropy of *I*).
6. If $\frac{En_I(i+1)-En_I(i)}{En_I(i)} < \delta$, go to 7; else, go to 3.
7. Apply *FCM* on neutrosophic set:
   a. *N* is the size of particle swarm, *m* is fuzzy value, *c1* and *c2* are learning parameters, *C* is the initial number of classes, *w* is inertia weight and *MaxIt* is the maximum iteration number.
   b. Initialize cluster centers. Then, code them. Therefore, *N* first generation particles are

produced. *pbest* is the primary current position for every particle, while *gbest* is the best position of all particles in the current population and records $k = 0$.

c. Compute the vectors $C(k)$ which are center vectors and the membership values provided for each cluster center $U(k)$ at the k^{th} step.

d. Calculate the fitness of each particle. To determine whether it is needed to update the individual and the optimal position of the particles or not, comparison of the fitness may be done. When a particle's position is better than the best position it remembers, updating operates. When the current global best position is better than the best position of all particles, the global best position will be updated.

e. Next generation of particle swarm is produced by updating the velocity and position of each particle.

f. Iteration stops when the current iteration number exceeds the maximum iteration number. The best center of cluster will be found in the last generation; otherwise, go to 3.

8. Results of image segmentation is obtained.

Authors in [59] proposed the following algorithm:

- Input the original image.
- Transform to gray-level image.
- Convert to neutrosophic domain as following:
  - Determine filters in NS.
  - Find *T*, *I* and *F*
  - Compute the entropy of *I*.
  - Acquire the neutrosophic image *T*.

Start 1:

- Training: Apply optimizer in order to obtain the optimal value(s).
- set the default values of the parameters which will be optimized.
- Define the fitness function.
- Find *T*, *I* and *F*.
- Obtain the updated *T* using *I* .
- Repeat the above three steps.
- Save acquired optimal values(s) for parameters.

Stop 1

Start 2

- Testing: optimal value(s) but no optimization.
- Convert the test images to the neutrosophic domain.
- Use needed image processing.

Stop 2

- **End**

Since segmentation of skin lesion is very important in automatically diagnosis based on dermoscopic images, a clustering estimation approach based on histogram can be applied to get the primary cluster numbers along with their corresponding centroids; it leads to guarantee efficient unsupervised clustering-based segmentation. Therefore, authors in [60] proposed a segmentation method for skin lesion which is called optimized clustering estimation for neutrosophic graph cut algorithm (OCE-NGC). At the beginning, they applied the genetic algorithm (GA) to optimize the histogram-based clustering estimation process. By optimizing this process, the optimal definition of the primary number of clusters and their corresponding centroids for more application in the introduced clustering process will be assured. Therefore, the images of skin lesion dermoscopic were then transformed into the neutrosophic domain; it would be performed using NCM which groups the pixels of images of dermoscopic by the best number of clusters acquired earlier using the optimized HBCE. At the end, a cost function for the graph cut (GC) approach would be defined in neutrosophic domain to perform segmentation.

In [61], author presented an image segmentation algorithm which was based on the NS and neutrosophic entropy (NE). This method was entitled as neutrosophic-entropy based adaptive thresholding segmentation algorithm (NEATSA). He considered MR images of Parkinson's disease.

As it is obvious, most researches in neutrosophic applications in image processing considers diagnosis using medical images. However, authors in [62] focused on industry application of neutrosophic set.

Industry applies nondestructive testing (NDT) to determine a defect in metal and tries not to damage it. Using image segmentation to detect the defect from an NDT image is difficult because of uncertainties existed in the pattern of NDT image. In order to segment an NDT image effectively, it is important to handle the uncertainties effectively. Authors in [62] presented a method to segment an NDT image. They handled the uncertainties using NS.

In [63], authors introduced triangular neutrosophic sets with the aim of having truth, falsity and indeterminacy regions. These were then applied to acquire the centroids and membership degrees needed for fuzzy c-means. Finally, they were able to obtain the tissues of the brain.

In [64], authors proposed a framework consisted of some steps: 1) Two pre-trained convolutional neural networks were trained again by transfer learning. Features were obtained from the layers which were fully connected. 2) The features which were discriminative, were selected by the help of a probabilistic method (Euclidean norm and geometric mean maximization along with conditional entropy). 3) The robust features aggregation was done by canonical correlation analysis.

Then, the aggregated features were sent to several classifiers to get to final recognition.

The above authors introduced a deep learning approach in [65] for lesion segmentation and classification. They also introduced a fully automated computerized aided diagnosis (CAD) system in [66], because they considered the fact that according to the American Cancer Society (ACS), more than one million of Americans live with melanoma.

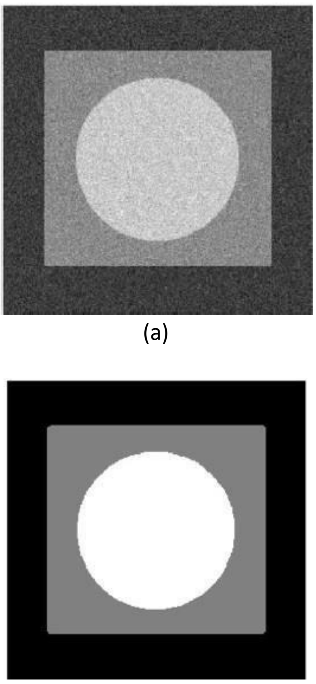
Survey [67] gives a review on neutrosophic medical image segmentation.

A. Neutrosophic and Noise Reduction from Images

Some concepts and operators for neutrosophic set are introduced in [8] and are applied for noise removal. This research processes noisy images which have different levels of noise, also it processes different types of noise. Algorithm which is described in [8] is:

1. Convert the image to NS (Find *T*,*I* and *F*).
2. Apply γ-median-filtering process on *T* to have $\widehat{T}_{\gamma}$.
3. Obtain the entropy of $\hat{I}_{\gamma}$, $En_{\hat{I}_{\gamma}}(i)$;
4. If $\frac{En_{\hat{I}_{\gamma}}(i+1)-En_{\hat{I}_{\gamma}}(i)}{En_{\hat{I}_{\gamma}}(i)} < \delta$, go to 5; else $T = \widehat{T}_{\gamma}$, go to 2;
5. Convert $\widehat{T}_{\gamma}$, from neutrosophic domain to gray level domain.

Fig. 6 depicts the result of noise reduction using neutrosophic.



(a)

(b)

Fig. 6: Noise reduction using neutrosophic. (a) Original image with Gaussian noise. (b) Result of noise reduction [43].

Neutrosophic is used for image thresholding applications and noise removal from image. Authors in [26] introduced thresholding based on neutrosophic; which can define threshold effectively and automatically. Here, you can see the algorithm:

1. Convert the image to NS.
2. Do λ-mean on *T* .
3. Define the entropy of *I*, $En_I(i)$;
4. If $\frac{En_I(i+1)-En_I(i)}{En_I(i)} < \delta$, go to 5; else go to 2;
5. Threshold definition on *I*; here, δ = 0.05.

Authors proposed a filter for image denoising in [68] which was based on neighborhood; it was used to eliminate salt and pepper noise. The proposed filter was user friendly and very helpful because it was based on neighborhoods. Here, the algorithm is proposed:

1. Pixels corrupted by high noise intensity are restored.
2. Pixels corrupted by low noise intensity are restored as much as possible.
3. Original image is restored as much as possible.

B. Neutrosophic and Image Retrieval

Topics covered so far was only about object segmentation and noise removal in image and video; Yet, in the following, we discuss about using neutrosophic for image retrieval.

In [25], image retrieval is done using four steps: image segmentation, visual descriptor, dimension reduction and similarity adaption. He used neutrosophic to segment images, carefully aiming better retrieval. Authors defined geometric moments of a one dimensional signal S(x) as (18):

$$M_n(x) = \int_{-\omega}^{\omega} S(x+t)t^n dt \qquad n = 0,1,2 \tag{18}$$

where $M_n(x)$ is the moment of order *n* obtained from a window of size $(2\omega+1)$ centered at x. Geometric moments of a two dimensional image *I(x,y)* are obtained as (19):

$$M_{m,n}(x,y) = \int_{-\varpi 1}^{\varpi 1} \int_{-\varpi 2}^{\varpi 2} I(x+u, y+v) u^m v^n du dv$$

$$m,n = 0,1,2 \tag{19}$$

Authors in [69] extended [63] based on neutrosophic set and found image attributes in neutrosophic environment to retrieve the image.

Authors introduced neutrosophic contrast (20), neutrosophic energy (21) and neutrosophic homogeneity (22).

$$Cont_{NS} = Cont_T + Cont_I + Cont_F$$

$$Cont_T = \sum_i \sum_j (i-j)^2 P_T(i,j)$$

$$Cont_I = \sum_i \sum_j (i-j)^2 P_I(i,j)$$

$$Cont_F = \sum_i \sum_j (i-j)^2 P_F(i,j) \quad (20)$$

where *P* contains the histogram counts.

$$En_{NS} = En_T + En_I + En_F$$

$$En_T = \sum_i \sum_j P_T^2(i,j)$$

$$En_I = \sum_i \sum_j P_I^2(i,j)$$

$$En_F = \sum_i \sum_j P_F^2(i,j) \quad (21)$$

$$Homo_{NS} = Homo_T + Homo_I + Homo_F$$

$$Homo_T = \sum_i \sum_j \frac{P_T(i,j)}{1+|i-j|}$$

$$Homo_I = \sum_i \sum_j \frac{P_I(i,j)}{1+|i-j|}$$

$$Homo_F = \sum_i \sum_j \frac{P_F(i,j)}{1+|i-j|} \quad (22)$$

Authors in [70] translated images into neutrosophic environment; segmentation was done in that environment. For each image in neutrosophic domain, vector of color feature was acquired from segmented image and vector of texture feature was acquired from the entire image. Consequently, the most relevant feature would be applied for retrieval. Researchers believed that they can study on adaptive adjustment of the number of clusters in future to progress their research.

Image retrieval in neutrosophic domain for color images was considered in [71]. Authors in [72] used doubt value for image retrieval. Fig. 7 illustrates image retrieval.

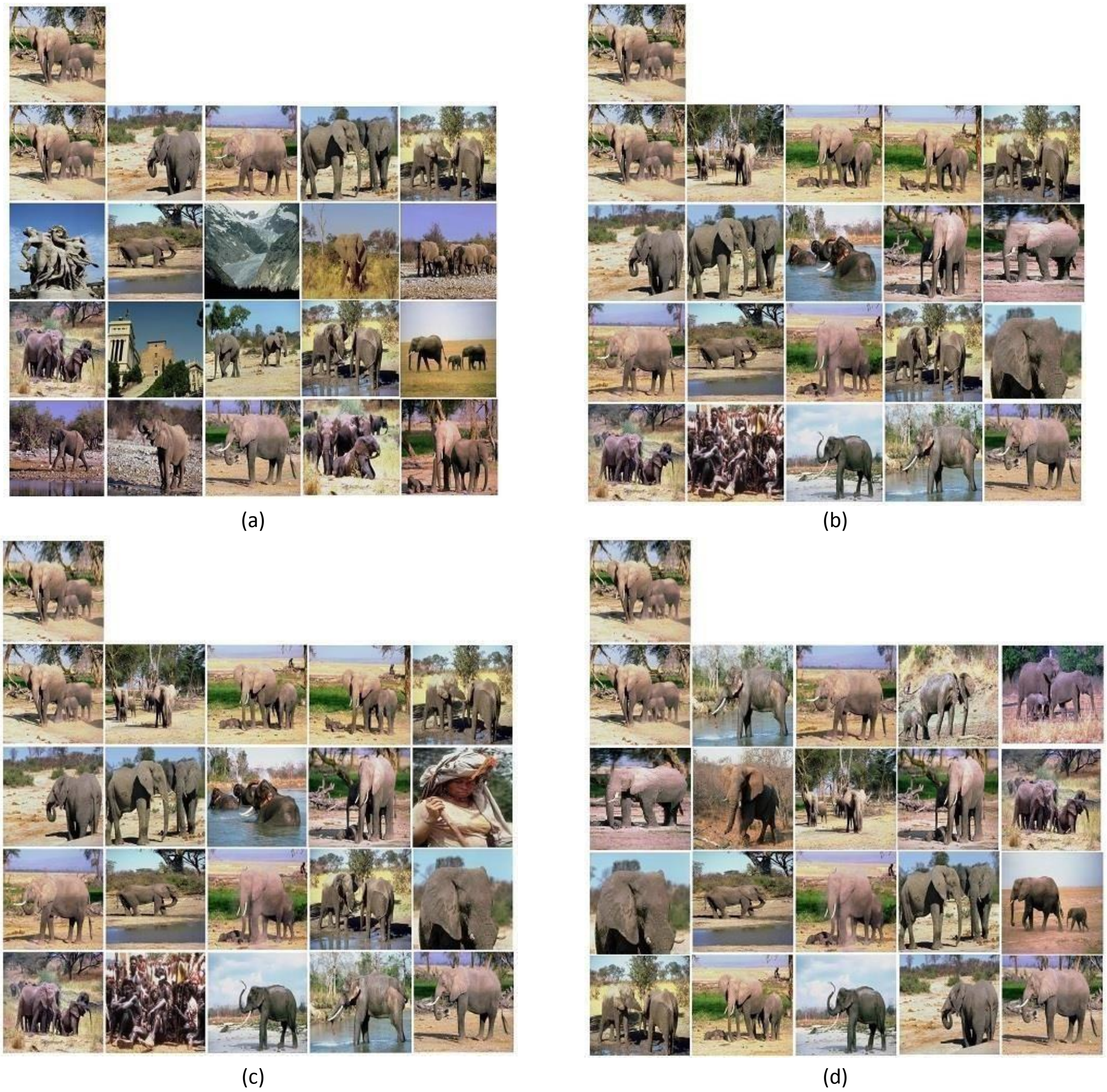


Fig. 7: Image retrieval. (a) Retrieved image in [73]. (b) Retrieved image in [74]. (c) Retrieved image in [75]. (d) Retrieved image in [76].

Researchers of [77] defined image in neutrosophic environment using doubt degree and texture feature in neutrosophic domain. Researchers believed that a more suitable similarity measure must be determined in the future to find distance between the corresponding image and the available images in database. They improved (20)-(22) as (23)-(25), respectively.

$$Cont_{\pi} = 3 - (Cont_T + Cont_I + Cont_F) \tag{23}$$

$$En_{NS} = 3 - (En_T + En_I + En_F) \tag{24}$$

$$Homo_{NS} = 3 - (Homo_T + Homo_I + Homo_F) \tag{25}$$

You can see [78]–[80] for more information about neutrosophic application in information retrieval. In [78], authors aimed to estimate the advantage of neutrosophic usage for healthcare document retrieval applying neutrosophic logic. They analyzed its advantages or disadvantages over the traditional retrieval strategies which were based on fuzzy logic.

Authors believed in [79] that just neutrosophic logic is the theory which unifies all earlier logics in the common global theoretical framework. They proposed a novel neutrosophic string similarity measure which was based on the longest common subsequence (*LCS*); this approach considered uncertainty in search of string information. This approach had been compared to other classical string similarity measures. The analyses showed better performance for the proposed neutrosophic similarity measure.

In [80], authors believed that a NS may be a usual structure for the hesitation analysis of big data sets.

Results and Discussion

Figs. 8-10 depict an abstraction of advantages and disadvantages of uncertainty algorithms.

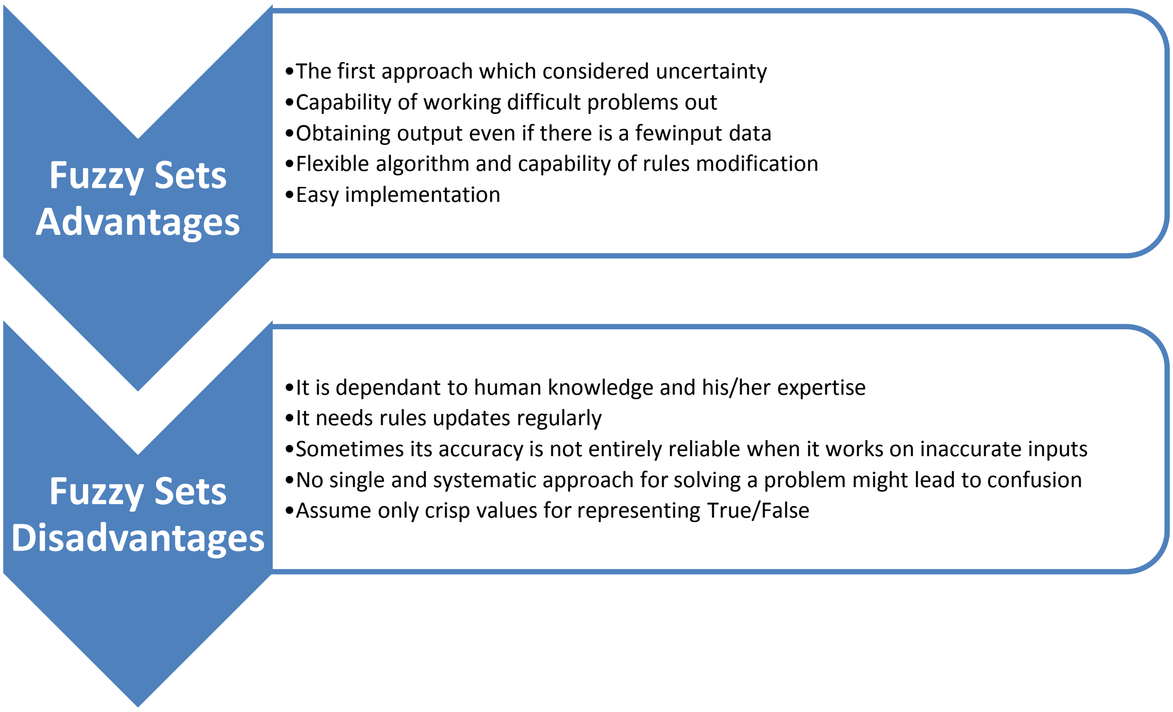


Fig 8: Advantages and disadvantages of fuzzy sets.

Fig. 11 shows an example of image segmentation using neutrosophic domain for dental X-ray image. Most researches in image segmentation using neutrosophic sets include medical images such as dental X-ray images or MRI images.

It is worthy to state that there are few researches which consider color image segmentation.

Fig. 12 depicts an example of noise reduction using neutrosophic sets.

As you can see in Fig. 12, image segmentation is combined into noise reduction. Both of them are applied using neutrosophic sets; input image is with Gaussian noise, the resulted image is the segmented one of (a) which reduced the noise [24].

Fig. 13 shows the result of image retrieval; it uses neturosophic sets to retrieve images and applies VDs (visual descriptors) which include shape, color and edges [72].

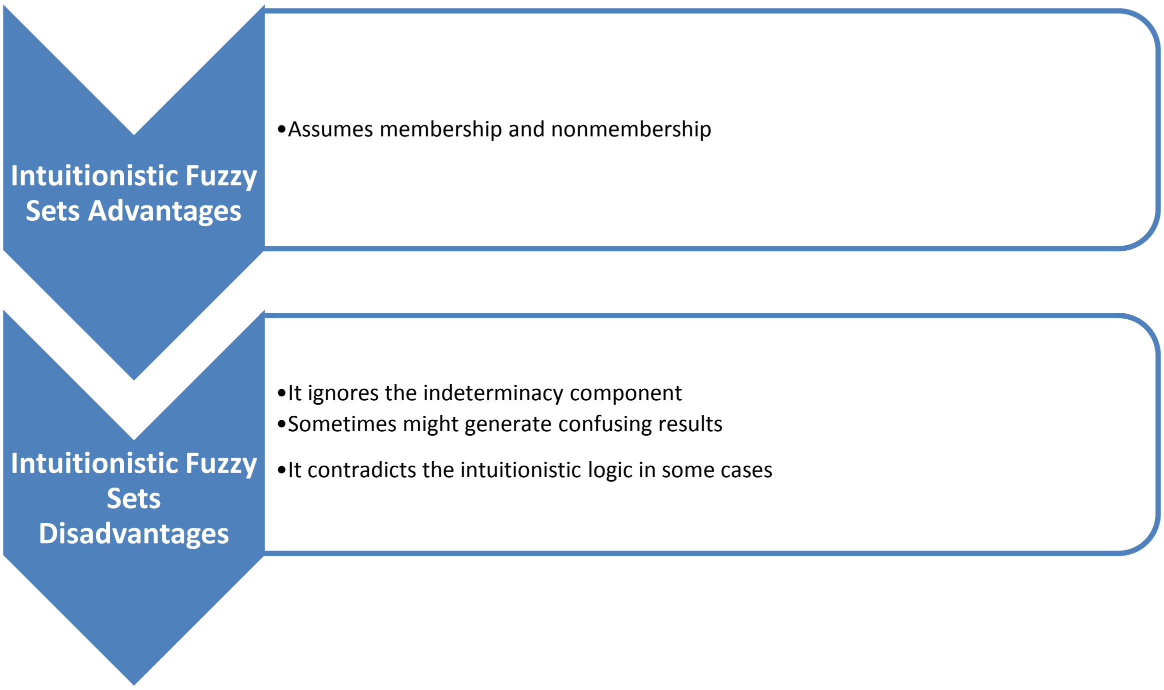


Fig 9: Advantages and disadvantages of intuitionistic fuzzy sets.

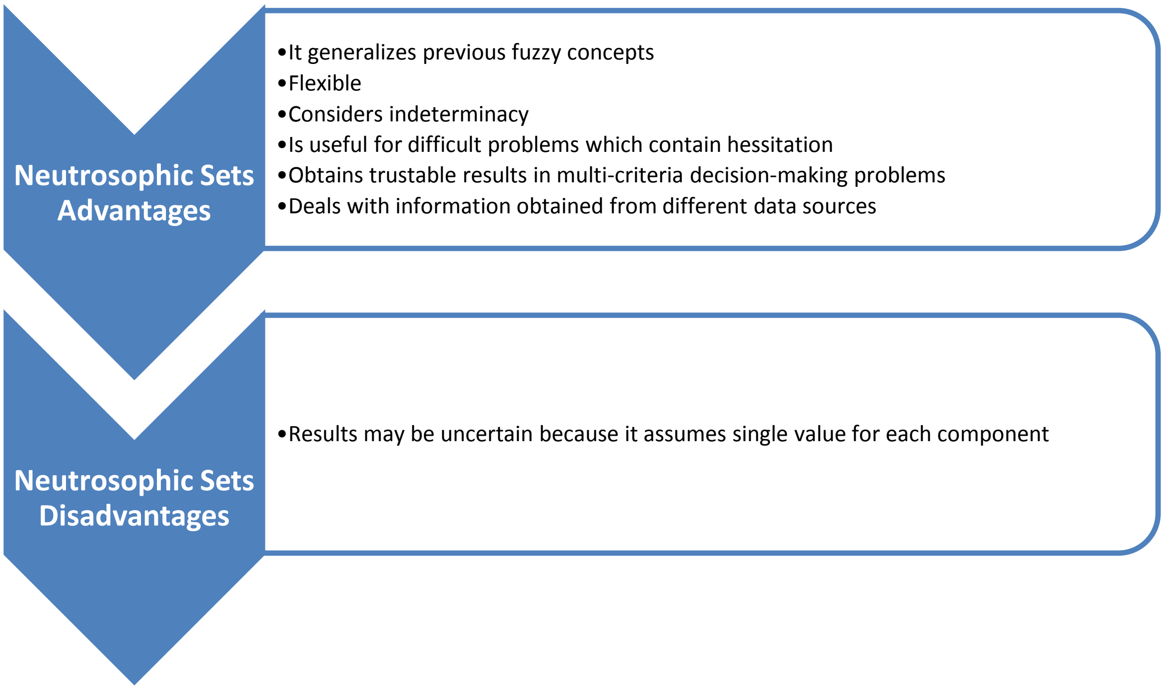


Fig 10: Advantages and disadvantages of neutrosophic fuzzy sets.

(a)

(b)

Fig. 11: Image segmentation. (a) Input image. (b) Segmented image [56].

(a)

(b)

Fig. 12: Noise reduction. (a) Input image with Gaussian noise. (b) Result of noise reduction [24].

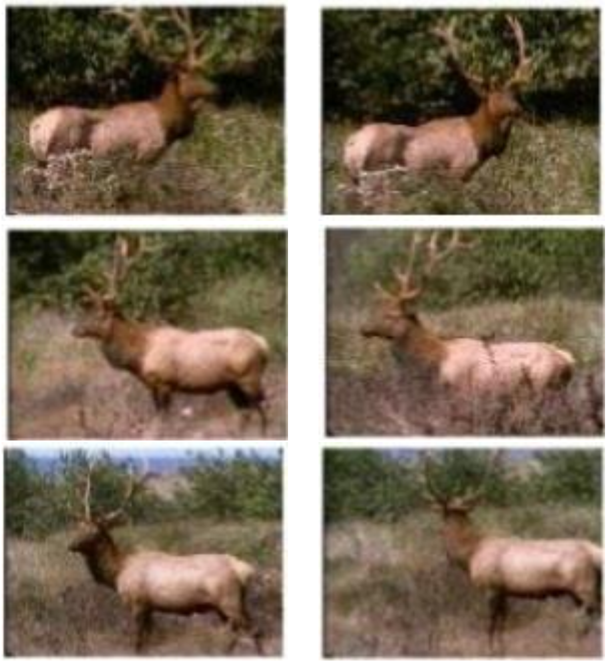


Fig. 13: Image retrieval [72].

Conclusion

Neutrosophic sets which are actually an extension of intuitionistic fuzzy sets, become a noticable subject in image processing and computer vision. Applications such as segmentation, noise reduction and image retrieval are some examples in which neutrosophic sets are used.

Neutrosophic usage in medical images brings forward improvement in accurate diagnosis; it is done by more accurate segmentation which ends to more accurate diagnosis. To mention some real world usages for this, we can refer to dental X-ray images diagnosis, skin lesion diagnosis and etc.

Although, neutrosophic is used for image restoration and segmentation; input images are usually medical images or gray level natural images. The remarkable point is that there are few researches which focuse on image restoration or segmentation using neutrosophic and consider color images. Therefore, color image restoration and segmentation in neutrosophic environment is novel to be done.

Neutrosophic applying in image retrieval brings out an improvement in average recall and precision measure compared to earlier methods. Considering different textures and shapes can extend usages of neutrosophic space in image retrieval applications.

Author Contributions

A. Koochari and A. Ghanbari Talouki considered the idea of image processing and its importance in nowadays lives. S. A. Edalatpanah brought out the idea of neutrosophic domain which is growing in different sciences and can be applied into image processing applications.

All authors decided to select some certain image applications such as segmentation, noise reduction and image retrieval. In the following, they studied related researches and prepared a survey paper.

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Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

Abbreviations

L	Low importance
M	Moderate importance
H	High importance
VH	Very High importance
NS	Neutrosophic set
DCNN	Deep convolutional neural network
SVM	Support vector machine
FCM	Fuzzy C-means
MRI	Magnetic resonance imaging
DME	Diabetic macular edema
OCT	Optical coherence tomography
ILM	Inner limiting membrane
RPE	Retinal pigment epithelium
OPL	Outer plexiform layer
ISM	Inner segment myeloid
HP	High pass
LP	Low pass
NCM	Neutrosophic C-means
NLM	Non-local means
US	Ultrasound
ROI	Region of interest
PSO	Particle swarm optimization
OCE-NGC	Optimized clustering estimation for neutrosophic graph cut algorithm
GA	Genetic algorithm
GC	Graph cut
NE	Neutrosophic entropy
NEATSA	Neutrosophic-entropy based adaptive thresholding segmentation algorithm
NDT	Nondestructive testing
	Jackknife coefficient of determination
CAD	Computerized aided diagnosis
ACS	American Cancer Society
VD	Visual descriptor

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