Research Article

Some Similarity Measures of Neutrosophic Sets Based on the Euclidean Distance and Their Application in Medical Diagnosis

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Similarity measure is an important tool in multiple criteria decision-making problems, which can be used to measure the difference between the alternatives. In this paper, some new similarity measures of single-valued neutrosophic sets (SVNSs) and interval-valued neutrosophic sets (IVNSs) are defined based on the Euclidean distance measure, respectively, and the proposed similarity measures satisfy the axiom of the similarity measure. Furthermore, we apply the proposed similarity measures to medical diagnosis decision problem; the numerical example is used to illustrate the feasibility and effectiveness of the proposed similarity measures of SVNSs and IVNSs, which are then compared to other existing similarity measures.

1. Introduction

The concept of fuzzy set (FS) \(A = \{\langle x_i, u_A(x_i)\rangle | x_i \in X\}\) in \(X = \{x_1, x_2, \ldots, x_n\}\) was proposed by Zadeh [1], where the membership degree \(u_A(x_i)\) is a single value between zero and one. The FS has been widely applied in many fields, such as medical diagnosis, image processing, supply decision-making [2–4], and so on. In some uncertain decision-making problems, the degree of membership is assumed not exactly as a numerical value but as an interval. Hence, Zadeh [5] proposed the interval-valued fuzzy set (IVFS). However, the FS and IVFS only have the membership degree, and they cannot describe the nonmembership degree of the element belonging to the set. For example, in the national entrance examination for postgraduate, a panel of ten professors evaluated the admission of a student; five professors considered the student can be accepted, three professors disapproved of his or her admission, and two professors remained neutral. In this case, the FS and IVFS cannot represent such information. In order to solve this problem, Atanassov et al. [6] proposed the intuitionistic fuzzy set (IFS) \(E = \{\langle x_i, u_E(x_i), v_E(x_i)\rangle | x_i \in X\}\), where \(u_E(x_i) (0 \leq u_E(x_i) \leq 1)\) and \(v_E(x_i) (0 \leq v_E(x_i) \leq 1)\) represent the membership degree and nonmembership degree, respectively, and the indeterminacy-membership degree \(\pi_E(x_i) = 1 - u_E(x_i) - v_E(x_i)\). The IFS is more effective to deal with the vague information than the FS and IVFS. Then, the information about the admission of the student can be represented as an IFS \(E = (0.5, 0.3, 0.2)\) where 0.5, 0.3, and 0.2 stand for the membership degree, nonmembership degree, and indeterminacy-membership degree, respectively. However, the IFS also have limitation in expressing the decision information. For example, three groups of experts evaluate the benefits of the stock, a group of experts thinks the possibility of loss is 0.3, the third group of experts is not sure whether the stock that will be profitable is 0.4. In this case, the IFS cannot express such information because \(0.6 + 0.3 + 0.4 > 1\). Therefore, Wang et al. [7] proposed a single-valued neutrosophic set (SVNS) \(N = \{\langle x_i, T_N(x_i), I_N(x_i), F_N(x_i)\rangle | x_i \in X\}\), where \(T_N(x_i), I_N(x_i), F_N(x_i)\) represent the degree of the truth-membership, indeterminacy-membership, and falsity-membership, respectively, and they belong to \([0, 1]\). So, the information about the benefits of the stock can be represented as \(N = (0.6, 0.4, 0.3)\). However, due to the uncertainty of the decision-making environment in multiple criteria decision-making problems, the single numerical value...
cannot meet the needs of evaluating information. Then, Wang [8] defined the interval-valued neutrosophic set (IVNS) based on the SVNS, which used the interval to describe truth membership degree, indeterminacy membership degree, and falsity membership degree, respectively. Since the neutrosophic set was proposed, there have been some researchers focusing on this subject [9–12].

On the other hand, similarity measure is an important tool in multiple criteria decision-making problems, which can be used to measure the difference between the alternatives. Many studies about the similarity measure are obtained. For example, Beg et al. [13] proposed a similarity measure of FSS based on the concept of epsilon-fuzzy transitivity and discussed the degree of transitivity of different similarity measures. Song et al. [14] considered the similarity measure of IFSs and proposed corresponding distance measure between intuitionistic fuzzy belief functions. Majumdar and Samanta [15] proposed a similarity measure between SVNSSs based on the membership degree.

In addition, cosine similarity measure is also an important similarity measure, and it can be defined as the inner product of two vectors divided by the product of their lengths. There are some scholars who study the cosine similarity measures [16–21]. For example, Ye [16] proposed the cosine similarity measure and weighted cosine similarity measure of IVNSs with risk preference, and they were applied to the supplier selection problem. Then, Ye [17] proposed the cosine similarity measure of IFSs and applied it to medical diagnosis and pattern recognition. Furthermore, Ye [18] defined the cosine similarity measure of SVNSSs and IVNSs, but when the SVNSSs are not triangular, the cosine similarity measure of SVNSSs and IVNSs cannot be applied. Furthermore, Ye [19] proposed the improved cosine similarity measures of SVNSSs and IVNSs based on cosine function.

In this paper, we propose a new method to construct the similarity measures of SVNSSs, which is based on the existing similarity measure proposed by Majumdar and Samanta [15] and Ye [18], respectively. They play an important role in practical application, especially in pattern recognition, medical diagnosis, and so on. Furthermore, we will propose the corresponding similarity measures of IVNSs.

The rest of the paper is organized as follows. In Section 2, the basic definition and some properties about SVNSSs and IVNSs are given. In Section 3, we proposed a method to construct the new similarity measures of SVNSSs and IVNSs, respectively. In Section 4, we apply the proposed new similarity measures to medical diagnosis problems, the numerical examples are used to illustrate the feasibility and effectiveness of the proposed similarity measures, which are then compared to other existing similarity measures. Finally, the conclusions and future studies are discussed in Section 5.

2. Preliminaries

In this section, we give some basic knowledge about the SVNSSs and the IVNSs. Some existing distance measures are also introduced, which will be used in the next section.

2.1. SVNSSs

**Definition 1.** Given a fixed set \(X = \{x_1, x_2, \ldots, x_n\}\) [7], the SVNSS \(N\) in \(X\) is defined as follows:

\[
N = \left\{ (x_i, T_N(x_i), I_N(x_i), F_N(x_i)) \right\} | x_i \in X \right\},
\]

where the function \(T_N(x_i) : X \rightarrow [0, 1]\) defines the truth-membership degree, the function \(I_N(x_i) : X \rightarrow [0, 1]\) defines indeterminacy-membership degree, and the function \(F_N(x_i) : X \rightarrow [0, 1]\) defines the falsity-membership degree, respectively. For any SVNSS \(N\), it holds that \(0 \leq T_N(x_i) + I_N(x_i) + F_N(x_i) \leq 3\) (\(\forall x_i \in X\)).

For any two SVNSSs \(N_1 = \{x_i, T_{N_1}(x_i), I_{N_1}(x_i), F_{N_1}(x_i)\} | x_i \in X\) and \(N_2 = \{x_i, T_{N_2}(x_i), I_{N_2}(x_i), F_{N_2}(x_i)\} | x_i \in X\) [\(\forall x_i \in X\)], the following properties are satisfied:

(1) \(N_1 \subseteq N_2\) if and only if \(T_{N_1}(x_i) \leq T_{N_2}(x_i)\), \(I_{N_1}(x_i) \geq I_{N_2}(x_i)\), and \(F_{N_1}(x_i) \geq F_{N_2}(x_i)\)

(2) \(N_1 = N_2\) if and only if \(N_1 \subseteq N_2\) and \(N_2 \subseteq N_1\)

2.2. IVNSs

**Definition 2.** Given a fixed set \(X = \{x_1, x_2, \ldots, x_n\}\) [8], the IVNSS \(N'\) on \(X\) is defined as follows:

\[
N' = \left\{ (x_i, [T^L(x_i), T^U(x_i)], [I^L(x_i), I^U(x_i)], [F^L(x_i), F^U(x_i)]) \right\} | x_i \in X \right\},
\]

where \(T^L(x_i) = [T^L_{N_1}(x_i), T^L_{N_2}(x_i)], I^L(x_i) = [I^L_{N_1}(x_i), I^L_{N_2}(x_i)], F^L(x_i) = [F^L_{N_1}(x_i), F^L_{N_2}(x_i)]\) represent the truth-membership function, the indeterminacy-membership function, and the falsity-membership function, respectively. For any \(x_i \in X\), it holds that \(T^U_N(x_i), I^U_N(x_i), F^U_N(x_i) \in [0, 1]\) and \(0 \leq T^U_N(x_i) + I^U_N(x_i) + F^U_N(x_i) \leq 3\).

For any two IVNSSs \(N'_1 = \{x_i, [T^L_{N'_1}(x_i), T^U_{N'_1}(x_i)], [I^L_{N'_1}(x_i), I^U_{N'_1}(x_i)], [F^L_{N'_1}(x_i), F^U_{N'_1}(x_i)]\} | x_i \in X\) and \(N'_2 = \{x_i, [T^L_{N'_2}(x_i), T^U_{N'_2}(x_i)], [I^L_{N'_2}(x_i), I^U_{N'_2}(x_i)], [F^L_{N'_2}(x_i), F^U_{N'_2}(x_i)]\} | x_i \in X\) [\(\forall x_i \in X\)], the following properties are satisfied:

(1) \(N'_1 \subseteq N'_2\) if and only if \(T^L_{N'_1}(x_i) \leq T^L_{N'_2}(x_i), T^U_{N'_1}(x_i) \leq T^U_{N'_2}(x_i), I^L_{N'_1}(x_i) \geq I^L_{N'_2}(x_i), I^U_{N'_1}(x_i) \geq I^U_{N'_2}(x_i), F^L_{N'_1}(x_i) \geq F^L_{N'_2}(x_i), F^U_{N'_1}(x_i) \geq F^U_{N'_2}(x_i)\)

(2) \(N'_1 = N'_2\) if and only if \(N'_1 \subseteq N'_2\) and \(N'_2 \subseteq N'_1\)

**Remark 1.** When \(T^L_{N'_1}(x_i) = T^U_{N'_1}(x_i), I^L_{N'_1}(x_i) = I^U_{N'_1}(x_i), F^L_{N'_1}(x_i) = F^U_{N'_1}(x_i)\), the IVNSS \(N'_1\) is reduced to the SVNSS \(N_1\).

2.3. Existing Distance Measures between SVNSSs and IVNSSs

**Definition 3.** Let \(N_1 = \{x_i, T_{N_1}(x_i), I_{N_1}(x_i), F_{N_1}(x_i)\} | x_i \in X\) and \(N_2 = \{x_i, T_{N_2}(x_i), I_{N_2}(x_i), F_{N_2}(x_i)\} | x_i \in X\) be any two SVNSSs in \(X = \{x_1, x_2, \ldots, x_n\}\) [15]; then, the Euclidean distance between SVNSSs \(N_1\) and \(N_2\) is defined as follows:

\[
D(N_1, N_2) = \sqrt{\sum_{i=1}^{n} (T_{N_1}(x_i) - T_{N_2}(x_i))^2 + (I_{N_1}(x_i) - I_{N_2}(x_i))^2 + (F_{N_1}(x_i) - F_{N_2}(x_i))^2}.
\]
Definition 4. Let $N'_1 = \{\langle x_i, [T^L_{N'_1}(x_i), T^U_{N'_1}(x_i)], [I^L_{N'_1}(x_i), I^U_{N'_1}(x_i)], [F^L_{N'_1}(x_i), F^U_{N'_1}(x_i)]\rangle | x_i \in X \}$ and $N'_2 = \{\langle x_i, [T^L_{N'_2}(x_i), T^U_{N'_2}(x_i)], [I^L_{N'_2}(x_i), I^U_{N'_2}(x_i)], [F^L_{N'_2}(x_i), F^U_{N'_2}(x_i)]\rangle | x_i \in X \}$ be any two IVNSs in $X = \{x_1, x_2, \ldots, x_n\}$ [22]; the Euclidean distance between IVNSs $N'_1$ and $N'_2$ is defined as follows:

$$D_{\text{IVNS}}(N'_1, N'_2) = \sqrt{\sum_{i=1}^{n} \left( (T^L_{N'_1}(x_i) - T^L_{N'_2}(x_i))^2 + (I^L_{N'_1}(x_i) - I^L_{N'_2}(x_i))^2 + (F^L_{N'_1}(x_i) - F^L_{N'_2}(x_i))^2 \right)}$$

(4)

Next, we propose a new method to construct the similarity measures of SVNSs and IVNSs based on the Euclidean distance measure.

3. Several New Similarity Measures

The similarity measure is a widely used tool to evaluate the relationship between two sets. The following axiom about the similarity measure of SVNSs (or IVNSs) should be satisfied:

**Lemma 1.** Let $X = \{x_1, x_2, \ldots, x_n\}$ be the universal set [18] if the similarity measure $S(N_1, N_2)$ between SVNSs (or IVNSs) $N_1$ and $N_2$ satisfies the following properties:

1. $0 \leq S(N_1, N_2) \leq 1$
2. $S(N_1, N_2) = 1$ if and only if $N_1 = N_2$

$$S_{\text{SVNS}}(N_1, N_2) = \frac{\sum_{i=1}^{n} \left( \min\left( T_{N_1}(x_i), T_{N_2}(x_i) \right) + \min\left( I_{N_1}(x_i), I_{N_2}(x_i) \right) + \min\left( F_{N_1}(x_i), F_{N_2}(x_i) \right) \right)}{\sum_{i=1}^{n} \left( \max\left( T_{N_1}(x_i), T_{N_2}(x_i) \right) + \max\left( I_{N_1}(x_i), I_{N_2}(x_i) \right) + \max\left( F_{N_1}(x_i), F_{N_2}(x_i) \right) \right)}.$$  

(5)

It is already known that the similarity measure $S_{\text{SVNS}}$ defined by Majumdar et al. [15] satisfies the properties in Lemma 1. It is proposed based on the membership degree; in this section, we adopt the various methods for calculating the similarity measure between neutrosophic sets.

Firstly, we propose a new method to construct a new similarity measure of SVNSs, which is based on the similarity measure proposed by Majumdar et al. [15] and the Euclidean distance; it can be defined as follows:

**Definition 6.** Let $X = \{x_1, x_2, \ldots, x_n\}$ be a universal set, for any two SVNSs $N_1 = \{x_i, T_{N_1}(x_i), I_{N_1}(x_i), F_{N_1}(x_i) \} | x_i \in X \}$ and $N_2 = \{x_i, T_{N_2}(x_i), I_{N_2}(x_i), F_{N_2}(x_i) \} | x_i \in X \}$; a new similarity measure $S_{\text{SVNS}}^*(N_1, N_2)$ is defined as follows:

$$S_{\text{SVNS}}^*(N_1, N_2) = \frac{1}{2} \left( S_{\text{SVNS}}(N_1, N_2) + 1 - D_{\text{SVNS}}(N_1, N_2) \right).$$

(6)

The proposed similarity measure of SVNSs satisfies the following Theorem 1.

**Theorem 1.** The similarity measure $S_{\text{SVNS}}^*(N_1, N_2)$ between $N_1 = \{x_i, T_{N_1}(x_i), I_{N_1}(x_i), F_{N_1}(x_i) \} | x_i \in X \}$ and $N_2 = \{x_i, T_{N_2}(x_i), I_{N_2}(x_i), F_{N_2}(x_i) \} | x_i \in X \}$ satisfies the following properties:

1. $0 \leq S_{\text{SVNS}}^*(N_1, N_2) \leq 1$
2. $S_{\text{SVNS}}^*(N_1, N_2) = 1$ if and only if $N_1 = N_2$
3. $S_{\text{SVNS}}^*(N_1, N_2) = S_{\text{SVNS}}^*(N_2, N_1)$
For two SVNSs any two SVNSs a new similarity measure proposed by Ye [18] and the Euclidean distance measure of SVNS based on the cosine similarity measure Ye [18], which overcomes its shortcoming. SVNS based on the cosine similarity measure proposed by Majumdar et al. [15], we know 0 ≤ S_{1 SVNS}^*(N_1, N_2) ≤ 1, i.e., 0 ≤ S_{1 SVNS}^*(N_1, N_2) ≤ 1.

(2) If $S_{1 SVNS}^*(N_1, N_2) = 1$, we have $S_{1 SVNS}^*(N_1, N_2) + 1 - D_{SVNS}(N_1, N_2) = 2$, that is, $S_{1 SVNS}^*(N_1, N_2) = 1 + D_{SVNS}(N_1, N_2)$. Because $D_{SVNS}(N_1, N_2)$ is the Euclidean distance measure, $0 ≤ D_{SVNS}(N_1, N_2) ≤ 1$. Furthermore, $0 ≤ S_{1 SVNS}^*(N_1, N_2) ≤ 1$ is obtained in Proposition 4.2.2 [15], then $S_{1 SVNS}^*(N_1, N_2) = 1$ and $D_{SVNS}(N_1, N_2) = 0$ should be established at the same time. If the Euclidean distance measure $D_{SVNS}(N_1, N_2) = 0$, $N_1 = N_2$ is obvious. According to Proposition 4.2.2 by Majumdar et al. [15], when $S_{1 SVNS}^*(N_1, N_2) = 1$, $N_1 = N_2$; so, if $S_{1 SVNS}^*(N_1, N_2) = 1$, $N_1 = N_2$ is obtained.

From Example 1, we know the cosine similarity measure defined by Ye [18] does not satisfy Lemma 1.

**Example 1.** For two SVNSs $N_1 = x$, 0.4, 0.2, 0.6 and $N_2 = x$, 0.2, 0.1, 0.3, we can easily know $N_1 ≠ N_2$. But using formula (7) to calculate the cosine similarity measure $S_{1 SVNS}^*(N_1, N_2)$, we have $S_{1 SVNS}^*(N_1, N_2) = 1$. That is to say, when $N_1 ≠ N_2, S_{1 SVNS}^*(N_1, N_2) = 1$, which means the cosine similarity measure $S_{1 SVNS}^*(N_1, N_2)$ defined by Ye [18] does not satisfy the necessary condition of property 2 in Lemma 1; thus, it is not a genuine similarity measure. Furthermore, Ye [19] proposed the improved cosine similarity measures of SVNS based on the cosine similarity measure proposed by Ye [18], which overcomes its shortcoming.

In this paper, we go on proposing another new similarity measure of SVNSs based on the cosine similarity measure proposed by Ye [18] and the Euclidean distance $D_{SVNS}$. It considers the similarity measure not only from the point of view of algebra but also from the point of view of geometry, which can be defined as:

$$S_{2 SVNS}^*(N_1, N_2) = \frac{1}{n} \sum_{i=1}^{n} \frac{T_{N_1}(x_i) T_{N_2}(x_i) + I_{N_1}(x_i) I_{N_2}(x_i) + F_{N_1}(x_i) F_{N_2}(x_i)}{\sqrt{T_{N_1}(x_i)^2 + I_{N_1}(x_i)^2 + F_{N_1}(x_i)^2} \sqrt{T_{N_2}(x_i)^2 + I_{N_2}(x_i)^2 + F_{N_2}(x_i)^2}}. \tag{7}$$

**Theorem 2.** The similarity measure $S_{2 SVNS}^*(N_1, N_2)$ between $N_1 = \{x_1, T_{N_1}(x_1), I_{N_1}(x_1), F_{N_1}(x_1)\} \{x_i \in X\}$ and $N_2 = \{x_2, T_{N_2}(x_2), I_{N_2}(x_2), F_{N_2}(x_2)\} \{x_i \in X\}$ satisfies the following properties: (1) $0 ≤ S_{2 SVNS}^*(N_1, N_2) ≤ 1$ (2) $S_{2 SVNS}^*(N_1, N_2) = 1$ if and only if $N_1 = N_2$ (3) $S_{2 SVNS}^*(N_1, N_2) = S_{2 SVNS}^*(N_2, N_1)$

**Proof.** The proof of the properties (1) and (3) are similar to Theorem 1; here, we only give the proof of property (2). If $S_{2 SVNS}^*(N_1, N_2) = 1$, we have $S_{2 SVNS}^*(N_1, N_2) + 1 - D_{SVNS}(N_1, N_2) = 2$, i.e., $S_{2 SVNS}^*(N_1, N_2) = 1 + D_{SVNS}(N_1, N_2)$, because $D_{SVNS}(N_1, N_2)$ is the Euclidean distance measure, $0 ≤ D_{SVNS}(N_1, N_2) ≤ 1$. According to the property of $S_{2 SVNS}^*(N_1, N_2)$ in Ye [18], $0 ≤ S_{2 SVNS}^*(N_1, N_2) ≤ 1$; then, $S_{2 SVNS}^*(N_1, N_2) = 1$ and $D_{SVNS}(N_1, N_2) = 0$ should be held at the same time. When $S_{2 SVNS}^*(N_1, N_2) = 1$, we have $T_{N_1}(x_i) = k \cdot T_{N_2}(x_i), I_{N_1}(x_i) = k \cdot I_{N_2}(x_i), F_{N_1}(x_i) = k \cdot F_{N_2}(x_i)$ (k is a constant). When $D_{SVNS}(N_1, N_2) = 0$, we have $N_1 = N_2$. Then $N_1 = N_2$ is obtained.

On the other hand, according to formulae (3) and (7), if $N_1 = N_2, D_{SVNS}(N_1, N_2) = 0$ and $S_{2 SVNS}^*(N_1, N_2) = 1$ are obtained, respectively; then we can get $S_{2 SVNS}^*(N_1, N_2) = 1$.

Thus, $S_{2 SVNS}^*(N_1, N_2)$ satisfies all the properties in Theorem 2.
3.2. Some New Similarity Measures between IVNSs. In some situations, it is difficult to provide the truth-membership degree, false-membership degree, and indeterminate-membership degree with a precise numerical value; Wang [8] used the interval numbers to express the related membership degrees. Furthermore, Broumi et al. [22] proposed the corresponding similarity measure of IVNSs based on the similarity measure $S_{IVNS}$ proposed by Majumdar et al. [15].

$$S_{IVNS}(N'_1, N'_2) = \frac{1}{2} \left( S_{IVNS}(N'_1, N'_2) + 1 - D_{IVNS}(N'_1, N'_2) \right).$$

The proposed similarity measure also satisfies Theorem 3.

Definition 9. Let $X = \{x_1, x_2, \ldots, x_n\}$ be a universal set, for any two IVNSs $N'_1 = \{x_i, [T_{N'_1}(x_i), T_{N'_1}(x_i)]\}$, $N'_2 = \{x_i, [T_{N'_2}(x_i), T_{N'_2}(x_i)]\}$ and $N'_2 = \{x_i, [T_{N'_2}(x_i), T_{N'_2}(x_i)]\}$, if $N'_1 = \{x_i, [T_{N'_1}(x_i), T_{N'_1}(x_i)]\}$ and $N'_2 = \{x_i, [T_{N'_2}(x_i), T_{N'_2}(x_i)]\}$, the similarity measure between IVNSs $N'_1$ and $N'_2$ is defined as follows:

$$S_{IVNS}(N'_1, N'_2) = \frac{1}{2} \left( S_{IVNS}(N'_1, N'_2) + 1 - D_{IVNS}(N'_1, N'_2) \right).$$

Theorem 3. The similarity measure $S_{IVNS}(N'_1, N'_2)$ satisfies the following properties:

1. $0 \leq S_{IVNS}(N'_1, N'_2) \leq 1$
2. $S_{IVNS}(N'_1, N'_2) = 1$ if and only if $N'_1 = N'_2$
3. $S_{IVNS}(N'_1, N'_2) = S_{IVNS}(N'_2, N'_1)$

Proof. The proof is similar to Theorem 1; hence, we omit it here.

Next, we will use the same method to define the similarity measure $S_{2IVNS}(N'_1, N'_2)$ between IVNS, which is based on the cosine similarity measure $S_{IVNS}(N'_1, N'_2)$ proposed by Ye [21] (Definition 11) and the Euclidean distance $D_{IVNS}(N'_1, N'_2)$ defined in formula (4).

Definition 11. Let $X = \{x_1, x_2, \ldots, x_n\}$ be a universal set, for any two IVNSs $N'_1 = \{x_i, [T_{N'_1}(x_i), T_{N'_1}(x_i)]\}$, $N'_2 = \{x_i, [T_{N'_2}(x_i), T_{N'_2}(x_i)]\}$ and $N'_2 = \{x_i, [T_{N'_2}(x_i), T_{N'_2}(x_i)]\}$, the cosine similarity measure $S_{2IVNS}(N'_1, N'_2)$ is defined as follows:

$$S_{2IVNS}(N'_1, N'_2) = \frac{1}{n} \sum_{i=1}^{n} \left( T_{N'_1}(x_i)T_{N'_2}(x_i) + U_{N'_1}(x_i)U_{N'_2}(x_i) + I_{N'_1}(x_i)I_{N'_2}(x_i) + F_{N'_1}(x_i)F_{N'_2}(x_i) \right).$$

$$S_{2IVNS}(N'_1, N'_2) = \frac{1}{n} \sum_{i=1}^{n} \left( T_{N'_1}(x_i)T_{N'_2}(x_i) + U_{N'_1}(x_i)U_{N'_2}(x_i) + I_{N'_1}(x_i)I_{N'_2}(x_i) + F_{N'_1}(x_i)F_{N'_2}(x_i) \right).$$

and the Euclidean distance measure $D_{IVNS}(N'_1, N'_2)$ as follows:

Definition 12. Let $X = \{x_1, x_2, \ldots, x_n\}$ be a universal set, for any two IVNSs $N'_1 = \{x_i, [T_{N'_1}(x_i), T_{N'_1}(x_i)]\}$, $N'_2 = \{x_i, [T_{N'_2}(x_i), T_{N'_2}(x_i)]\}$ and $N'_2 = \{x_i, [T_{N'_2}(x_i), T_{N'_2}(x_i)]\}$, the Euclidean distance measure $D_{IVNS}(N'_1, N'_2)$ is defined as follows:

$$D_{IVNS}(N'_1, N'_2) = \left( \sum_{i=1}^{n} \left( T_{N'_1}(x_i) - T_{N'_2}(x_i) \right)^2 + \left( U_{N'_1}(x_i) - U_{N'_2}(x_i) \right)^2 + \left( I_{N'_1}(x_i) - I_{N'_2}(x_i) \right)^2 + \left( F_{N'_1}(x_i) - F_{N'_2}(x_i) \right)^2 \right)^{1/2}.$$
a new similarity measure \( S^*_{2IVNS}(N'_1, N'_2) \) can be defined as follows:

\[
S^*_{2IVNS}(N'_1, N'_2) = \frac{1}{2} \left( S_{2IVNS}(N'_1, N'_2) + 1 - D_{IVNS}(N'_1, N'_2) \right).
\] (12)

**Remark 4.** In Example 2, when \( N'_1 \neq N'_2 \), the similarity measure \( S_{2IVNS}(N'_1, N'_2) = 1 \), this is inconsistent with the real decision problems. But, using formula (12) to calculate it again, we have \( S^*_{2IVNS}(N'_1, N'_2) = 0.8185 \). Obviously, the proposed similarity measure \( S^*_{2IVNS}(N'_1, N'_2) \) can rectify the existing cosine similarity measure \( S^*_{2IVNS}(N'_1, N'_2) \) defined by Ye [22].

**Theorem 4.** The similarity measure \( S^*_{2IVNS}(N'_1, N'_2) \) satisfies the following properties:

1. \( 0 \leq S^*_{2IVNS}(N'_1, N'_2) \leq 1 \)
2. \( S^*_{2IVNS}(N'_1, N'_2) = 1 \) if and only if \( N'_1 = N'_2 \)
3. \( S^*_{2IVNS}(N'_1, N'_2) = S^*_{2IVNS}(N'_2, N'_1) \)

**Proof.** The proof is similar to Theorem 2, we also omit it here.

In the next section, we will apply the proposed new similarity measures to medical diagnosis decision problem; numerical examples are also given to illustrate the application and effectiveness of the proposed new similarity measures.

### 4. Applications of the Proposed Similarity Measures

#### 4.1. The Proposed Similarity Measures between SVNSs for Medical Diagnosis

We first give a numerical example about a medical diagnosis (adapted from Ye [19]) to illustrate the feasibility of the proposed new similarity measures \( S^*_{1IVNS} \) and \( S^*_{2IVNS} \) between SVNSs.

**Example 3.** Consider a medical diagnosis decision problem; suppose a set of diagnoses \( Q = \{Q_1 \text{(viral fever)}, Q_2 \text{(malaria)}, Q_3 \text{(typhoid)}, Q_4 \text{(gastritis)}, Q_5 \text{(stenocardia)}\} \) and a set of symptoms \( S = \{S_1 \text{(fever)}, S_2 \text{(headache)}, S_3 \text{(stomach pain)}, S_4 \text{(cough)}, S_5 \text{(chestpain)}\} \) and a set of patients \( P_1 \) has all the symptoms in the process of diagnosis, the SVNS evaluate information about \( P_1 \) is

\[
P_1 \text{ (Patient) } = \{S_1, 0.8, 0.2, 0.1\}, \{S_2, 0.6, 0.3, 0.1\}, \{S_3, 0.2, 0.1, 0.8\}, \{S_4, 0.6, 0.5, 0.1\}, \{S_5, 0.1, 0.4, 0.6\}.
\] (13)

The diagnosis information \( Q_i \) (\( i = 1, 2, \ldots, 5 \)) with respect to symptoms \( S_i \) (\( i = 1, 2, \ldots, 5 \)) also can be represented by the SVNSs, which is shown in Table 1.

<table>
<thead>
<tr>
<th>( Q_1 )</th>
<th>( Q_2 )</th>
<th>( Q_3 )</th>
<th>( Q_4 )</th>
<th>( Q_5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>{0.4, 0.2, 0.5}</td>
<td>{0.3, 0.1, 0.6}</td>
<td>{0.1, 0.5, 0.4}</td>
<td>{0.2, 0.3, 0.4}</td>
<td>{0.1, 0.3, 0.5}</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( S_1 )</th>
<th>( S_2 )</th>
<th>( S_3 )</th>
<th>( S_4 )</th>
<th>( S_5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>0.2</td>
<td>0.3</td>
<td>0.1</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: The relation between the diagnosis and the symptom for SVNS decision information.

By applying formulae (6) and (8), we can obtain the similarity measure values \( S^*_{1IVNS}(P_1, Q_1) \) and \( S^*_{2IVNS}(P_1, Q_1) \); the results are shown in Table 2.

<table>
<thead>
<tr>
<th>( P_1 )</th>
<th>( Q_1 )</th>
<th>( Q_2 )</th>
<th>( Q_3 )</th>
<th>( Q_4 )</th>
<th>( Q_5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5526</td>
<td>0.5526</td>
<td>0.5526</td>
<td>0.5526</td>
<td>0.5526</td>
<td></td>
</tr>
<tr>
<td>0.5526</td>
<td>0.5526</td>
<td>0.5526</td>
<td>0.5526</td>
<td>0.5526</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: The similarity measures between \( P_1 \) and \( Q_i \).

We can calculate the similarity measures \( S^*_{1IVNS}(P_1, Q_i) \) and \( S^*_{2IVNS}(P_1, Q_i) \) (\( i = 1, 2, \ldots, 5 \)), then the diagnoses of the patient \( P_1 \) can be classified by \( R_1 = \arg \max_{i \leq 5} |S^*_{1IVNS}(P_1, Q_i)| \) (\( j = 1, 2 \)).

4.2. The Proposed Similarity Measures between IVNSs for Medical Diagnosis

We know if the doctor examines the patient two or three times a day, then the interval values of multiple inspections for the patient are obtained. In this section, we will apply the proposed similarity measures \( S^*_{1IVNS} \) and \( S^*_{2IVNS} \) to medical diagnosis, the example is also adapted from Ye [19].

**Example 4.** Let us reconsider Example 3, assume a patient \( P_2 \) has all the symptoms, which can be expressed by the following IVNS information.

\[
P_2 \text{ (Patient) } = \{S_1, [0.3, 0.5], [0.2, 0.3], [0.4, 0.5]\}, \{S_2, [0.7, 0.9], [0.1, 0.2], [0.1, 0.2]\}, \{S_3, [0.4, 0.6], [0.2, 0.3], [0.3, 0.4]\}, \{S_4, [0.3, 0.6], [0.1, 0.3], [0.4, 0.7]\}, \{S_5, [0.5, 0.8], [0.1, 0.4], [0.1, 0.3]\}.
\] (14)

The same way as Example 3 in Ye [19], the diagnosis information of SVNSs \( Q_i \) with respect to symptoms \( S_i \) (\( i = 1, 2, \ldots, 5 \)) are transformed into IVNSs, which are shown in Table 3.

<table>
<thead>
<tr>
<th>( Q_1 )</th>
<th>( Q_2 )</th>
<th>( Q_3 )</th>
<th>( Q_4 )</th>
<th>( Q_5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>{0.4, 0.2, 0.5}</td>
<td>{0.3, 0.1, 0.6}</td>
<td>{0.1, 0.5, 0.4}</td>
<td>{0.2, 0.3, 0.4}</td>
<td>{0.1, 0.3, 0.5}</td>
</tr>
</tbody>
</table>

By applying formulae (10) and (12), we obtain the similarity measure values \( S^*_{1IVNS}(P_2, Q_i) \) and \( S^*_{2IVNS}(P_2, Q_i) \), the results are shown in Table 4.

From the two similarity measure values in Table 4, we can see that the patient \( P_2 \) suffers from typhoid (\( Q_2 \)); the diagnosis results are the same as shown by Ye [19].
4.3. Comparative Analyses of Existing Similarity Measures.

To illustrate the effectiveness of the proposed similarity measures for medical diagnosis, we will apply the existing similarity measures of SVNSs and IVNSs for comparative analyses.

At first, we introduce the existing similarity measures between SVNSs as follows:

Let \( N_1 = \{ (x_1^i, T_{N_1}^i(x_1), L_{N_1}^i(x_1), I_{N_1}^i(x_1), F_{N_1}^i(x_1)) \mid x_1 \in X \} \) and \( N_2 = \{ x_2^i, T_{N_2}^i(x_2), L_{N_2}^i(x_2), I_{N_2}^i(x_2), F_{N_2}^i(x_2) \mid x_2 \in X \} \) be two SVNSs.

\[
SC_{SVNS}(N_1, N_2) = \frac{1}{n} \sum_{i=1}^{n} \cos \left[ \pi \cdot \max \left\{ \left| T_{N_1}(x_1) - T_{N_2}(x_2) \right|, \left| L_{N_1}(x_1) - L_{N_2}(x_2) \right|, \left| I_{N_1}(x_1) - I_{N_2}(x_2) \right|, \left| F_{N_1}(x_1) - F_{N_2}(x_2) \right| \right\} \right],
\]

\[
SC_{SVNS}(N_1, N_2) = \frac{1}{n} \sum_{i=1}^{n} \cos \left[ \pi \left( \left| T_{N_1}(x_1) - T_{N_2}(x_2) \right| + \left| L_{N_1}(x_1) - L_{N_2}(x_2) \right| + \left| I_{N_1}(x_1) - I_{N_2}(x_2) \right| + \left| F_{N_1}(x_1) - F_{N_2}(x_2) \right| \right) \right].
\]

(4) Yang et al. [25] proposed the similarity measure \( SY_{SVNS}(N_1, N_2) \):

\[
SY_{SVNS}(N_1, N_2) = \frac{SC_{SVNS}(N_1, N_2)}{SC_{SVNS}(N_1, N_2) + D_{SVNS}(N_1, N_2)}.
\]  

Example 3'. We apply formulae (5), (7), and (15)–(19) to calculate Example 3 again; the similarity measure values between \( P_1 \) and \( Q_i \) \((i = 1, 2, \ldots, 5)\) are shown in Table 5.

As we can see from Table 5, the patient \( P_1 \) is still assigned to malaria (\( Q_2 \)), and the results are same as the proposed similarity measures in this paper, which means the proposed similarity measures are feasible and effective.

Next, we introduce the existing similarity measures between IVNSs as follows:

\[
S_{IVNS}(P_1, Q) = \arg \max_{Q \in S} \left( S_{IVNS}(P_1, Q) \right),
\]

\[
S_{IVNS}(P_1, Q) = \frac{1}{n} \sum_{i=1}^{n} \cos \left[ \pi \cdot \max \left\{ \left| T_{N_1}(x_1) - T_{N_2}(x_2) \right|, \left| L_{N_1}(x_1) - L_{N_2}(x_2) \right|, \left| I_{N_1}(x_1) - I_{N_2}(x_2) \right|, \left| F_{N_1}(x_1) - F_{N_2}(x_2) \right| \right\} \right],
\]

\[
SY_{IVNS}(N_1, N_2) = \frac{SC_{IVNS}(N_1, N_2)}{SC_{IVNS}(N_1, N_2) + D_{IVNS}(N_1, N_2)}.
\]

(1) Broumi et al. [23] proposed the similarity measure \( SM_{IVNS} \):

\[
SM_{IVNS}(N_1, N_2) = 1 - D_{IVNS}(N_1, N_2).
\]

(2) Sahin and Ahmet [24] proposed the similarity measure \( SD_{IVNS} \):

\[
SD_{IVNS}(N_1, N_2) = \frac{1}{1 + D_{IVNS}(N_1, N_2)}.
\]

(3) Ye [19] proposed the improved cosine similarity measures \( SC_{IVSN} \) and \( SC_{2IVSN} \):

\[
SC_{IVSN}(N_1, N_2) = \frac{1}{n} \sum_{i=1}^{n} \cos \left[ \pi \left( \left| T_{N_1}(x_1) - T_{N_2}(x_2) \right| + \left| L_{N_1}(x_1) - L_{N_2}(x_2) \right| + \left| I_{N_1}(x_1) - I_{N_2}(x_2) \right| + \left| F_{N_1}(x_1) - F_{N_2}(x_2) \right| \right) \right].
\]

Let \( N_1^i = \{ (x_i, T_{N_1}^i(x_1), T_{N_1}^i(x_2), I_{N_1}^i(x_1), L_{N_1}^i(x_1)) \mid x_i \in X \} \) and \( N_2^i = \{ x_i, T_{N_2}^i(x_1), T_{N_2}^i(x_2), I_{N_2}^i(x_1), L_{N_2}^i(x_1)) \mid x_i \in X \} \) be two IVNSs in \( X = \{ x_1, x_2, \ldots, x_n \} \); the existing similarity measures between \( N_1^i \) and \( N_2^i \) are defined as follows:

\[
SY_{IVNS}(N_1^i, N_2^i) = \frac{SC_{IVNS}(N_1^i, N_2^i)}{SC_{IVNS}(N_1^i, N_2^i) + D_{IVNS}(N_1^i, N_2^i)}.
\]
(3) Broumi and Smarandache [22] proposed the improved cosine similarity measures \( SC_{ISVNS} \) and \( SC_{2SVNS} \):

\[
SC_{ISVNS}(N'_1, N'_2) = \frac{1}{n} \sum_{i=1}^{n} \cos \frac{\pi}{4} \left[ \max \left( |T^L_{N'_1}(x_i) - T^L_{N'_2}(x_i)|, |I^L_{N'_1}(x_i) - I^L_{N'_2}(x_i)|, |F^L_{N'_1}(x_i) - F^L_{N'_2}(x_i)| \right) \right]
\]

\[
+ \max \left( |T^U_{N'_1}(x_i) - T^U_{N'_2}(x_i)|, |I^U_{N'_1}(x_i) - I^U_{N'_2}(x_i)|, |F^U_{N'_1}(x_i) - F^U_{N'_2}(x_i)| \right),
\]

\[ (22) \]

\[
SC_{2SVNS}(N'_1, N'_2) = \frac{1}{n} \sum_{i=1}^{n} \cos \frac{\pi}{12} \left( |T^L_{N'_1}(x_i) - T^L_{N'_2}(x_i)| + |I^L_{N'_1}(x_i) - I^L_{N'_2}(x_i)| + |F^L_{N'_1}(x_i) - F^L_{N'_2}(x_i)| \right)
\]

\[
+ |T^U_{N'_1}(x_i) - T^U_{N'_2}(x_i)| + |I^U_{N'_1}(x_i) - I^U_{N'_2}(x_i)| + |F^U_{N'_1}(x_i) - F^U_{N'_2}(x_i)|
\]

\[ (23) \]

(4) Yang et al. [25] proposed the similarity measure \( SY_{SVNS}(N'_1, N'_2) \):

\[
SY_{SVNS}(N'_1, N'_2) = \frac{SC_{IVNS}(N'_1, N'_2)}{SC_{IVNS}(N'_1, N'_2) + D_{IVNS}(N'_1, N'_2)}
\]

\[ (24) \]

**Example 4'.** Applying formulae (9), (11), and (20)–(24) to calculate Example 6 again, the similarity measure values between \( P_2 \) and \( Q_i (i = 1, 2, \ldots , 5) \) are shown in Table 6.

The results of Table 6 show that the patient \( P_2 \) should be assigned to typhoid \( (Q_3) \), they are same as the proposed similarity measures \( S_{ISVNS} \) and \( S_{2IVNS} \) in the paper, which means the proposed methods are feasible and effective.

The proposed similarity measures in the paper have some advantages in solving multiple criteria decision-making problems. They are constructed based on the existing similarity measures and Euclidean distance, which not only satisfy the axiom of the similarity measure but also consider the similarity measure from the points of view of algebra and geometry. Furthermore, they can be applied more widely in the field of decision-making problems.

### 5. Conclusions

The similarity measure is widely used in multiple criteria decision-making problems. This paper proposed a new method to construct the similarity measures combining the existing cosine similarity measure and the Euclidean distance measure of SVNSs and IVNSs, respectively, which are based on the above existing similarity measures and the Euclidean distance measure. And, the similarity measures are proposed not only from the points of view of algebra and geometry but also satisfy the axiom of the similarity measure. Furthermore, we apply the proposed similarity measures to medical diagnosis decision problems, and the numerical example is used to illustrate the feasibility and effectiveness of the proposed similarity measure, which are then compared to other existing similarity measures. In future research, we will focus on studying the similarity measure between linguistic neutrosophic set and the application of the proposed similarity measures of neutrosophic sets, such as pattern recognition, supplier selection, and so on.

### Data Availability

The data used to support the findings of this study are included within the article.

### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication for the paper.

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References


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