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Cotangent Similarity Measure of n-Valued Interval Neutrosophic Sets for Medical Diagnosis

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Abstract

Each illness presents with specific signs and symptoms. The proposed approach effectively identifies relationships between groups of illnesses and the symptoms that patients experience, supporting medical professionals in reaching a likely diagnosis. Medical diagnosis relies heavily on n-valued interval neutrosophic sets and their applications. This study examines aspects of cotangent similarity among n-valued interval neutrosophic sets and proposes a method utilizing these concepts. This approach serves as a valuable tool for addressing uncertainties and limitations in existing diagnostic methods. The application of this method in medical diagnosis is evaluated to accurately identify the illness affecting the patient. The diagnostic results demonstrate the effectiveness of the proposed strategy.

Keywords: n-valued interval neutrosophic sets, Cotangent similarity measure, Medical diagnosis uncertainty modeling, Fuzzy decision-making in healthcare, Neutrosophic logic in symptom analysis.

1 | Introduction

Kumbakonam is a thickly populated town. Although an underground drainage system is available here, it is yet to cover all the houses in the town. So, an open drainage system continues to be implemented in different parts of the town. Further, this town is racing fast toward total sanitation in all spheres. As a result, Kumbakonam continues to be a repository of all new kinds of diseases. This created an urge to carry out research in the medical field. By introducing innovative methods in the study, diseases can be diagnosed instantly and infallibly.

A number of real-life problems in engineering, medical sciences, social sciences, economics, etc., involve imprecise data, and their solution consists of using mathematical principles based on uncertainty and imprecision. Such uncertainties are dealt with with topics like probability theory, fuzzy set theory1, rough set

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theory, etc. The healthcare industry has been trying to complement the services offered by conventional clinical decision-making systems with the integration of fuzzy logic techniques. As it is not an easy task for a clinician to derive a foolproof diagnosis, it is advantageous to automate a few initial steps of diagnosis that would not require expert intervention. A Neutrosophic Set (NS), which is a generalized set, possesses all attributes necessary to encode a medical knowledge base and capture medical inputs.

As medical diagnosis contains a lot of uncertainties and an increased volume of information available to physicians

With new medical technologies, classifying different sets of symptoms under a single disease name becomes difficult. In some practical situations, each element may have different truth membership and indeterminate and false membership functions. The unique feature of the n-valued interval NS is that it contains multi-truth membership, indeterminate, and false membership. By taking a one-time inspection, there may be an error in diagnosis. Hence, a multi-time inspection gives the best diagnosis by taking the same patient's samples at different times. So, n-valued interval NSs and their applications play a vital role in medical diagnosis.

In 1965, the fuzzy set theory was first introduced by Zadeh [1], and it is applied in many real applications to handle uncertainty. Sometimes, the membership function is uncertain and hard to define with a crisp value. So, the concept of interval-valued fuzzy sets was proposed to capture the uncertainty of the membership grade. In 1986, Atanassov [2] introduced the intuitionistic fuzzy sets, which consider both truth-membership and falsity-membership. Edward Samuel and Narmadhagnanam [3] proposed and applied the tangent inverse distance and sine similarity measure of intuitionistic fuzzy sets in medical diagnosis. Kozae et al. [4] applied intuitionistic fuzzy sets in corona covid-19 determination. Rajkalpana et al. [5] applied intuitionistic fuzzy sets and their operators in medical diagnosis.

Shinoj and John [6] extended the concept of fuzzy multisets by introducing intuitionistic fuzzy multisets. Rajarajeswari and Uma [7], [8] proposed several methods among intuitionistic fuzzy multisets. Edward Samuel and Narmadhagnanam [9] proposed sine inverse distance of intuitionistic fuzzy multisets and applied them in medical diagnosis. Later on, intuitionistic fuzzy sets were extended to the interval-valued intuitionistic fuzzy sets. Intuitionistic fuzzy sets and interval-valued intuitionistic fuzzy sets can only handle incomplete information, not indeterminate information, and inconsistent information, which exists commonly in belief systems. So, the NS (a generalization of fuzzy sets, intuitionistic fuzzy sets, and so on) defined by Smarandache [10] has the capability to deal with uncertain, imprecise, incomplete, and inconsistent information that exists in the real world from a philosophical point of view. In 1982, Pawlak [11] introduced the concept of a rough set as a formal tool for modeling and processing incomplete information in information systems.

Two basic elements in rough set theory, crisp set and equivalence relation, constitute the mathematical basis of rough sets. The basic idea of a rough set is based upon the approximation of sets by a pair of sets known as the lower approximation and the upper approximation of a set. Here, the lower and upper approximation operators are based on equivalence relations. Nanda and Majumdar [12] examined fuzzy rough sets. Broumi et al. [13] introduced rough NSs. Pramanik and Mondal [14], [15] introduced cosine and cotangent similarity measures of rough NSs. Pramanik et al. [16] introduced the correlation coefficient of rough NSs. Edward Samuel and Narmadhagnanam [17–20] proposed a few methods among rough NSs and applied them to medical diagnosis. Bera and Mahapatra [21] applied generalized single-valued neutrosophic numbers in neutrosophic linear programming. Ulucay et al. [22] proposed a new approach for multi-attribute decision-making problems in bipolar NSs. Wang et al. [23] proposed the single-valued NS. Majumdar and Samanta [24] proposed the similarity and entropy of NSs. Ye [25] proposed the cotangent similarity measure of single-valued NSs.

Broumi et al. [26] proposed single-valued (2N+1) sided polygonal neutrosophic numbers and single-valued (2N) sided polygonal neutrosophic numbers. Li et al. [27] slope stability assessment method using the arctangent and tangent similarity measure of neutrosophic numbers. Edward Samuel and Narmadhagnanam [28], [29] introduced cosine logarithmic distance and tangent inverse similarity measure among single valued

NSs and applied it in medical diagnosis. Edward Samuel and Narmadhagnanam [30] introduced sine exponential measure among single valued NSs and applied it in medical diagnosis. Chai et al. [31] proposed new similarity measures of single-valued NSs. Ye and Ye [32] introduced the concept of single-valued neutrosophic multisets. Edward Samuel and Narmadhagnanam [33] introduced cosine exponential distance among single-valued neutrosophic multisets and applied it to medical diagnosis. In 2013, Smarandache [34] extended the classical neutrosophic logic to n-valued refined neutrosophic logic by refining each neutrosophic component T, I, F into respectively, T1,T2,..,Tm,I1,I2,...,Ip and F1,F2,..,Fr. Neutrosophic refined sets are a generalization of fuzzy multisets and intuitionistic fuzzy multisets.

In 2014, Broumi and Smarandache [35] extended the improved cosine similarity of a single-valued NS proposed by Ye [36] to the case of neutrosophic refined sets. Edward Samuel and Narmadhagnanam [37–39] introduced a few methods in neutrosophic refined sets and applied them to medical diagnosis. Broumi et al. [40] generalize the concept of n-valued NSs to the case of n-valued interval NSs. Edward Samuel and Narmadhagnanam [41–44] introduced many methods in n-valued interval NSs and applied them to medical diagnosis. The proposed method had more accuracy than the others, and they could handle the limitations and drawbacks of the previous works well. This study discovers the relationship between the symptoms found within patients and a set of diseases. This study will help the researcher discover the diseases that impact the patients. The method employed is free from the limitations commonly found in other studies. Without such limitations, a new theory on image processing, cluster analysis, etc., has been developed in this study.

The rest of the article is structured as follows. In Section 2, we briefly present the basic definitions. Section 3 deals with the proposed definition and some of its properties. Sections 4, 5, and 6 deal with methodology, algorithm, and the case study related to medical diagnosis. A significance statement is given in Section 7. The conclusion is given in Section 8.

2 | Preliminaries

Definition 1 ([45]). Let X be a universe of discourse, with a generic element in X denoted by x; the NS A is an object having the form

$$A=\{\langle x:T_A(x),I_A(x),F_A(x)\rangle,x\in X\},$$

where the functions define $T,I,F:X\to\,]^-0,1^+[$ respectively the degree of membership (or truth), the degree of indeterminacy and the degree of non-membership(or falsehood) of the element $x\in X$ to the set A with the condition

$$^-0\le T_A(x)+I_A(x)+F_A(x)\le 3^+.$$

Definition 2 ([40]). Let X be a universe, a n-valued interval NS on X can be defined as follows:

$$A=\left\{\begin{array}{l}x,\left(\left[\inf T_A^1(x),\sup T_A^1(x)\right],\left[\inf T_A^2(x),\sup T_A^2(x)\right],\ldots,\left[\inf T_A^p(x),\sup T_A^p(x)\right]\right),\\ \left(\left[\inf I_A^1(x),\sup I_A^1(x)\right],\left[\inf I_A^2(x),\sup I_A^2(x)\right],\ldots,\left[\inf I_A^p(x),\sup I_A^p(x)\right]\right),\\ \left(\left[\inf F_A^1(x),\sup F_A^1(x)\right],\left[\inf F_A^2(x),\sup F_A^2(x)\right],\ldots,\left[\inf F_A^p(x),\sup F_A^p(x)\right]\right):x\in X,\end{array}\right\}$$

where $\inf T_A^1(x),\inf T_A^2(x),\ldots,\inf T_A^p(x)$, $\inf I_A^1(x),\inf I_A^2(x),\ldots,\inf I_A^p(x)$, $\inf F_A^1(x),\inf F_A^2(x),\ldots,\inf F_A^p(x)$, $\sup T_A^1(x),\sup T_A^2(x),\ldots,\sup T_A^p(x)$, $\sup I_A^1(x),\sup I_A^2(x),\ldots,\sup I_A^p(x)$, $\sup F_A^1(x),\sup F_A^2(x),\ldots,\sup F_A^p(x)\in[0,1]$ such that
$0\le \sup T_A^j(x)+\sup I_A^j(x)+\sup F_A^j(x)\le 3,\ \text{forall } j=1,2,3,\ldots,p.$

Definition 3 ([40]). A n-valued interval NS A is contained in the other n-valued interval NS B, denoted by $A\subseteq B$, if and only if

$$\begin{aligned}
&\inf T_A^1(x)\le \inf T_B^1(x),\ \inf T_A^2(x)\le \inf T_B^2(x),\ \ldots, \inf T_A^p(x)\le \inf T_B^p(x),\\
&\sup T_A^1(x)\le \sup T_B^1(x),\ \sup T_A^2(x)\le \sup T_B^2(x),\ldots,\ \sup T_A^p(x)\le \sup T_B^p(x),\\
&\inf I_A^1(x)\ge \inf I_B^1(x),\ \inf I_A^2(x)\ge \inf I_B^2(x),\ldots,\ \inf I_A^p(x)\ge \inf I_B^p(x),\\
&\sup I_A^1(x)\ge \sup I_B^1(x),\ \sup I_A^2(x)\ge \sup I_B^2(x),\ldots,\ \sup I_A^p(x)\ge \sup I_B^p(x),\\
&\inf F_A^1(x)\ge \inf F_B^1(x),\ \inf F_A^2(x)\ge \inf F_B^2(x),\ldots,\ \inf F_A^p(x)\ge \inf F_B^p(x),\\
&\sup F_A^1(x)\ge \sup F_B^1(x),\ \sup F_A^2(x)\ge \sup F_B^2(x),\ldots,\ \sup F_A^p(x)\ge \sup F_B^p(x),\ \text{forall}\ x\in X.
\end{aligned} \tag{1}$$

3 | Proposed Definition

Definition 4. Let

$$A=\left\{\begin{array}{l}
x,\left(\left[\inf T_A^1(x),\sup T_A^1(x)\right],\left[\inf T_A^2(x),\sup T_A^2(x)\right],\ldots,\left[\inf T_A^p(x),\sup T_A^p(x)\right]\right),\\
\left(\left[\inf I_A^1(x),\sup I_A^1(x)\right],\left[\inf I_A^2(x),\sup I_A^2(x)\right],\ldots,\left[\inf I_A^p(x),\sup I_A^p(x)\right]\right),\\
\left(\left[\inf F_A^1(x),\sup F_A^1(x)\right],\left[\inf F_A^2(x),\sup F_A^2(x)\right],\ldots,\left[\inf F_A^p(x),\sup F_A^p(x)\right]\right): x\in X,
\end{array}\right\}$$

and

$$B=\left\{\begin{array}{l}
x,\left(\left[\inf T_B^1(x),\sup T_B^1(x)\right],\left[\inf T_B^2(x),\sup T_B^2(x)\right],\ldots,\left[\inf T_B^p(x),\sup T_B^p(x)\right]\right),\\
\left(\left[\inf I_B^1(x),\sup I_B^1(x)\right],\left[\inf I_B^2(x),\sup I_B^2(x)\right],\ldots,\left[\inf I_B^p(x),\sup I_B^p(x)\right]\right),\\
\left(\left[\inf F_B^1(x),\sup F_B^1(x)\right],\left[\inf F_B^2(x),\sup F_B^2(x)\right],\ldots,\left[\inf F_B^p(x),\sup F_B^p(x)\right]\right): x\in X,
\end{array}\right\}$$

be two n-valued interval NSs, then the cotangent similarity measure

$$COT_{NVINS}(A,B)=\frac{1}{p}\sum_{j=1}^{p}\left[\sum_{i=1}^{n}\frac{1}{2n}\cot\left[\frac{\pi}{24}\left[\begin{array}{l}
6+\left|\inf T_A^j(x_i)-\inf T_B^j(x_i)\right|+\left|\sup T_A^j(x_i)-\sup T_B^j(x_i)\right|+\\
\left|\inf I_A^j(x_i)-\inf I_B^j(x_i)\right|+\left|\sup I_A^j(x_i)-\sup I_B^j(x_i)\right|+\\
\left|\inf F_A^j(x_i)-\inf F_B^j(x_i)\right|+\left|\sup F_A^j(x_i)-\sup F_B^j(x_i).\right|
\end{array}\right]\right]\right] \tag{2}$$

Proposition 1

I. $COT_{NVINS}(A,B)\in[0,1]$.

II. $COT_{NVINS}(A,B)=COT_{NVINS}(B,A)$.

III. If $A\subseteq B\subseteq C$ then $COT_{NVINS}(A,C)\le COT_{NVINS}(A,B)$ & $COT_{NVINS}(A,C)\le COT_{NVINS}(B,C)$.

Proof:

I. The proof is straightforward.

II. The proof is straightforward.

III. By (1).

$$\begin{aligned}
&\inf T_A^j(x_i)\le \inf T_B^j(x_i)\le \inf T_C^j(x_i),\\
&\sup T_A^j(x_i)\le \sup T_B^j(x_i)\le \sup T_C^j(x_i),\\
&\inf I_A^j(x_i)\ge \inf I_B^j(x_i)\ge \inf I_C^j(x_i),\\
&\sup I_A^j(x_i)\ge \sup I_B^j(x_i)\ge \sup I_C^j(x_i),
\end{aligned}$$

$\inf F_A^j(x_i) \geq \inf F_B^j(x_i) \geq \inf F_C^j(x_i)$,
$\sup F_A^j(x_i) \geq \sup F_B^j(x_i) \geq \sup F_C^j(x_i)$..

Hence,

$$|\inf T_A^j(x_i) - \inf T_B^j(x_i)| = |\inf T_B^j(x_i) - \inf T_A^j(x_i)|,$$
$$|\sup T_A^j(x_i) - \sup T_B^j(x_i)| = |\sup T_B^j(x_i) - \sup T_A^j(x_i)|,$$
$$|\inf I_A^j(x_i) - \inf I_B^j(x_i)| = |\inf I_B^j(x_i) - \inf I_A^j(x_i)|,$$
$$|\sup I_A^j(x_i) - \sup I_B^j(x_i)| = |\sup I_B^j(x_i) - \sup I_A^j(x_i)|,$$
$$|\inf F_A^j(x_i) - \inf F_B^j(x_i)| = |\inf F_B^j(x_i) - \inf F_A^j(x_i)|,$$
$$|\sup F_A^j(x_i) - \sup F_B^j(x_i)| = |\sup F_B^j(x_i) - \sup F_A^j(x_i)|.$$

Here, the cotangent similarity measure is a decreasing function.

$\therefore COT_{NVINS}(A,C) \leq COT_{NVINS}(A,B)$ & $COT_{NVINS}(A,C) \leq COT_{NVINS}(B,C)$.

4 | Methodology

In this section, an application of an n-valued interval NS was presented in medical diagnosis. In a given pathology, suppose S is a set of symptoms, D is a set of diseases, and P is a set of patients and let Q be an n-valued interval neutrosophic relation from the set of patients to the symptoms. i.e., $Q(P \rightarrow S)$ and R be an interval neutrosophic relation from the set of symptoms to the diseases, i.e., $R(S \rightarrow D)$ and then the methodology involves three main jobs:

I. Determination of symptoms.

II. Formulation of medical knowledge based on n-valued interval NSs & interval NSs.

III. Determination of diagnosis based on new computation technique of n-valued interval NSs.

5 | Algorithm

Step 1. The patients' symptoms are given to obtain the patient symptom relation Q and are noted in *Table 1*.

Step 2. The medical knowledge relating the symptoms with the set of diseases under consideration is given to obtain the symptom-disease relation R, and is noted in *Table 2*.

Step 3. The computation T (relation between patients and diseases) is found using (2) between *Table 1* and *Table 2* is noted in *Table 3*.

Step 4. Finally, the maximum value from *Table 3* of each row was selected to find the possibility of the patient affected with the respective disease, and then it was concluded that the patient $P_k (k = 1,2\&3)$ was suffering from the disease $D_r (r = 1,2,3\&4)$.

6 | Case Study

In this section, an example adapted from Broumi et al. [40] (an application of n- valued interval NSs in medical diagnosis) is used.

Let there be three patients $P=\{P_1, P_2, P_3\}$ and the set of symptoms $S = \{S_1 =$temperature, $S_2 =$cough, $S_3 =$throat pain, $S_4 =$headache, $S_5 =$body pain$\}$. The n-valued interval neutrosophic relation $Q(P \rightarrow S)$ is given as in *Table 1*. Let the set of diseases $D=\{D_1 =$Viral fever, $D_2 =$tuberculosis, $D_3 =$typhoid, $D_4 =$throat disease$\}$. The interval neutrosophic relation $R(S \rightarrow D)$ is given as in *Table 2*.

Table 1. Patient-symptom relation (using step 1).

Q	Temperature	Cough	Throat Pain	Headache	Body Pain
P_1	[0.3,0.4],[0.4,0.5],[0.3,0.7] [0.0,0.3],[0.1,0.3],[0.0,0.5] [0.0,0.6],[0.4,0.5],[0.3,0.4]	[0.1,0.2],[0.3,0.6],[0.6,0.8] [0.0,0.5],[0.4,0.7],[0.4,0.5] [0.2,0.3],[0.0,0.5],[0.4,0.6]	[0.0,0.5],[0.2,0.6],[0.0,0.4] [0.3,0.4],[0.2,0.3],[0.3,0.4] [0.0,0.7],[0.3,0.7],[0.3,0.5]	[0.2,0.3],[0.3,0.5],[0.0,0.7] [0.4,0.5],[0.4,0.7],[0.3,0.6] [0.2,0.6],[0.0,0.6],[0.3,0.4]	[0.0,0.4],[0.6,0.7],[0.2,0.5] [0.2,0.4],[0.4,0.5],[0.1,0.2] [0.1,0.3],[0.1,0.3],[0.2,0.3]
P_2	[0.2,0.3],[0.4,0.5],[0.1,0.2] [0.4,0.5],[0.2,0.5],[0.0,0.3] [0.6,0.7],[0.4,0.5],[0.4,0.5]	[0.5,0.7],[0.0,0.4],[0.7,0.8] [0.6,0.7],[0.0,0.5],[0.4,0.5] [0.4,0.6],[0.2,0.7],[0.0,0.3]	[0.5,0.6],[0.0,0.6],[0.2,0.3] [0.4,0.7],[0.4,0.6],[0.3,0.4] [0.1,0.3],[0.2,0.3],[0.5,0.7]	[0.2,0.5],[0.5,0.6],[0.1,0.5] [0.2,0.3],[0.2,0.5],[0.5,0.6] [0.1,0.3],[0.3,0.4],[0.4,0.5]	[0.2,0.4],[0.4,0.6],[0.1,0.4] [0.0,0.5],[0.2,0.4],[0.5,0.6] [0.5,0.7],[0.0,0.7],[0.2,0.4]
P_3	[0.1,0.3],[0.0,0.5],[0.4,0.6] [0.1,0.2],[0.3,0.4],[0.2,0.5] [0.2,0.4],[0.4,0.5],[0.3,0.7]	[0.2,0.3],[0.0,0.7],[0.1,0.4] [0.5,0.6],[0.0,0.3],[0.3,0.5] [0.3,0.5],[0.2,0.5],[0.4,0.6]	[0.2,0.4],[0.3,0.6],[0.0,0.6] [0.4,0.5],[0.0,0.3],[0.3,0.4] [0.5,0.7],[0.4,0.6],[0.3,0.7]	[0.2,0.3],[0.5,0.6],[0.4,0.5] [0.2,0.4],[0.0,0.4],[0.2,0.7] [0.4,0.5],[0.2,0.3],[0.3,0.5]	[0.0,0.6],[0.4,0.7],[0.2,0.3] [0.2,0.3],[0.2,0.3],[0.1,0.2] [0.0,0.6],[0.2,0.4],[0.4,0.6]

Table 2. Symptom-disease relation (using step 2).

R	Viral Fever	Tuberculosis	Typhoid	Throat Disease
Temperature	[0.2,0.4],[0.3,0.5],[0.3,0.7]	[0.1,0.4],[0.2,0.6],[0.6,0.7]	[0.0,0.3],[0.4,0.6],[0.0,0.2]	[0.3,0.4],[0.2,0.5],[0.0,0.6]
Cough	[0.2,0.4],[0.2,0.3],[0.0,0.5]	[0.3,0.4],[0.2,0.5],[0.7,0.8]	[0.3,0.4],[0.2,0.3],[0.1,0.2]	[0.4,0.5],[0.1,0.3],[0.0,0.5]
Throatpain	[0.0,0.4],[0.2,0.4],[0.2,0.4]	[0.0,0.2],[0.3,0.6],[0.6,0.7]	[0.1,0.2],[0.4,0.5],[0.3,0.4]	[0.2,0.4],[0.2,0.5],[0.3,0.7]
Headache	[0.4,0.7],[0.0,0.3],[0.3,0.5]	[0.1,0.2],[0.0,0.5],[0.0,0.6]	[0.3,0.4],[0.2,0.3],[0.2,0.5]	[0.0,0.3],[0.3,0.6],[0.2,0.5]
Bodypain	[0.1,0.4],[0.2,0.5],[0.3,0.4]	[0.5,0.7],[0.4,0.5],[0.2,0.5]	[0.2,0.3],[0.2,0.4],[0.2,0.3]	[0.0,0.4],[0.1,0.2],[0.1,0.3]

Table 3. Cotangent similarity measure (using step 3 and step 4).

T	Viral Fever	Tuberculosis	Typhoid	Throat Disease
P_1	0.3952	0.3696	0.3804	0.3839
P_2	0.3697	0.3595	0.3754	0.3863
P_3	0.4000	0.3693	0.3892	0.3976

7 | Significance Statement

This study discovers the relationship between the symptoms found within patients and a set of diseases. This study will help the researcher to find out the diseases accurately that impacted the patients. The method employed is free from the limitations commonly found in other studies. Without such limitations, a new theory on image processing, cluster analysis, etc., has been developed in this study.

8 | Conclusion

This study analyzed the relationship between the set of symptoms found within the patients and the set of diseases. Then, one method(cotangent similarity measure) was employed to find out the diseases that possibly affected the patient. The techniques considered in this study are reliable and trustworthy for handling medical diagnosis problems quite comfortably. It could avoid the limitations and drawbacks of previous works as the method is more accurate in handling the diagnosis.

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Conflict of Interest

The authors declare no conflict of interest.

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