A survey of the State-of-arts on Neutrosophic Sets in Biomedical Diagnoses

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Abstract

In real world applications, soft computing is an inspirational domain for encoding imprecision and uncertainty. Soft computing procedures integrated with medical applications can support the existing medical systems to allow solutions for unsolvable problems. Fuzzy techniques have extensive solutions for the medical domain applications; however incorporating a new neutrosophic approaches in the medical domain proves its superiority. The current study reported the main neutrosophic sets (NS) definitions along with different medical applications based on NS. In addition, an extensive discussion for the possibility of prolonging the abilities of the fuzzy systems using the neutrosophic systems was included. The preceding studies established that the NS has a significant role in medical images de-noising, clustering, and segmentation. As a future scope, it was suggested that the neutrosophic medical systems can be exploited for neutrosophic scores; continuous truth/indeterminate/falsity versions of conventional score schemes. The integrated methods of the NS in medical domain would lead to tabular or rule-based mapping from input to output variables. The qualitative simulation of the reported studies established that the neutrosophic model based diagnosis is promising aspirants for future research. Furthermore, the current work highlighted the main medical image processes that can be developed using the NS, including de-noising, thresholding, segmentation, clustering and classification. The general algorithms that can be used to include NS in each task were proposed.

Keywords- Data clustering, image segmentation, medical artificial intelligence, neutrosophic sets, neutrosophic logic, neutrosophic clustering.

1. Introduction

Real-world applications provide massive information which is incomplete, imprecise, fuzzy, and inconsistent. The uncertainty may originate from acquisition errors, incomplete knowledge, or stochasticity [1]. In order to manage such vague information, several existing theories and techniques were proposed including probability theory [2], fuzzy set theory [3], intuitionistic fuzzy set theory [4], and para-consistent logic theory [5]. However, these theories can deal with one imprecise problem aspect instead of the whole in one framework, for example the fuzzy set theory can manage only vague and fuzzy information without handling any inconsistent and incomplete problems within the same information. Therefore, in order to resolve such issues in one framework neutrosophy approach [6], which is a philosophy branch combining the philosophy knowledge, set theory, logics, and probability/statistics can be applied. Neutrosophy is the basis of neutrosophic logic that denotes indeterminacy using a new model called <Neut-A> to solve specific problems that fuzzy logic cannot solve [7]. Typically, the fuzzy logic can be defined as an extension of two-valued logic at which it is unnecessary for the statements to be True or False, but may have a truth degree between 0 and 1. The neutrosophic logic and intuitionistic fuzzy logic are generally present a percentage of "indeterminacy" compared to all other logics. This is due to unpredicted parameters that can be hidden in some unknowness or propositions, however the neutrosophic logic let each component (T, I, F) be even overflooded (boiling) over 1, i.e. be '1+', or underdried under 0 (freezing), i.e. be '0' in order to be able to make dissimilarity between relative truth and absolute truth as well as between relative falsity and absolute falsity.

Smarandache stated that 'Neutrosophy is a new branch of philosophy which studies the origin, nature, and scope of neutralities, as well as their interactions with different ideational spectra' [8]. Neutrosophy is a multiple value logic that specifies classical logic, fuzzy logic, and imprecise probability. Neutrosophy is closer to human rational as it describes the imprecision of knowledge or linguistic inaccuracy established by several observers. Generally, one of the neutrosophy is the neutrosophic set which studies the nature, origin, and scope of neutralities along with their relations. Every event in the neutrosophy theory has certain degree of truth, falsity degree, and an indeterminacy degree, which should be considered independently from each other [8]. Recently, the neutrosophic set is a general, dominant, and proper framework.

Since the medical data from the patients 'symptoms and diseases is changeable/ imperative, partial, imprecise, imperfect and vague. Thus, there is no fixed treatment scheme including precise drug usage or modalities of treatment. Furthermore, the ambiguities, indecisiveness, uncertainties in the medical expert system inputs are varying due to the variety between the physical examination, patients' history, and the laboratory-tests. Generally, medical diagnosis requires large amount of information processing, where large portion of which is computable as well as rapid unconscious data processing, so the entire process offers low inter- and intra-person consistency. Consequently, indeterminacy, inconsistency, contradictions, and fuzziness should be solved. Artificial intelligence based medical diagnosis has received attention from the research society of both computer science and computer applicable mathematics. Kala *et al.* [9] applied modular evolutionary neural networks to breast cancer diagnosis. For superior understanding and prevention of unwanted medical cases, Tan *et al*. [10] carried out a two-stage hybrid evolutionary classification procedure to extract classification rules for hepatitis and breast cancer cases. In the first stage, a hybrid evolutionary algorithm (EA) was proposed to restrict the search space by developing a pool of superior candidate rules including the genetic algorithm (GA) and genetic programming (GP). Afterward, these candidate rules were used to optimize the rules' number and order in the evolution for accurate rule sets.

Parthiban and Subramanian [11] presented a new technique based on coactive neuro-fuzzy inference system (CANFIS) for heart disease prediction. The CANFIS model integrated the adaptive abilities of the neural network and the fuzzy logic qualitative approach which is then combined with the GA to identify the existence of the disease. Healthcare systems try to complement the offered services by conventional clinical decision making methods with the incorporation of fuzzy logic procedures in [12-14]. Recently, soft computing domain is developed, neutrosophic logic and neutrosophic set have significant role in the medical applications. Since the neutrosophic systems performance is close to the medical reality in a superior way compared to their fuzzy counterparts. These neutrosophic approaches are generalized logic/sets that can possess all the necessary attributes to encode the medical information and capture the medical inputs. Neutrosophic sets provide a new opening to bridge the gap between the innovative medical systems and the medical fuzzy systems. It can handle the medical systems main processes including the acquired data, generated information, indeterminacy, truth, and the falsity. Thus, the neutrosophic set can be described independently by a truth-, indeterminate-, and false- membership function. Recently, Ye [15] developed a cosine similarity measures for simplified neutrosophic sets (SNSs) based on the cosine function, including single valued- and interval- neutrosophic cosine similarity measures for medical diagnosis problems. Afterward, the weighted cosine similarity measures of SNSs were used. Wang *et al*. [5] applied a single valued neutrosophic sets (SVNS), which is an instance of neutrosophic sets for real engineering applications. Extensive use for the neutrosophic sets to medical diagnosis problems were proposed based on vector similarity, dice similarity, distance-based similarity, tangent similarity measures and trapezoidal numbers of neutrosophic sets [16-21].

Consequently, the *main objective* of the current study is to report the existing medical image processing techniques that supported by neutrosophic sets (NS) with clear explanation for the NS concepts. The remaining sections are organized as follows. The neutrosophic sets concept and model are introduced in section 2. Section 3 reports the several medical image processes based on NS framework. Section 4 introduces the neutrosophic set in medical diagnosis for different medical modalities. Section 5 reports the challenges and new perspectives. Finally, the conclusion is conducted in section 6.

2. Neutrosophic set concept and data model

Neutrosophy is an extension of the fuzzy set and the classical set as well. The neutrosophic theory refers to neutrosophy which is applied in several domains to solve problems related to indeterminacy and uncertainty. Neutrosophy is new mathematical theories that generalize both classical and fuzzy methods. Such neutrosophy approaches includes neutrosophic probability, neutrosophic set theory, neutrosophic Logic, and neutrosophic statistics. In neutrosophy theory, every event has a definite degree of truth, falsity and indeterminacy for independent consideration from each other. Smarandache [22] represented the neutrosophy as a dialectics generalization that studies the nature, origin, and scope of neutralities with their interactions for various ideational spectra. The neutrosophic set is a broad framework for the concept of the classic set, fuzzy set, interval valued fuzzy set, paraconsistent set, intuitionistic fuzzy set, interval valued intuitionistic fuzzy set, paradoxist set, dialetheist set, and tautological set [23-26]. The neutrosophic statistics is required through performing statistical analysis of a sample or population that has indeterminate (ambiguous, imprecise, incomplete, vague, unknown) data. Generally, several definitions are given for the NS as follows [27, 28]:

Definition 1 (Neutrosophic set)

An event, theory, concept, or entity, {N} is deliberated with its reverse {Anti-N} and the neutrality {Neut-N}, where {Neut-N} is neither {N} nor {Anti-N}. The {Neut-N} and {Anti-N} are denoted to as {Non-N}. Based on the neutrosophy theory, every event {N} is neutralized and balanced by {Anti-N} and {Non-N} [28]. Typically, <N>, <Neut-N> and <Anti-N> are disjoint two by two. In several cases, the margins between these notions are imprecise and vague, thus it is conceivable that <N>, <Neut-N>, <Anti-N> and <Non-N> have joint parts two by two as well. In the NS, the truth-, indeterminacy-, and falsity-membership are independent. Generally, the neutrosophic set can be defined as follows: Let X be an universe of discourse, with a generic element in X denoted by x, then a neutrosophic set A is an object having the form $A = \{< x: T\_A(x), I\_A(x), F\_A(x) >, x \in X\}$, where the functions T, I, F : X→]−0, 1+[are the degree of membership (or Truth), the degree of indeterminacy and the degree of non-membership (or Falsehood); respectively of the element x ∈ X to the set A with the condition: $-0 \leq T\_A(x) + I\_A(x) + F\_A(x) \leq 3+$. From the philosophical point of view, the NS takes its value from real standard or non-standard subsets of]−0, 1+[. Thus, instead of] −0, 1+[, the interval [0, 1] is considered for the technical applications, because]−0, 1+[will be difficult to apply in the real applications, such as in the scientific and engineering problems.

Definition 2

Let T, I and F are the neutrosophic components as well as A be a universe of discourse, and a NS N is included in A. An element y in set N is noted as $y(T, I, F)$, where T refers to true in the set, I refers to the indeterminate in the set, and F denotes false in the set.

Definition 3

T, I and F are real standard or non-standard sets of]−0,1+ [with $sup\ T = t\_sup, inf\ T = t\_inf$, $sup\ I = i\_sup$, $inf\ I = i\_inf, sup\ F = f\_sup, inf\ F = f\_inf$ and $n\_sup = t\_sup + i\_sup + f\_sup$, $n\_inf = t\_inf + ...$ $i\_inf + f\_inf$.

Definition 4 (Neutrosophic image)

For A, a neutrosophic image H_{NS} is described by three membership sets T, I and F. A pixel H in the image is defined as $H(T, I, F)$. Afterward, the pixel $H(i, j)$ in the image domain is transformed into the NS domain using the following expression:

$$H_{NS}(i,j) = \{T(i,j), I(i,j), F(i,j)\} \tag{1}$$

Definition 5 (Neutrosophic image entropy)

Similarity is a basic concept in several fields including psychology, linguistics and computational intelligence to compare two sets. Similarity can be measured to know whether two images or patterns are matching or almost identical or at least to what degree they are matching. Similar elements are viewed from different viewpoints by using proximity, distances, resemblances, closeness and dissimilarities. Conversely, the entropy has a significant role in image processing and optimization as it measures the fuzziness. It is a measure of defectiveness of information that signified by a set. Consequently, the entropy measurement of single valued NS is useful in cases at which modeling of indeterminate situations is done by Single Valued Neutrosophic Set (SVNS). Conversely, the Typically, the entropy is measured to evaluate the gray levels distribution in an image, which has maximum value if the intensities have equal probability, while small entropy indicates non-uniform intensity distribution [29]. The neutrosophic entropy of an image is defined as the summation of the entropies of three subset T, I and F is defined as the neutrosophic entropy of an image, which is given by:

$$E_{NS} = E_T + E_I + E_F \tag{2}$$

$$E_T = -\sum_{i=\min\{T\}}^{\max\{T\}} H_T(i) \ln H_T(i) \tag{3}$$

$$E_I = -\sum_{i=\min\{I\}}^{\max\{I\}} H_I(i) \ln H_I(i) \tag{4}$$

$$E_F = -\sum_{i=\min\{F\}}^{\max\{F\}} H_F(i) \ln H_F(i) \tag{5}$$

where, E_T, E_I and E_F are the entropies of sets T, I and F, respectively. In addition, $H_T(i)$, $H_I(i)$ and $H_F(i)$ are the probabilities in T, I and *F;* respectively, of the elements whose values equal to i.

Generally, in order to measure the indeterminate degree of element $H_{NS}(i, j)$, the values of *I* (*i*, *j*) is employed. Furthermore, the set *I* can be correlated with *T* and *F*, if the changes in *T* and *F* effect the elements distribution in *I* and vary the entropy of I , where the entropy is used to measure the performance of the NS. The entropy is exploited for an image to evaluate the gray levels distribution. Thus, maximum entropy refers to the equal probability intensities of the image pixels, while if the entropy is small, the intensity distribution is non-uniform.

3. Neutrosophic set in medical imaging

Generally, the neutrosophic set (NS) approaches were applied successfully into image processing including image de-noising based on neutrosophic median filtering [30], image thresholding [31], and image segmentation [32, 33]. Neutrosophic set introduced by Florentin Smarandache is a general dominant framework that generalizes the model of the fuzzy set, classic set, intuitionistic fuzzy set, interval valued fuzzy set, and interval-valued intuitionistic fuzzy set. Recently, neutrosophic sets and their varieties, including simplified neutrosophic sets, single valued neutrosophic sets, fuzzy neutrosophic sets, Interval valued neutrosophic sets, rough neutrosophic sets, intuitionistic neutrosophic sets, interval neutrosophic sets, neutrosophic soft sets, neutrosophic hesitant fuzzy sets have been employed in different domains, such as computer application, medical applications, and control system. Several studies were carried out using neutrosophic set based medical diagnosis. Broumi and Smarandache [34] applied an extended Hausdorff distance approach and similarity measure of refined neutrosophic sets to medical diagnosis applications. Pramanik and Mondal [35] proposed a rough neutrosophic sets approach for medical diagnosis applications. In thoracic computed tomography, Guo *et al*. [36] applied neutrosophic sets for lung images segmentation. Akhtar *et al*. [37] combined the k-means clustering and neutrosophic logic (NL) to remove the pixels' uncertainty. The indeterminacy set was compared to a threshold value to determine whether a pixel belongs to certain cluster or more than one cluster.

Broumi *et al*. [38] proposed an n-valued interval neutrosophic sets (NVINS) based on basic operations, namely union, scalar division, scalar multiplication, intersection, multiplication, addition, truth-favorite and false-favorite. Afterward, the distances between the NVINS were calculated. The experimental results proved the effectiveness of the proposed method for accurate medical diagnosis. Zhang *et al*. [39] studied the nature, and scope of the neutrosophy with its interactions in different ideational spectra. The authors employed neutrosophy to develop a fully automatic algorithm for image segmentation. As follows the common image processing techniques that can be supported by NS in the medical applications.

3.1 Neutrosophic set for medical image de-noising

Noise is one kind of indeterminant information on images. Hence, NS can be successfully applied into image de-noising research domain. The neutrosophic image properties allow the NS to achieve superior performance in several image de-noising applications in computer vision and image processing. Guo *et al*. [27] proposed a novel method for image de-noising based on neutrosophic set approach. Three membership sets T, I and F in the NS set were used to describe an image G. For evaluating the indetermination, the entropy in the neutrosophic image domain was measured. In order to remove the image noise and to reduce the set's indetermination, a novel filtering operation, namely the γ-median-filtering operation was carried out. The results established NS supported image de-noising for several scenarios, namely with different noise levels and with different noise kinds without knowing the noise type. Faraji *et al*. [40] applied a new NS based pre-processing technique to enhance and to remove noise form facial features in original face images.

Mohan *et al.* [41] removed the Rician noise from simulated magnetic resonance image (MRI) from Brainweb database using NS Neutrosophic set (NS) approach with wiener filtering. The NS was applied into image domain and defined some operators for image de-noising. The three membership sets, namely True (T), Indeterminacy (I) and False (F) were defined to transform the image into the NS domain. Furthermore, the NS entropy was employed to calculate the indeterminacy. The ω-wiener filtering operation was applied on T and F in order to remove the noise and to decrease the set indeterminacy. The proposed filter performance was compared with unbiased non local mean filter (UNLM) and anisotropic diffusion filter (ADF).

Mohan *et al.* [42] defined some neutrosophic set's operators for medical images de-noising. The nonlocal mean was used with the noisy magnetic resonance image (MRI). Afterward, the resulting nonlocal means filtered image was transformed into NS domain by applying three membership sets, namely: true (T), indeterminacy (I) and false (F) using the definitions given in equations (1) to (5). The neutrosophic set entropy was employed to measure the indeterminacy. In order to remove the noise and to decrease the set indeterminacy, the Wiener filtering operation was applied on T and F. The experimental results established that the nonlocal neutrosophic set (NLNS) Wiener filter produced superior de-noising results in terms of quantitative and qualitative measures compared to other de-noising techniques, such as the anisotropic diffusion filter, classical Wiener filter, the nonlocal means filter and the total variation minimization.
Typically, from the preceding studies which are related to employing the NS approaches in de-noising process improvement, the common procedure for de-noising filtration using NS can be given in the following algorithm.

Algorithm: Medical image de-noising using NS technique

Start

Identify the Neutrophic Set as given in (Definition 1)
Represent the medical image in the neutrosophic set as given in equation (1)
Transform the image to the NS domain by calculating the three membership sets, namely *T*, *I* and *F* using the following expressions:

$$T(i,j)=\frac{\bar{p}(i,j)-\bar{p}_{\min}}{\bar{p}_{\max}-\bar{p}_{\min}} \tag{6}$$

$$\bar{p}(i,j)=\frac{1}{n\times n}\sum_{m=i-n/2}^{i+n/2}\sum_{c=j-n/2}^{j+n/2}p(m,c) \tag{7}$$

$$I(i,j)=\frac{\eta(i,j)-\eta_{\min}}{\eta_{\max}-\eta_{\min}} \tag{8}$$

$$\eta(i,j)=abs\left(p(i,j)-\bar{p}(i,j)\right) \tag{9}$$

$$F(i,j)=1-T(i,j) \tag{10}$$

Apply *the used de-noising filter on the filtered true subset* $T_{filtered}$ *and its local mean value*
Measure the neutrosophic image entropy of the indeterminate subset $I_{filtered}$

If $\frac{E_{I_{filtered}}(i+1)-E_{I_{filtered}}(i)}{E_{I_{filtered}}(i)}<\eta$

Transform the subset $T_{filtered}$ from the neutrosophic domain into the gray level domain

Else

$T = T_{filtered}$

End if

End

where, $p(i,j)$ is the pixels local mean value of the filter window, $\eta(i,j)$ is the absolute value of difference between intensity $p(i,j)$ and its local mean value $\bar{p}(i,j)$ [29]. This algorithm represents the framework that can be used with any de-noising filter using the NS. Based on the applied filter, the NS provide efficient de-noising which can be independent on the noise type and/or level. Finally, in order to evaluate the de-noising process, some quality metrics can be measured including the peak-signal-to-noise ratio (PSNR), structural similarity (SSIM) index, mean square error, and average difference.

3.2 Neutrosophic set for medical image clustering

Clustering refers to grouping a set of samples/objects into number of clusters containing similar common members. One of the most prevalent fuzzy clustering techniques is the fuzzy c-means (FCM) algorithm. In FCM, an iterative minimization of a cost function is performed to obtain the data membership degrees. For each data, this cost function is subjected to certain constraint, namely the sum of membership degrees over the clusters should be equal to 1. However, the FCM procedure has some drawbacks, such as i) it is very sensitive to the presence of noise, ii) it tries to minimize the intra-cluster variance, iii) it has local minimum, and iv) the results depend on the initial values. The membership of noise points might be significantly high. Consequently, researchers are interested with developing new techniques to overcome such problems. In order to manage the uncertainty associated with the fuzzy clustering algorithms' parameters, the NS was proposed as it is considered a powerful tool to handle the indeterminacy.

Guo and Sengur [43] proposed a novel clustering algorithm based on the NS, called neutrosophic c-means (NCM) clustering. This NCM algorithm for uncertain data clustering combined the NS and fuzzy *c*-means frameworks. At the same time for each data points, the degrees belonging to the determinant/indeterminate clusters were calculated using the NCM method. The membership *T* can be measured as the membership degree to determinant clusters, while for each data point, the other two memberships, namely *I* and *F* were used to define two types of the indeterminate clusters: i) an ambiguity cluster, and ii) an outlier cluster; respectively. Ambiguity cluster facilities the consideration of the data points which lie near to the boundaries of clusters and the outlier cluster allows rejection of the very far data points from the centers of each cluster. Since both ambiguity and outlier clusters are presented in the clustering iterations, thus the degrees of membership to the ambiguity and outlier class of a data point are clear. Hence, the membership functions are noise immune. A new objective function was minimized to achieve more resistant parameter estimation to noise and outliers. In addition, the clustering problem was formulated as a constrained minimization problem. In the objective function, the ambiguity rejection handling the patterns near the cluster boundaries, and the distance rejection concerning far away patterns from all the clusters were engaged. These measures managed the uncertainty due to incomplete and/or imprecise definition of the clusters. The experimental results established that the proposed procedure can be considered a promising tool for image processing and data clustering, where the FCM incapability to detect atypical data points can be solved. Yu *et al.* [44] adopted the mean shift clustering in NS domain for images segmentation in order to detect constructions with a stable threshold. The proposed technique was compared with three developed supervised techniques, which proved its superiority in constructions detection. A general algorithm for the clustering process using the FCM based on NS can be given as follows.

Algorithm: Clustering algorithm using FCM based on neutrosophic set

Start

Consider the degrees belonging to determinate clusters as well as the indeterminate clusters

Assume new unique set *A* defined by: $A = C_j \cup E \cup S,\ j = 1,\ldots,C$

Define the NS membership sets, namely *T* defines as the degree to determinant clusters, *I* denotes the degree to the boundary clusters, and *F* refers to the degree belonging to the noisy data set.

Consider clustering with indeterminacy

Perform the partitioning process through an iterative optimization of the objective function

Update the membership sets and the cluster centers c_j

Assign each data into the class with the largest *[T, I, F]*

End

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where, C_j is an indeterminate cluster, *E* refers to the clusters in boundary regions, *S* is related to the noisy data and $\cup$ is the union operation. *E* and *S* are indeterminate clusters.

3.3 Neutrosophic set for medical image thresholding

Image thresholding is a significant process to segment the images and extract objects. A variety of procedures have been proposed in this domain. Typically, in the classical set, each element indetermination in the set cannot be described and evaluated. The traditional fuzzy set uses a real number to signify the membership of fuzzy set N defined on universe A. However, the fuzzy sets approaches consider only the truth membership supported by the evidence without considering the falsity membership which is against the evidence, which is invalid in several applications. Meanwhile, the NS generalizes concept of the classic set, interval valued fuzzy set, fuzzy set, interval valued intuitionistic fuzzy set, and the intuitionistic fuzzy set. In the NS, the indeterminacy is quantified clearly and the truth membership (*T*), indeterminacy-membership (*I*) and falsity membership (*F*) are independent. Thus, several studies were conducted to improve the thersholding performance using NS.

Guo *et al*. [45] suggested a new algorithm based on neutrosophic similarity score to execute thresholding on image. The NS was utilized for image thresholding. Any image was represented in the NS domain through the three membership subsets *T, I* and *F*. Afterward, a neutrosophic similarity score (NSS) was defined to measure the degree to the ideal object. Lastly, an optimized value was chosen on the NSS to complete the image thresholding process. Cheng and Guo [46] transformed the images into NS domain using the three subsets, namely T, I and F with calculating the NS entropy to evaluate the indetermination. A new λ-mean operation was proposed to reduce the indetermination in the NS. The proposed technique was carried out for image thresholding to select the thresholds efficiently and automatically. In addition, it can process clean images, images with different types of noise and images with multiple types of noise. A general algorithm for this process can be given as follows.

Algorithm: Image Thersholding algorithm using neutrosophic set

Start

Identify the NS as given in (Definition 1)

Represent the medical image in the neutrosophic set given in equation (1)

Transform the image to the NS domain by calculating the three membership sets, namely *T*, *I* and *F*

Calculate the entropy of the indeterminate subset

Employ new operation to reduce the indetermination degree (to produce more uniform and homogenous image for thresholding)

Thresholded the image in the *NS* is using a histogram threholding technique

End

3.4 Neutrosophic set for medical image segmentation

Medical image segmentation is an essential process in pattern recognition and image processing that determines the final analysis quality as it separates objects from the background. Generally, during segmentation the image is divided into non-overlapping different regions. Fuzzy theory retains more information when applied for image segmentation compared to hard segmentation methods. Furthermore, FCM allows a data's segment to belong to two or more clusters. However, the indeterminancy of each element in the set using classical set approach cannot be described and evaluated. Thus, fuzzy see has been carried out to deal with uncertainty. Recently, neutrosophy offers a prevailing tool for handling indeterminacy. Cheng and Guo [46] integrated the k-means with the NS for image segmentation. This method achieved superior results with clean and noisy images. Nevertheless, it fail if the entropy is varying, which may cause boundaries and edges blur. Moreover, the performance of k-means clustering becomes poor when some pixels did not entirely belong to one cluster. In order to overcome these drawbacks, NS is applied with the image segmentation approach, where an integrated FCM and NS were carried out. Anter *et al*. [47] proposed an enhanced segmentation method based on the NS and fuzzy c-mean clustering (FCM). The segmentation method was carried out to segment abdominal computerized tomography (CT) images. These abdominal CT images were transformed into NS domain using the three known subsets, namely: the truth percentage in a subset T, indeterminacy percentage in the subset I, and falsity percentage in the subset F. The entropy in the NS was employed to evaluate the indeterminacy. The threshold for NS images was adapted using FCM algorithm. Lastly, the abdominal CT images were segmented and the liver parenchyma was selected using connected component approach. The proposed technique was compared with FCM using Dice Coecient and Jaccard Index. Finally, the CT images were segmented and liver parenchyma was selected using connected component algorithm. The results demonstrated that the proposed NS-FCM technique was less sensitive to noise and performed superior performance with non-uniform CT images.

Zhang *et al*. [48] applied the neutrosophy to image processing through defining a neutrosophic domain using the three subsets *T*, *I*, and *F*. Afterward, the watershed algorithm was applied to segment the image in the neutrosophic domain. The results established that the proposed technique provided superior results compared with that obtained by the existing techniques. Shan *et al*. [49] proposed fully automatic and accurate breast lesion segmentation for ultrasound (BUS) images. A novel neutrosophic clustering approach was applied to detect the precise lesion boundary. Initially, a region of interest was determined to cut off complex background. Afterward, a phase in max-energy orientation (PMO) algorithm was applied to improve the image quality. The PMO was proposed 2D phase feature attained by filtering the image in the frequency domain and manipulating the phase accumulation in the orientation with maximum energy. Finally, a proposed novel clustering technique called neutrosophic l-means (NLM) was carried out to detect the lesion of vague boundaries with superior handling for the uncertainty. The proposed NLM was compared with the traditional FCM clustering, level set, active contour, and watershed-based segmentation approaches. A general algorithm for the image segmentation using FCM based on NS is depicted as follows.

Algorithm: Image Segmentation algorithm using neutrosophic set based FCM

Start

Identify the NS as given in (Definition 1)

Represent the medical image in the neutrosophic set as given in equation (1)

Include certain-mean operation iteratively to reduce the indeterminacy of the image

Transform the image to the NS domain by calculating the three membership sets, namely *T*, *I* and *F*

Calculate the entropy of the indeterminate subset

Re-define and update the membership value in the FCM clustering according to the indeterminacy value

Terminate the iterative process

Segment the image based on the clustering result

End

3.5 Neutrosophic set for medical images classification

Kraipeerapun *et al*. [50] proposed medical binary classification using ensemble neural networks (NN) based on bagging technique and interval neutrosophic sets (INS). In the ensemble, each component consisted of a pair of NN trained to predict the truth and false membership values' degree. The indeterminacy membership values were applied to represent and estimate the uncertainties in the prediction. An interval neutrosophic set formed by collecting the three membership values. The outputs of an ensemble were dynamically weighted and summed to combine and to classify the outputs from components in the ensemble. The offered method has been tested with three benchmarking UCI data sets, namely the pima, ionosphere, and liver. The proposed ensemble improved the classification performance compared to the simple majority vote and averaging approaches which were applied only to the truth membership value. The results depicted that the INS represented uncertainty information and supported the classification quite well.

Ju [51] proposed an integrated NS into a reformulated support vector machine (SVM) called NSVM classifier. Image categorization is an important yet challenging research topic in computer vision. The images were first segmented by a two-stage self-organizing map (HSOM) using texture and color features. Based on homogeneity properties, a novel method was proposed to select the training samples of the HSOM. By viewing an image as a bag of instances corresponding to the obtained regions from the segmented image, a diverse density SVM (DDSVM) framework was then carried out the image categorization problem. The categorization was then transformed to a classification problem. Afterward, the proposed N-SVM based on the NS was used as the classifier in the new bag space. The N-SVM treated the samples differently according to the weighting function, and it reduced the outliers' effects. The results established the effectiveness and validity of the proposed NS technique for the input samples of SVM based on the distances between the sample and the class centers. NS explored the training samples spatial distribution and can solve the outliers' problems when integrated into the reformulated SVM.

4. Neutrosophic set in medical diagnosis

For accurate medical diagnosis, researchers are interested with developing new algorithms to handle the modalities variety output [52- 62]. Recently, a new trend is to use the NS approaches in the processing stages to achieve precise diagnoses from the captured images. The NS has a significant role compared to the classical logic (CL), where the logical variable in the CL is restricted to two values only, namely true (T) and false (F), while the NS is considered an extension to the CL set by adding a third logical value, namely the indeterminate value to address the uncertainties. In a NS as described in section 2, every element y is represented as an ordered triplet $x = (t, i, f)$, where t, i, and f are the degree of truth, indeterminacy, and falseness, respectively to characterize the absolute true and absolute false sets, and I is for indeterminate or uncertain set. Consequently, one of the neutrosophy advantages is its ability to interpret true, false, and indeterminate set along with the neutrosophic operations such as the logical OR/AND operation that can be compliantly designed in order to reduce the indeterminacy of the whole set. Using this description along with the main framework stated in the preceding sections, several applications for the NS on different captured images from the different modalities were reported as follows for some of these studies. Furthermore, many other works using different modalities for different organs, and diseases may be found that includes NS in the medical image processing phases.

4.1 Neutrosophic set in medical diagnosis for computed tomography images

Computed tomography (CT) devices are non-invasive, accurate and fast automatic imaging modality that assists pathologists to investigate the internal organs giving detailed cross sectioned view of internal tissues. Jayanthi [63] discussed the possibility of different segmenting techniques for liver from the abdominal CT imaging to detect and classify liver regions. Different segmentation algorithms such as the label connected, seeded region growing, and NS with thresholding were compared. For liver segmentation from abdominal CT images, Sayed *et al*. [64] proposed a hybrid segmentation technique based on modified Watershed procedure and Neutrosophic logics. After the pre-processing phase, the CT image was transformed to Neutrosophic domain for further post-processing phase. The histogram equalization and median filter were applied in the pre-processing phase to enhance the intensity and contrast values as well as to remove the noise through the three membership sets. Finally, a mathematical morphology and modified watershed procedures were used to enhance the attained truth image formed from the previous phase and to extract liver from the CT images. The experimental results established accuracy of 95%.

In several image analysis applications, Lung segmentation is the main process for lung abnormalities/ diseases in the thoracic CT. Previous works have been done for lung segmentation based on the morphological operations (EMM) and the expectation-maximization (EM) analysis in CT pulmonary angiography (CTPA). Nonetheless, due to the large variations in pathology, it was complex to extract the lung regions precisely in the thoracic CT images, especially if the lung parenchyma contains widespread lung diseases. Consequently, several studies have been conducted to develop novel techniques for accurate lung segmentation, including affected lung with many diseases.

Guo *et al*. [65] proposed an iterative neutrosophic lung segmentation (INLS) scheme to develop the EMM segmentation using the anatomic features of the lungs and ribs. The ribs were extracted using three-dimensional hierarchical EM segmentation. In addition, the ribcage features were constructed using morphological operations. Initially, the EMM segmentation based on the anatomic features was distinguished using the INLS to determine the final lung regions. During the INLS technique, the anatomic features were mapped into a neutrosophic domain. Afterward, in order to refine the ILRs, the neutrosophic operation was executed iteratively. Relative to reference standard images, several metrics were used to evaluate the proposed approach, including the percentage overlap area (POA), the average distance (AvgDist), and the Hausdorff distance (Hdist) of the lung boundaries. The experimental results established that the proposed technique has larger POAs and smaller distance errors compared to the EMM method. Furthermore, the INLS identified the affected lung boundaries cases. The results proved that both the EMM and the INLS methods segmented the lung without diseases more accurately compared to the cases with lung diseases. However, the INLS technique achieved better performance than the EMM in both without/with lung disease cases. Thus, the proposed new INLS technique using the anatomic features of the lung and rib improved the lung segmentation accuracy. Chawla *et al*. [66] proposed an effective method for CT images de-noising to remove the Additive white Gaussian Noise (AWGN) and to improve the images quality. The proposed work was comprised of three steps including i) pre-processing for the CT images which are affected by the AWGN noise, ii) transform the images using multi-wavelet transformation, and iii) in the training step the obtained multi-wavelet coefficients were given as input to the Adaptive Neuro-Fuzzy Inference System (ANFIS) to enhance the CT images quality of thresholding. Afterward, the image was reconstructed.

4.2 Neutrosophic set in medical diagnosis for magnetic resonance images

One of the most effective modality for medical imaging is the magnetic resonance imaging (MRI). It scanners the body part using radio waves and magnetic fields in order to produce images internal parts of the body. Several studies were conducted on the MRI images to develop algorithms and techniques for medical image processing. Recently, researchers are directed to involve NS for developing such techniques.

Mohan *et al*. [67] proposed a NS approach of MRI for de-noising. The NS technique of median filter was applied to reduce the Rician noise in the MR images. A validation based on structural similarity such as quality index based on local variance (QILV) and structural similarity index (SSIM) were carries out. The diagnostic and visual quality of the de-noised image was well preserved. The filter performance is compared with the non-local mean filter (NLM) and median filter. Elnazer *et al*. [68] proposed a developed segmentation technique based on NS and Modified Non local Fuzzy c-mean clustering (NLFCM). Brain tumor MRI images were transformed into the NS domain. The NS was described using three subsets namely; the percentage of truth (T%), the percentage of indeterminacy (I%) , and the percentage of falsity (F%). In addition, the entropy in NS was measured to evaluate the indeterminacy. Afterward, the image was adapted using Modified Non-local Fuzzy C-mean algorithm (MNLFCM) for final brain tumor images' segmentation. The tumor was selected using Modified Level Sets (MLS). The proposed technique was compared with studies using Dice Coefficient and Jaccard Index.

The results proved that the proposed technique was less sensitive to noise and performed superior performance on MRI brain images, where 100% detection rate was achieved by the proposed method in all 34 cases with average of high specificity (99. 26%), high dice (99.37%) and, modified Hausdroff distance (1.302) and lower missing rate (0.52).

4.3 Neutrosophic set in medical diagnosis for ultrasound images

Other studies used the NS for enhancing the image processing steps for captured images from different modalities. Zhang *et al*. [69] were concerned with ultrasound for breast cancer diagnosis. The authors employed the Neutrosophy, which extend fuzzy logic and are the basis of neutrosophic logic, neutrosophic set theory, neutrosophic probability theory, and neutrosophic statistics. The Neutrosophy is the origin, nature, and scope of neutralities and their relations with different ideational spectra. The authors developed the neutrosophy to fully automate an algorithm for BUS (breast ultrasound) image segmentation. The results established that the proposed technique was effective, accurate, and robust. Shan *et al*. [70] developed a new fully automatic technique for BUS images segmentation using a novel neutrosophic clustering method to detect the accurate lesion boundary. First, a ROI (region of interest) was determined to cut off complex background. Afterward, in order to improve the image quality, an enhancement process based on the phase in max-energy orientation (PMO) was developed. Finally, the authors suggested a new clustering method called neutrosophic l-means (NLM) to detect the lesion boundary. The NLM was applied to segment the images with vague boundaries, and to deal the uncertainty. The proposed method was compared with the traditional level set, active contour, fuzzy c-means clustering, and watershed-based segmentation approaches. The results established that the proposed technique generated the most similar boundaries to the radiologist's manual delineations with 92.4%TP rate, 7.2%FP rate, and 86.3%similarity rate; and 4.8 pixels of the mean absolute distance with effective processing 9.8 s per image average speed. In addition, the sensitivity analysis proved the robustness of the proposed technique.

5. Discussion, challenges and future perspectives for medical image processing using neutrosophic set

From the preceding studies it is established that NS has an imperative role in medical image processing tasks with potential applications of NS in decision making and other processed [71-78]. To be more specific, NS is applied for image de-noising, image thersholding, image clustering image segmentation and image classification in several domains including the medical image processing applications. However, there is no studies were conducted to use the NS in image registration, image compression, and/or image restoration. Consequently, it is recommended to use the NS approaches in such tasks compared to the existing techniques. In addition, it is observed that the most clustering technique that can be integrated with the NS to reduce the uncertainty is the FCM for clustering. Thus, it is recommended to integrate the NS with other clustering techniques.

Furthermore, since medical imaging diagnosis systems are based mainly on the relationship between patients and diseases by considering diseases and symptoms as well as symptoms and patients. However, this is not always applied correctly as these are sometimes missing, for example ignoring the patient diagnosis's history is another drawback. Thus, previous studies depend on the de-neutrosophication process, correlation coefficients, similarity measures, and distance measure operations have been considered in the medical diagnosis problem, which requires more analysis and study. Furthermore, a hybrid structure based on NS can be proposed for accurate medical diagnosis to handle the NS limitations concerning missing information and historic diagnosis of the medical patient.

In addition, since there is some shortcomings of the cross entropy between Single Valued Neutrosophic Sets (SVNSs) when handling decision-making problems. Thus, Ye [52] proposed an improved cross entropy measure of SVNSs and investigated its properties. The author extended the SVNS to a cross entropy measure between interval neutrosophic sets (INSs). Moreover, the cross entropy measures were carried out for multicriteria decision making problems with interval neutrosophic information and single valued neutrosophic information. The decision-making approaches using the suggested cross entropy measures can competently deal with decision making problems with indeterminate, incomplete and inconsistent medical information. In the future, several classification techniques using NS can be applied to the problem of multiclass classification.

Generally speaking, it is clear that medical image segmentation is the task that used NS in several medical applications. Moreover, form the proposed algorithms it is noticeable that there are common framework steps for all image processing when using the NS, which are:

Start

    Identify the NS as given in (Definition 1)

    Represent the medical image in the neutrosophic set as given in equation (1)

    Transform the image to the NS domain by calculating the three membership sets, namely *T*, *I* and *F*

    Calculate the entropy of the indeterminate subset

    …..

    …..

End

Afterward, based on the involved medical image processing technique, the algorithm is completed. Lately, numerous theories have been investigated to deal with imprecision, uncertainty and vagueness. Consequently, the refined neutrosophic set, where *T*, *I*, *F* are refined/split in *n* subcomponents [79] is recommended in biomedical imaging. Generally, the neutrosophic refined sets have several definitions including convex, intersection, union, and strongly convex to handle the inconsistent/indeterminate information. In addition, it is recommended to refer to the following studies [80-95] on the neutrosophic sets as well as fuzzy logic that can be applied in different medical and other applications in several domains.

6. Conclusion

Many real life decision making problems involve impreciseness, uncertainty, vagueness, inconsistent, incompleteness, and indeterminacy, thus NS and logic are gaining significant attention to solve such problems. Neutrosophic refers to the development and applications of the neutrosophic- set, logic, measure, and probability. The importance of the current work lies in assisting researchers and interested scientists with the NS applications in the medical image processing domain. Extensive definitions for the NS model and applications were introduced.

A general framework was introduced for image processing using NS, where the NS is initially represented using the three main components, namely: T, I, and F denoting the degree of truth, indeterminacy, and falseness; respectively. Afterward, the medical image is to be represented in the neutrosophic set domain. This transformation is performed by calculating the three membership sets. Then, the entropy of indeterminate subset is calculated. In order to attain superior performance for the medical image process under concern, the value of indeterminate subset is to be minimized.

Typically, the NS has an imperative role in medical images segmentation, de-noising, and clustering. However, for classification, restoration and registration there is no reported work for using NS with such tasks without any clear reason. Thus, researchers are recommended to use NS with such processes with comparative studies.

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