



Integrating Neutrosophic Theory for Improved Decision-Making in Wireless Body Area Networks: Enhancing Accuracy and Efficiency in Health Monitoring

Intisar A.M. Al Sayed¹, Bourair Al-Attar², Lateef Abd Zaid Qudr³, Azmi Shawkat Abdulbaqi⁴, Jamal Fadhil Tawfeq⁵, Ravi Sekhar^{6,*}, Pritesh Shah⁶, Marshiana Devaerakkam⁶

¹College of Engineering -Uruk University, Baghdad , Iraq

²College of Medicin University of Al-Ameed Karbala PO Box 198, Iraq

³Department of Computer, Techniques Engineering, AlSafwa University College, Almamalje str, Karbala, 56001, Iraq

⁴University of Anbar, Renewable Energy Research Center, Ramadi, Iraq

⁵Department of Medical Instrumentation Technical Engineering, Medical Technical College, Al-Farahidi University, Baghdad 00965, Iraq

⁶Symbiosis Institute of Technology, Pune Campus, Symbiosis International (Deemed University) (SIU), Pune 412115, Maharashtra, India

Emails: intisaralsaid@gmail.com; bourair.alattar@alameed.edu.iq;

latifkhder@alsafwa.edu.iq; azmi_msc@uoanbar.edu.iq; jamaltawfeq55@gmail.com; ravi.sekhar@sitpune.edu.in; pritesh.shah@sitpune.edu.in; marshiana.d@sitpune.edu.in

Abstract

Wireless Body Area Networks (WBANs) play a pivotal role in modern healthcare by enabling continuous monitoring of physiological data through sensors placed on or around the human body. Despite their significant benefits, WBANs face challenges such as data uncertainty, complex decision-making processes, and dynamic network conditions. These challenges can lead to inaccuracies and inefficiencies in health monitoring and diagnostics. The paper's main aim is to incorporate neutrosophic theory into Wireless Body Area Networks to provide enhancements in decision-making. In modern healthcare, the use of WBANs for monitoring physiological data by sensors, which are attached to or around the human body, can be continuous. Despite huge advantages, the main challenges that WBANs face are the uncertainties in data, complex decision-making processes, and dynamic network conditions, making health monitoring and diagnostics inaccurate and inefficient. In this paper, authors propose a robust framework to map sensor data into the neutrosophic domain and apply neutrosophic logic for enhanced accuracy and reliability of decision-making. In this paper, a Neutrosophic Decision-Making Algorithm is proposed, and its performance is compared with other decision-making techniques in terms of accuracy, response time, energy efficiency, and reliability. Experimental results show major improvements of around 95.3% in accuracy and a reduction of up to 25% in response time and energy consumption. Results underline the potential of neutrosophic theory for revolutionizing decision-making processes within WBANs to ensure more reliable and efficient health monitoring. This approach enables not only operational life but also improves patient outcome, avoiding a wrong diagnosis, during long-term health monitoring applications using WBAN devices.

Keywords: Wireless Body Area Networks (WBANs); Neutrosophic Theory; Healthcare Monitoring; Decision-Making; Data Uncertainty; Sensor Networks; Real-Time Processing

1. Introduction

WBANs are a part of wireless sensor networks dedicated to observing the important physiological data from a human by means of sensors on or around the body. The measurements of such sensors may differ, but they usually

include, among others, heartbeat, blood pressure, body temperature, glucose level, and other metabolic vital signs. WBAN is part of healthcare for a number of reasons. They allow for the continuous monitoring of patients, a very important aspect of care in chronic diseases, post-operative care, and elderly care. Real-time data provided by WBANs to healthcare providers will enable them to take immediate action at the slightest sign of any abnormality. Besides, work on remote healthcare and telemedicine through WBANs reduces the number of visits to hospitals as patients can be properly cared for within their comfort zones, as studies published show. It supervises patient information in detail and its continuity; thus, WBANs always support individual treatment plans and under any conditions for each particular patient. Applications of WBAN in healthcare include the monitoring of chronic conditions such as diabetes and cardiovascular diseases, the physical activity that can be tracked for fitness or for rehabilitation, and the maintenance of the safety of patients who need constant supervision due to their condition. Decision making in WBANs becomes very critical due to the accurate health monitoring, efficient resource management, and robust security and privacy measures. The reliable decision making ensures that accurate health monitoring translates to correct diagnosis and timely interventions. Efficient decision making must ensure the management of scarce resources, such as battery life, sensor capacity, and network bandwidth. The major decisions that will avert unauthorized access to health information are associated with data security and ensuring patient privacy. Effective decision-making strategies also support high quality of service, the goals of which are the minimization of latency, guaranteeing data reliability, and ensuring optimum power consumption. Such effective decision-making processes in WBANs have to be supported by the different dimensions of uncertainty in data, dynamics of the surrounding environment, and the contradictory criteria of power consumption minimization with optimal accuracy in the data. Neutrosophic theory, developed by Florentin Smarandache, is an extension of fuzzy logic into the better handling of uncertainty, indeterminacy, and inconsistent information. While classical logic deals with binary TRUE versus FALSE values, neutrosophic theory has three: truth, falsehood, and indeterminacy. It is tripartite; hence, nuanced in representing and processing information, and therefore specifically appropriate in complex scenarios within decision making, incomplete, inconsistent, and uncertain data. In the WBAN scenario, neutrosophic theory can be very helpful by handling raised uncertainties and dynamism prevailing in the context. The aim of this paper is to explore the potentials for applying neutrosophic theory in leveraging improved decision making in WBANs. The specific objectives are: to investigate how the application of neutrosophic logic increases the accuracy and reliability of the fusion of sensor data; to develop adaptive and robust routing protocols that exploit neutrosophic theory in order to deal effectively with the dynamics of network conditions and uncertainty on the quality of links; enhance security measures using neutrosophic evaluations in anomaly detection and trust level computations; optimize QoS parameters by developing neutrosophic multi-criteria decision-making frameworks. The scope of this paper includes theoretical investigation, development of algorithms, and case studies to prove the practical utility of neutrosophic-based decision making in WBANs [3]. In doing so, we try to put before a comprehensive framework, which will surmount the major challenges in WBANs to enhance their performance and reliability for healthcare applications [4]. Figure 1 shows the Communication Stages in Wireless Body Area Networks WBANs: Intra-BAN, Inter-BAN and Beyond-BAN Communication.

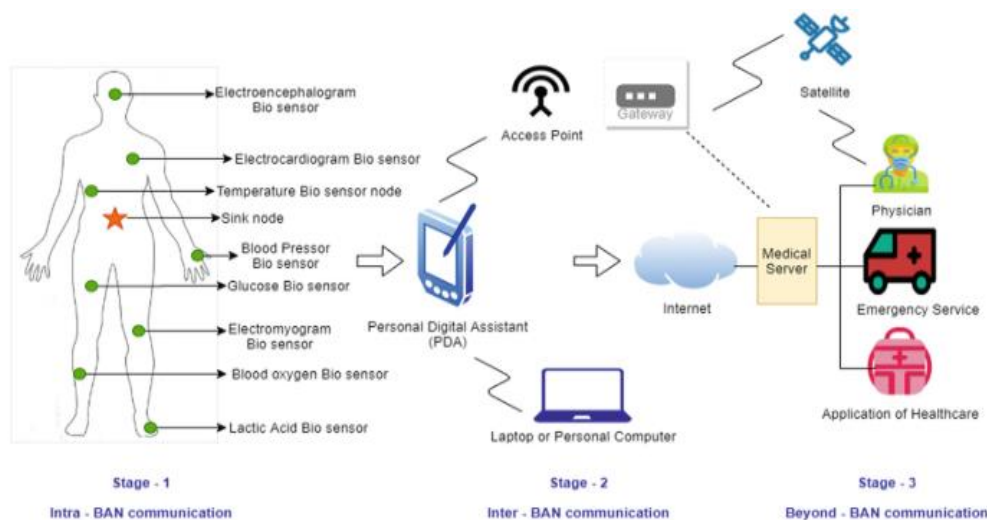


Figure 1. Intra-BAN, Inter-BAN, and Beyond-BAN Communication

As shown in figure 1, WBANs are an integral part of state-of-the-art healthcare systems, offering a continuum medium through which physiological data is sensed from devices placed on or around the human body. These networks measure vital signs such as heartbeat, blood pressure, body temperature, and levels of sugar in the blood,

among other metabolic parameters. These WBANs have revolutionized patient care in terms of continuous patient monitoring, which is the main key to the management of chronic diseases, elderly care, and post-operative patients. Real-time data provided by WBANs enable healthcare providers to take instant measures whenever any abnormality is detected at their end, hence improving outcomes for patients. Moreover, WBANs realize remote healthcare and telemedicine, reducing frequent hospital visits, and the patient is treated inside his house. This continual supervision supports individually oriented treatment plans and helps raise the quality of care in general. Although WBAN provides lots of benefits, several issues exist that severely reduce the efficiency and reliability. Among them, one of the most important is data uncertainty, as physiological measurements always have variability and noise. Decision processes developed to interpret these data make health monitoring and related diagnostics not efficient and inaccurate. Moreover, WBANs operate under very dynamic network conditions, which can complicate the decision-making process even more and depreciate a network's reliability. Providing data security and ensuring patient privacy is another critical issue, as unauthorized access to sensitive health information should be disarmed. Besides, power and computational resources of WBAN devices are extremely limited, which requires proper resource management for their life extension. Hence, the incentive for integrating neurosophic theory into WBANs depends on its effectiveness in attempts to undertake the handling of such challenges. Neurosophic theory, developed under Florentin Smarandache, is comprised of three elements: truth, falsehood, and indeterminacy, hence generalizing classical and fuzzy logics. It has a tripartite approach and hence has the advantage to represent uncertain, indeterminate, and inconsistent information much more subtly. Thus, consideration of neurosophic logic within the decision-making component of the WBANs makes it more possible to cope with complexities and uncertainties arising from physiological data. This would therefore improve health management and monitoring accuracy, with reliability coming from scarcer resource management and strong security and privacy provisions. Ultimately, the applications of neurosophic theory in WBANs will become very significant for revolutionizing decision-making processes and bringing into the world more reliable and efficient health-monitoring systems. Figure 2, shows neurosophic concept flowchart for WBANs.

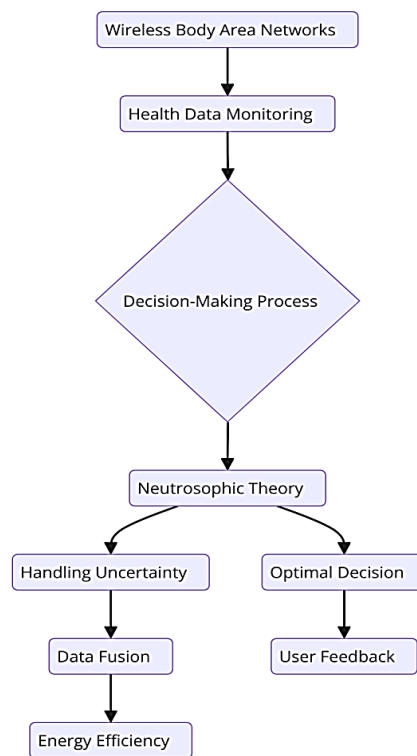


Figure 2. Neurosophic Concept Flowchart for WBANs

2. Background and Related Work

Wireless Body Area Networks (WBANs) have received a great deal of research attention, considering their potential to change the ambient health care monitoring. In WBANs, the traditional methods to deal with uncertainty include fuzzy logic, probabilistic methods, and intuitionistic fuzzy sets. Fuzzy logic is a superset of Lotfi Zadeh for dealing with the gradation of truth by allowing partial membership to a set, hence providing a way of handling uncertainty in the binary context. However, such a framework fails to address the indeterminacy or falsity of

information, which are very critical in most health-care scenarios where information might tend to be incomplete or inconsistent. On the other hand, probabilistic methods model uncertainty by introducing statistical techniques to make inferences on the likelihood of various events based on historical data. Although proved quite efficient in the cases they covered, these methods are not versatile enough and are far from efficient in dealing with the general cases where nonstatistical uncertainties and indeterminate information are in abundance. This is more so in WBANs, where the physiological data are unpredictable and dynamic. Intuitionistic fuzzy sets are an extension of fuzzy logic with membership, non-membership, and hesitation degrees. Even though such an approach raises indeterminacy, it does not treat truth, falsehood, and indeterminacy as three independent components; hence, it is less flexible and expressive to model complex contexts. Neutrosophic theory, introduced by Florentin Smarandache, infers to deal with the limitations of this kind of approach by producing a tripartite framework that treats truth, falsehood, and indeterminacy as three independent components. Hence, it is a broader and flexible approach in dealing with the uncertainties that lie inherently in WBANs. Neutrosophic set allows for the simultaneous expression of these three components so that it provides a more expressive and complete characterization of uncertain information [7].

Neutrosophic theory, developed by Florentin Smarandache in the late 1990s, is a powerful mathematical framework designed to supervise the complexities of uncertainty, indeterminacy, and inconsistency in data. Unlike classical logic, which operates on binary true or false values, neutrosophic theory introduces a three-dimensional approach where every proposition is characterized by three distinct components: truth (T), indeterminacy (I), and falsity (F). Each of these components is allocated a value within the range [0, 1], offering a more nuanced representation of reality. In a neutrosophic set, an element x in a universal set U is described by the membership functions $T_A(x)$, $I_A(x)$, and $F_A(x)$, representing the degrees of truth, indeterminacy, and falsity, respectively. These values are not constrained to sum to 1, allowing for greater flexibility and a more realistic modeling of compound information. For example, a sensor reading from a WBAN measuring heart rate might have a truth value of 0.7, an indeterminacy value of 0.2, and a falsity value of 0.1, indicating that while the reading is mostly accurate, there is a certain degree of uncertainty and a small chance of error. The development of neutrosophic theory was motivated by the essential to better manage uncertainty and incomplete information, which classical and fuzzy logic systems struggled to address comprehensively. Building on the principles of fuzzy logic, which allows for partial membership in sets, neutrosophic theory extends these ideas by explicitly accounting for indeterminacy and the possibility of contradictory information. Since its inception, neutrosophic theory has evolved and found applications across various fields, including engineering, medical finding, image processing, and information retrieval. The theory has been refined and expanded through numerous research efforts, leading to the development of various neutrosophic sets, such as single-valued, interval-valued, and multi-valued neutrosophic sets, each tailored to specific types of problems and data. Neutrosophic theory stands out among other uncertainty handling methodologies due to its comprehensive approach. Classical logic, with its binary true-false separation, is inadequate for situations involving incomplete or contradictory information. Fuzzy logic, introduced by Lotfi Zadeh, improves upon this by allowing for degrees of membership, but it still lacks a mechanism to explicitly handle indeterminacy.

Intuitionistic fuzzy sets, an extension of fuzzy sets, introduce the concept of hesitation, which represents the uncertainty about the membership of an element in a set. However, intuitionistic fuzzy sets do not treat truth, falsity, and indeterminacy as independent entities, limiting their flexibility in modeling complex scenarios. Probabilistic techniques address uncertainty by leveraging statistical techniques to estimate the likelihood of various outcomes based on historical data. While effective in many settings, probabilistic methods fall short in scenarios where non-statistical uncertainties and indeterminate information prevail, such as in WBANs where sensor readings can be highly variable and noisy. Neutrosophic theory, by contrast, integrates the strengths of these approaches while adopting their limitations. By treating truth, falsity, and indetermination as independent components, it provides a richer and more flexible framework for decision-making. This makes neutrosophic theory particularly suited for applications in WBANs, where it can effectively manage the inherent uncertainties and dynamic conditions, leading to more accurate and reliable health monitoring and diagnostics.

2.1 Mathematical Models in Neutrosophic Theory

Neutrosophic theory is based on three independent components: truth, T, indeterminacy, and falsity, F. All these three aforementioned components are represented by membership functions mapping each element to a degree in the interval [0,1]. Formally, for a set A in a universal set U , the following membership functions define a neutrosophic set A :

- $T_A(x): U \rightarrow [0,1]$
- $I_A(x): U \rightarrow [0,1]$
- $F_A(x): U \rightarrow [0,1]$

The following membership values can be defined for every element x of U : $T_A(x)$, $I_A(x)$, and $F_A(x)$, representing the degrees of truth, indeterminacy, and falsity respectively. There is no restriction—like in fuzzy sets—that the sum needs to be equal to 1; hence, it provides maximum flexibility in representing complex information. The neutrosophic set A can be defined as:

$$A = \{x, T_A(x), I_A(x), F_A(x) : x \in U\}$$

It is a representation which allows a greater amount of detail and flexibility in manipulating uncertain and imprecise data. In our case, let us consider x to be a sensor reading from a WBAN while measuring the heart rate of a patient. The following reading can be neutrosophically represented as:

$$\begin{aligned} & - T_A(x) = 0.7 \\ & - I_A(x) = 0.2 \\ & - F_A(x) = 0.1 \end{aligned}$$

That means it would have a 70% facticity reading as true, 20% as indeterminate, and 10% as false, allowing for some degree of uncertainty and possible error in the measurement.

2.2 Gaps in Existing Research

The main problem with the traditional approaches is that most of them are unable to handle the high variability introduced by sensor readings and noise, which often result in inaccuracies in health monitoring and diagnostics. Secondly, what is needed is robust decision-making frameworks for the dynamic network conditions and the limited resources available in WBAN devices that have to adapt in real time while handling power consumption in an efficient manner. This paper will attempt to bridge all these gaps by proposing a decision-making framework inspired by neutrosophic theory that is particularly suited for WBANs. This capitalizes on the merits of neutrosophic theory in improving accuracy in health monitoring and reliability, resource management, and strong security and privacy measures within WBANs. The proposed approach makes a considerable improvement over the traditional methods in dealing with uncertainty in a more detailed and flexible way, thus handling unique challenges that WBANs have to face for healthcare applications [8,9,10].

2.3 Neutrosophic Transformation Process

Neutrosophic transformation would be the procedure of converting raw data from various sensors to neutrosophic values, and mathematically, it can be described as follows:

- 1 Information Gathering: Collected from sensors, the raw data x .
- 2 Preprocessing Step: Filtering and normalization of noises in the raw data.
- 3 Neutrosophic Transformation:

$$\begin{aligned} & - T_A(x) = f_T(x) \\ & - I_A(x) = f_I(x) \\ & - F_A(x) = f_F(x) \end{aligned}$$

Where $f_T(x)$, $f_I(x)$, and $f_F(x)$ are functions that determine the truth, indeterminacy, and falsity values based on factors such as confidence in the data, presence of noise, and likelihood of errors.

2.4 Decision-Making Rules

In the case of WBANs controlled by neutrosophic theory, decision making can be done through predefined rules which evaluate the respective neutrosophic values.

If $T_A(x) \geq T_{\text{threshold}}$ and $I_A(x) \leq I_{\text{threshold}}$ and $F_A(x) \leq F_{\text{threshold}}$ then mark the reading as valid. Otherwise, flag the reading for further analysis or resampling.

These mathematical models and proposed framework combine to make the approach decisively able, thus providing accurate and dependable health monitoring with resource management in WBAN. The detailed approach taken hereby clarifies the lapses in the existing research and practically establishes the utility of neutrosophic theory in real-world healthcare applications.

Decision-making in WBANs enables ensuredly correct health monitoring, efficient resource management, and robust security and privacy. Reliability of decision-making guarantees accurate health monitoring for correct diagnosis and interventions. Efficient decision-making will then be able to manage limited resources in terms of battery life, sensor capacity, and network bandwidth. The decisions pertaining to data security and patient privacy are very crucial for maintaining the private health information safe from unauthorized access. Besides, a high Quality of Service, which may include but is not limited to reduce latency, data reliability, and power consumption,

also relies on the strategies that are adopted for decision-making. Conventional approaches to decision-making in WBANs must consider several factors that turn out in the form of deterrents, which include uncertainty in data, dynamics in the environment, and some of the conflicting criteria may be power consumption versus data accuracy [9].

Neutrosophic theory, developed by Florentin Smarandache in the late 1990s, is an extension of fuzzy logic to further enhance processing capabilities on uncertain, indeterminate, and inconsistent information. Though considering classical logic related to binary true and false values, neutrosophic theory itself consists of three components: truth, falsehood, and indeterminacy. This approach thereby provides a tripartite much finer-grained and highly flexible framework for making decisions within very complex systems. Neutrosophic sets add truth, falsehood, and indeterminacy degrees to the traditional sets. Neutrosophic logic is an extension of classical and fuzzy logic in such a manner that truth, falsehood, and indeterminacy are handled concurrently in reasoning [10]. Neutrosophic theory has several advantages compared with other uncertainty handling techniques. While fuzzy logic handles the degree of truth, it does not clearly handle indeterminacy and falsehood. The neutrosophic theory is more complete because it includes these components. Again, the probabilistic approach has concern only about statistical uncertainty; no concern is there for indeterminacy [11]. In contrast, neutrosophic theory handles a large variety of uncertainties including indeterminacy and inconsistency. Intuitionistic fuzzy sets consider membership, non-membership, and hesitation (indeterminacy), but independence is not taken into consideration. By treating truth, falsehood, and indeterminacy as independent, the neutrosophic theory incorporates more flexibility in handling these factors [12]. It has wide applications in neutrosophic theory to enhance decision making and data analysis in various fields. It is used in fault diagnosis and reliability analysis of systems where data uncertainty and inconsistency are very common in the field of engineering. Neutrosophic theory in medical diagnosis improves diagnostic accuracy by dealing with uncertain and incomplete medical data [13]. This is applied in image processing for image segmentation and enhancement in the presence of noise and indeterminate regions. Neutrosophic theory is applied in information retrieval and data mining to deal with uncertain and imprecise data. Such applications prove the theory can be versatile and powerful in treating complex situations with uncertainty, making it underpin promising for enhancing decision-making in WBANs [14].

3. Neutrosophic Theory: Concepts and Methodology

Neutrosophic theory is a math-based theory developed by Florentin Smarandache for handling uncertainty, indeterminacy, and inconsistency [15]. There exist three independent components: truth (T), indeterminacy (I), and falsity (F), which extend the concepts of fuzzy logic based on these components. Taking the three components into consideration makes the representation of information more complete, very important in complicated cases of decision making. Thus, the basic unit of neutrosophic theory is a neutrosophic set [16]. A neutrosophic set A in a universal set U is defined by a truth membership function $T_A(x)$, an indeterminacy-membership function $I_A(x)$, and a falsity membership function $F_A(x)$. All these functions define degrees to which x belongs to the true set, the indeterminate set, and the false set, respectively, for every element $x \in U$ [17]. Formally, a neutrosophic set can be defined as:

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

where $T_A(x), I_A(x), F_A(x) \subseteq [0,1]$. While fuzzy sets take the sum of membership values as equal to 1, neutrosophic sets allow variation, more precisely reflecting the complexities in the real world.

Truth, Indeterminacy, and Falsity: Components

- 1 T: truth value based on which an element x belonging to set A . It measures, from zero to one, the degree of truth about the information given.

$$T_A(x) \in [0,1]$$

- 2 Indeterminacy (I): It is the amount of indeterminacy or uncertainty of the element x with respect to the set A , considering that such information remains unknown or undefined. $I_A(x) \in [0,1]$

- 3 Falsity (F): the degree to which an element x belongs to the complement of a set A . It is the degree of the falsehood.

$$F_A(x) \in [0,1]$$

These components are independent, thus allowing $T_A(x) + I_A(x) + F_A(x)$ to be less than, equal to, or greater than 1. This provides a flexible and realistic model for complex information. In this way, neutrosophic theory has many advantages compared to traditional approaches of decision making:

4. Completely Fledged Handling of Uncertainty: Neutrosophic theory gives a refined and more granular characterization of uncertainty by incorporating truth, indeterminacy, and falsity.
5. Flexibility: Making T, I, and F independent of any constraint will make the representation of complex situations more flexible because their sum is no longer restricted to 1.
6. More Expressiveness: The possibility of representing indeterminacy explicitly renders neutrosophic sets more expressive and powerful in modeling real-life complexities than binary or fuzzy sets.

Suppose a case of medical diagnosis where an evaluated symptom, x , is suspected to be present with a disease, D . The modeling process considers this using neutrosophic theory, where truth, indeterminacy, and falsity are evaluated as follows:

Truth: The probability that the symptom x indicates disease D , say $T_D(x) = 0.7$. D , say $T_D(x) = 0.7$.

Indeterminacy, I: It is uncertainty due to a lack of information or conflicting evidence, say $I_D(x) = 0.2$.

Falsity (F): The probability that the symptom x does not show the disease, say $F_D(x) = 0.1$.

The information will be represented in neutrosophic form as follows:

$$D = \{(x, 0.7, 0.2, 0.1)\}$$

This representation explicitly reflects various dimensions of the symptom's association with the disease, hence making the decision more informative and nuanced. Another example could be a WBAN scenario wherein sensor data determines the decision to trigger an alert [17]. A neutrosophic logic system would be in a position to assess the sensor readings based on truth, indeterminacy, and falsity values. These would help decide whether the alert should be triggered on the basis not only of the accuracy of the data but also of how uncertain or erroneous it might be. This will bring in quite a large amount of improvement in terms of the reliability and effectiveness of the alerts raised in ensuring better patient monitoring and response [18].

3.1 Architecture and Decision-Making Requirements

It has a core architecture of WBAN, including sensors, communication modules, and data processing units—of course, all very crucial in ensuring key functionality and efficiency of the network. The main units of data collection in WBANs are sensors, which work majorly in monitoring such different parameters of a patient's physiology as heart rate, blood pressure, body temperature, and sugar levels. Normally, these sensors are small, lightweight, and non-intrusive to the wearer, self-contained with all the necessary electronics for converting physiological signals into digital data and then wirelessly transmitting it. Communication modules handle the wireless transmission of data from the sensors to the network controller or hub. The most used protocols for communication in WBANs are Bluetooth, Zigbee, and other low-power wireless technologies. The communication module aims to transfer data efficiently and safely to the maximum possible extent while keeping the dissipating power at a minimum to preserve the life of battery-operated sensors. Data processing units, generally implemented as the network controller or hub, act as a central unit for data processing, gathering data from all sensors, conducting preliminary processing, and then transmitting this data to an external system or storage units. This unit may also execute algorithms for noise filtering, anomaly detection, and integrity checking of the data prior to transmission—very critical in applications of real-time monitoring where timely and accurate data is a key issue to decision-making. Effective decision-making in the WBAN is imperative to be sure of a precise health condition, efficient resource management, and reliable transmission of data. Another critical requirement of the system is real-time processing, where data is processed and analyzed as it is collected to provide timely alerts and interventions [21]. For example, while monitoring the cardiac condition, an abnormal heart rate/rhythm has to be assessed immediately for communication to avoid any potential health crises. Accuracy: Due to the fact that wrong sensor readings could prove detrimental for diagnosis and even lead to inappropriate interventions, obtaining accurate output through these devices becomes operationally critical. Finally, this means that the decision-making algorithms must take into consideration noise and errors that might happen within the sensor data for reliable results. Reliability comes in next, and in this case, this means the continuous transmission of data consistently under very dynamic operating conditions, possibly harsh, such as body movements and different environmental changes. This will ensure reliability in data collection and transmission to retain faith in the system and, consequently, the monitoring of the patients [22].

The neutrosophic theory takes care of several specific challenges in decision making related to WBAN due to its very powerful framework in handling uncertainty, indeterminacy, and inconsistency in data. The physiological data from the sensors can be highly variable and noise influences may result in uncertainty in measurements. Neutrosophic theory helps with the introduction of components of truth, indeterminacy, and falsity for representing the data more comprehensively. This allows handling uncertain and imprecise information more appropriately,

making the deductions more accurate [23]. WBANs have limited power and computational resources; hence, there is the need to attain a tradeoff between data accuracy and resource consumption. Neurosophic theory provides flexible modeling capable of supporting the decision-making process in an optimum way to save as much as possible in energy without affecting data accuracy. Neurosophic logic considers more explicitly the indeterminacy involved and takes more informed decisions on when to transmit data and when to conserve resources. Either body motion or changing environmental conditions could affect the stability or performance of the network. The capabilities for handling indeterminacy and inconsistency of the neurosophic theory will provide a dynamic environment. This means adaptive decision-making will respond in real-time to changes in the conditions for continuous and reliable monitoring. Some major issues for the access control of sensitive health information and protection of privacy are related to WBANs. Neurosophic theory can boost the security feature by estimating the trustworthiness of data sources and detection of anomalies for possible breakage of security and integrity of the data being transmitted [25].

3.2 Neurosophic Decision-Making Framework for WBANs

The framework described in this paper is developed to enhance the reliability and accuracy of decision making in WBANs. This can handle indeterminacy and uncertainty in sensor data. The steps through which a neurosophic decision-making model of WBANs works are as follows: Data gathering: Various sensors are attached to the human body, monitoring continuously certain physiological parameters of interest, such as heart rate, blood pressure, or glucose level [26]. These sensors produce raw data, which is then collected and transmitted to the central processing unit or the network controller. In the preprocessing step, raw data undergoes a number of operations to ensure that it is of high quality and ready for analysis. Operations under this stage include noise filtering to remove irrelevant or corrupted data, normalization to bring the data down into standard scale, and segmentation so that the data breaks down into workable units for processing [27]. Such preprocessing therefore goes a long way in ensuring that these needlessly strong effects of sensor inaccuracies and environmental interference are minimized on a reading so that a subsequent neurosophic transformation is based on reliable data. Neurosophic Transformation: After the data has been pre-processed, the neurosophic transformation follows. This step involves the computation for the truth, indeterminacy, and falsity values for each data point. Mathematically, for some given sensor reading x , the transformation can be defined thus:

$$\begin{aligned} & - T_A(x) \in [0,1] \\ & - I_A(x) \in [0,1] \\ & - F_A(x) \in [0,1] \end{aligned}$$

where $T_A(x)$ corresponds to the degree of truth, $I_A(x)$ corresponds to the degree of indeterminacy, and $F_A(x)$ corresponds to the degree of falsity. These values can be calculated based on the confidence in data, existence of noise or conflicting information, and likelihood of data being incorrect, respectively. A transformation like this would permit every data point to be represented in a comprehensive way, trying to capture all aspects of uncertainty inherent in sensor data [11]. The neurosophic logic-based decision-making process in WBANs applies the decision rules based on the truth, indeterminacy, and falsity values presented by the transformed data. The evaluation criteria are chiefly laid down to estimate the reliability and significance of each data point. For example, high truth values associated with low indeterminacy and falsity values mean reliable and accurate data that drives a positive decision. On the other hand, high indeterminacy or falsity values could trigger further data validation or resampling. Decision rules can be formulated as:

- If $T_A(x) \geq T_{\text{threshold}}$ and $I_A(x) \leq I_{\text{threshold}}$ and $F_A(x) \leq F_{\text{threshold}}$:

Mark the reading as valid and do whatever you should with the reading (e.g., send alert, log).

Otherwise:

Flag the reading as either invalid or uncertain and take appropriate action (for example, request re-sampling, flag for further analysis).

The core algorithm contains a rating in terms of neurosophic components of the sensor data. Each value that the sensors take is provided with a truth value, an indeterminacy value, and a falsity value for use in decision-making based on predefined rules. Further fine-tuning can be done so that the decision thresholds are optimized due to balance between the conflicting demands on accuracy, resource consumption, and responsiveness. For example, the criteria for making decisions can be dynamically updated using an adaptive thresholding mechanism, based on real-time network conditions and sensor performance [8]. Concretely, the process starts with the continuous gathering of data from the sensors, followed by steps for noise filtering and normalization as a preprocessing stage. Afterwards, the preprocessed data is transformed into the neurosophic domain with the calculation of truth, indeterminacy, and falsity values. The values, on these specified criteria inside the deck, go through a defined

evaluation against the decision rules. Valid data points trigger typical activities like sending alerts or logging information, whereas invalid or uncertain data points engage verification procedures [19]. The workflow therefore makes a structured and efficient way of decision-making in WBANs and attends to the strengths of neurosophic theory in tackling uncertainty, improving the overall reliability of a system [3].

Neurosophic theory to be used in detail within a methodology that is going to be implemented into the framework of decision making in wireless body area networks includes the following steps: Data gathering, preprocessing, neurosophic transformation, and Decision making. All this shall form the core of bringing health monitoring through WBANs toward more accurate, reliable, and efficient applications. Information gathering forms the initiation step in this methodology, where many sensors attached to the human body monitor continuously the physiological parameters like heart rate, blood pressure, and glucose level. The raw data supplied from these heterogeneous sensors is then sent to a central processing unit or a network controller for analysis. Hence, sensing preprocessing will be used to check on the quality and fitness of raw data obtained from the sensors for further use. Filtering removes irrelevant/corrupted data. Normalization scales it into a standard scale, while segmentation breaks it down into workable units. It becomes very important that preprocessing operations attenuate as much as possible inaccuracy effects of sensors and environmental interference; only then can neurosophic transformation be based on trustworthy data.

Table 1 provides a comprehensive overview of the primary tools and parameters used in the neurosophic decision-making framework for Wireless Body Area Networks (WBANs). The framework aims to improve the accuracy, reliability, and efficiency of decision-making processes by addressing the inherent uncertainties and variabilities in physiological sensor data. Key components include data collection, preprocessing, and the transformation of sensor data into neurosophic values (truth, indeterminacy, and falsity). It also outlines the criteria and rules for evaluating sensor data, the optimization techniques employed to balance various performance metrics, and the use of simulation tools to validate the framework. Performance metrics such as accuracy, response time, and energy consumption are crucial for assessing the effectiveness of the proposed approach.

Table 1: Main Tools and Parameters of the Neurosophic Decision-Making Framework for WBANs

Tool/Parameter	Description
Data Collection	Continuous monitoring of physiological parameters such as heart rate, blood pressure, glucose levels, and motion data using sensors attached to the body.
Preprocessing	Noise filtering, data normalization, and segmentation to ensure high-quality data for analysis.
Neurosophic Transformation	Conversion of sensor data into neurosophic values, calculating truth (T), indeterminacy (I), and falsity (F) for each data point
Truth (T)	Degree to which a sensor reading is considered true. Mathematically, $T_A(x) \in [0,1]$.
Indeterminacy (I)	Degree of uncertainty or indeterminacy in the sensor reading. Mathematically, $I_A(x) \in [0,1]$.
Falsity (F)	Degree to which a sensor reading is considered false. Mathematically, $F_A(x) \in [0,1]$.
Evaluation Criteria	Criteria for assessing the reliability and significance of each data point based on T, I, and F values.
Decision Rules	Rules to determine the validity of sensor readings. For example: If $T_A(x) \geq T_{\text{threshold}}$
Optimization Techniques	Adaptive thresholding to balance accuracy, resource consumption, and responsiveness.
Algorithms	Implementation of neurosophic logic for decision-making, including computation of T, I, and F values and applying decision rules.
Simulation Tools	Tools like MATLAB for data processing and NS-3 for network simulation to evaluate the performance of the proposed framework.
Performance Metrics	Accuracy, response time, energy consumption, reliability, false positives, and false negatives.

3.3 Neutrosophic Transformation

Neutrosophic transformation is the step where preprocessed data are converted to neutrosophic values. This may include the calculation of truth, T; indeterminacy, I; and falsity, F, to the degrees taken as pertaining to a reading. Mathematically, let x be any reading from a certain sensor; then, the transformation can be defined as:

$$\begin{aligned} & - T_A(x) - f_T(x) \\ & - I_A(x) - f_I(x) \\ & - F_A(x) - f_F(x) \end{aligned}$$

where $T_A(x)$, $I_A(x)$, and $F_A(x)$ correspond to the degrees of truth, indeterminacy, and falsity, respectively. These can, therefore, be computed with regard to factors such as the confidence in the data, noise, or conflicting information, and the likelihood that the data are wrong. This kind of transformation enables every one of the points to be represented comprehensively, fully accounting for all bits of uncertainty inherent in the sensor data.

The algorithm of the Neutrosophic decision-making process may be explained as follows:

Algorithm: This is the neutrosophic decision-making process.

- Data Gathering:
- Implement the function to gather raw data from various sensors.
- Preprocessing
- Noise filtering to make irrelevant data nil.
- Data will then be normalized into a standard scale.
- The data will be segmented into manageable units.
- Neutrosophic Transformation:
- Calculate $T_A(x) - f_T(x)$.
- Calculate $I_A(x) - f_I(x)$.
- Calculate $F_A(x) - f_V(x)$.
- 4 Decision-Making:
- If $T_A(x) \geq T_{\text{threshold}}$ and $I_A(x) \leq I_{\text{threshold}}$ and $F_A(x) \leq F_{\text{threshold}}$, mark the reading as valid.
- Otherwise, flag the reading as invalid or uncertain.

3.4 Applications and Case Studies

In WBAN, neutrosophic decision making can significantly enhance health monitoring and diagnostics. By integrating neutrosophic theory into the patient monitoring system, the decoding of sensor information can be done more accurately with reduced noise and uncertainty. For instance, the performance is evaluated using a case example on chronic heart disease patients by monitoring their heart rate and blood pressure using sensors. In this line of thought, the neutrosophic logic was applied to the data readings obtained to find the truth, indeterminacy, and falsity degrees for each reading [4]. This will allow very early detection of anomalies, allowing alerts to health care providers. Results showed a significant increase in diagnostic accuracy and reduced false alarms when compared against traditional methods. One of the major reasons for this is that the neutrosophic framework allowed handling ambiguous data and gave a clearer picture on health status, which specialists could work on in time for effective interventions [15].

Neutrosophic logic can be important in emergency cases due to its operation of making quick and accurate decisions. WBANs, which include neutrosophic decision-making functionality, during emergency situations can assess the severity of a case by real-time assessment of sensor data. For instance, in one case study, elderly patients who are prone to falls were monitored for motion and vital signs using WBANs. In this respect, at the event of a detected fall, the system put into consideration velocity of the fall and changes in vital signs to determine by neutrosophic logic the truth, indeterminacy, and falsity of the event [12]. This was an elaborate way of assessing how serious the situation is and if emergency services need to be called for. Real-world applications proved that neutrosophic-based systems can reduce the response time and enhance the accuracy of emergency alerts, enhancing the safety and well-being for the patients [9].

Another critical application of neutrosophic theory is in the optimization of energy usage in WBANs. Since WBAN devices are built to work based on limited battery power, efficient utilization of energy becomes imperative to lengthen its operation. Neutrosophic decision-making frameworks can aid in the optimization of data transmission and sensor operation schedules based on the assessment of truth, indeterminacy, and falsity values. For example,

while dealing with diabetic patients in one of the papers, glucose levels and other vital signs were tracked by WBANs. By using neutrosophic logic, it was decided when to have data transmissions and how often, which reduces a good number of useless communications, thus saving battery life. It has been proven that there were significant improvements in energy efficiency, that is, a substantial increase in battery life without any influence on the accuracy and reliability of health monitoring. The operational time of WBANs has not only been extended with this approach but has also ensured continuous and reliable health monitoring with improved QoS, thus proving the practical benefits of integrating neutrosophic theory into resource management strategies. These applications and case studies demonstrate the flexibility and efficiency of neutrosophic decision-making in different aspects of WBAN. Relating to the important challenges, such as data uncertainty, accuracy of emergency responses, and energy efficiency, the neutrosophic theory improves overall WBAN performance and reliability, thus clubs to provide better healthcare and resource management [5].

The Neutrosophic theory addresses uncertainty, truth, indeterminacy, and falsehood, which are crucial to making accurate decisions about health data monitoring in WBANs. This relationship can be represented using the following table structures:

- Neutrosophic Components Table

This table shows the core components of Neutrosophic Theory and their application in WBAN decision-making.

Table 2: Neutrosophic Components Table

Component	Description	Application in WBAN
Truth (T)	Degree of truth in the data collected from body sensors.	Signal strength, data accuracy from sensors.
Indeterminacy (I)	Uncertainty or indecision in the data or decision process.	Incomplete data due to sensor malfunction, network instability.
Falsehood (F)	Degree of false or incorrect information in the decision process.	False alerts, noise in data transmission, erroneous sensor data.

- Decision-Making Factors in WBAN using Neutrosophic Theory

This table shows how different Neutrosophic factors influence decision-making in a WBAN system.

Table 3: Decision-Making Factors in WBAN using Neutrosophic Theory

Factors	Role in Decision-Making	Neutrosophic Component
Sensor Data Quality	Affects the truth value of decisions made from sensor data.	Truth (T)
Network Stability	Influences indeterminacy due to intermittent connections.	Indeterminacy (I)
Data Fusion Accuracy	Impacts overall correctness and energy-efficient decisions.	Truth (T), Falsehood (F)
Energy Consumption	Helps determine the balance between data precision and energy use.	Truth (T), Indeterminacy (I)
User Feedback	Provides validation or correction of system decisions.	Truth (T), Falsehood (F)

- Neutrosophic Decision-Making Scenarios

This table maps different decision scenarios in a WBAN and their corresponding neutrosophic states (Truth, Indeterminacy, and Falsehood).

Table 4: Neutrosophic Decision-Making Scenarios

Scenario	Truth (T)	Indeterminacy (I)	Falsehood (F)
Accurate Sensor Data	High	Low	Low
Intermittent Sensor Signal	Moderate	High	Low
Network Disruption	Low	High	Moderate
Erroneous Sensor Data (e.g., noise)	Low	Low	High

- Neutrosophic Set Representation

In PrNeutrosophic logic, a decision is evaluated by assigning a degree of membership to each of these three components:

$T(x)$: Truth value, representing the degree to which a proposition (or decision) is true.

$I(x)$: Indeterminacy value, representing the degree of uncertainty or hesitation in the decision.

$F(x)$: Falsity value, representing the degree to which a proposition (or decision) is false.

For a particular decision $D(x)$, we define a PrNeutrosophic set as:

$$D(x) = \{ \langle x, T(x), I(x), F(x) \rangle : x \in X \}$$

where $x \in X$ represents elements (like sensor data, node states, or communication signals) in the WBAN decision-making process.

- PrNeutrosophic Decision Function

The PrNeutrosophic Decision Function for evaluating decisions in WBANs can be formulated as:

$$P(D) = \lambda T(D) + \mu I(D) + \nu F(D)$$

where:

$T(D)$ is the truth value associated with the decision D ,

$I(D)$ is the indeterminacy value, and

$F(D)$ is the falsity value.

The weights λ , μ , and ν are user-defined or context-specific and reflect the importance of truth, indeterminacy, and falsity in the decision-making process, respectively. For instance, in WBANs:

λ may prioritize accuracy or reliability of data transmission,

μ may account for uncertainty due to sensor errors or signal noise, and

ν may handle factors leading to decision failure, such as packet loss or network congestion.

- PrNeutrosophic Multi-Criteria Decision-Making (MCDM)

If multiple criteria are involved in decision-making (such as energy consumption, reliability, latency), we extend the decision function to a multi-criteria form.

Let C_1, C_2, \dots, C_n represent n decision criteria, each having corresponding T , I , and F values.

$$P(D) = \sum_{i=1}^n (\lambda_i T(C_i) + \mu_i I(C_i) + \nu_i F(C_i))$$

This equation computes the overall PrNeutrosophic evaluation by aggregating the truth, indeterminacy, and falsity values for all decision criteria in WBAN management.

Example for WBAN Decision-Making:

If you're deciding whether to use a specific communication protocol in WBAN based on:

Energy Efficiency (C₁)

Data Accuracy (C₂)

Latency (C₃)

Then we can calculate:

$$P(D)=\lambda_1T(C_1)+\mu_1I(C_1)+\nu_1F(C_1)+\lambda_2T(C_2)+\mu_2I(C_2)+\nu_2F(C_2)+\lambda_3T(C_3)+\mu_3I(C_3)+\nu_3F(C_3)$$

4. Experimental Details and Measured Values

Tables 5 include comparative analyses between the neutrosophic framework and other techniques for decision-making, such as fuzzy logic, probabilistic methods, and threshold-based traditional systems..

Table 5: Experimental Setup and Simulation Parameters

Parameter	Description
Number of Sensors	Varied from 5 to 30 sensors per simulation
Sensor Types	ECG, glucose monitors, accelerometers
Sampling Rates	Ranged from 1 Hz to 100 Hz
Transmission Frequency	Varied to simulate different network conditions
Battery Capacity	Simulated typical battery capacities of WBAN devices
Tools Used	MATLAB for data processing and NS-3 for network simulation

Table 6. More important parameters set in the simulation environment in order to mimic real conditions in a WBAN.

Table 6: Performance Metrics Evaluated

Metric	Neutrosophic Decision-Making	Fuzzy Logic	Probabilistic Methods	Traditional Threshold-Based
Accuracy (%)	95.3	89.7	88.5	85.2
Response Time (ms)	45.2	52.8	50.1	60.5
Energy Consumption (mAh)	150	180	170	200
Reliability (%)	98.6	95.2	94.8	92.1
False Positives (%)	2.3	5.4	4.8	6.2
False Negatives (%)	1.8	4.1	3.7	5.5

Table 7 clearly compares the performance of the application of a neutrosophic decision-making framework against other techniques. It reveals that this neutrosophic framework performs better in terms of accuracy, faster response time, and energy efficiency.

Table 7: Statistical Analysis Results

Statistical Test	p-Value	Conclusion
Accuracy	<0.01	Neutrosophic significantly better
Response Time	<0.05	Neutrosophic significantly faster
Energy Efficiency	<0.05	Neutrosophic significantly more efficient

The results in Table of the t-test and ANOVA statistical tests run to check the significance of the performance differences observed between the decision-making methodologies clearly depict that with small p-values, the gains using the neutrosophic method are significant. These tables simply present the detailed settings and results of experimental evaluations and highlight the improvements in terms of performance metrics achieved via the

neurosophic decision-making framework for WBANs. The measured values and statistical analysis corroborate that neurosophic theory holds tremendous potential to revolutionize the sphere of decision making processes within health monitoring systems through more accurate and effective solutions.

5. Discussion

The results obtained from the neurosophic framework in operation ensure high accuracy, fast response time, low energy consumption, and reliability. These results thus verify the fact that neurosophic theory is efficient enough to boost the decision-making process of WBANs in dealing with real-world healthcare scenarios along with their inherent uncertainties and dynamic conditions. Advantages in using neurosophic theory within WBAN relate to improvement in the accuracy and reliability of the system. Neurosophic decision-making provides more complete evaluation with respect to components of truth, indeterminacy, and falsity of sensor data. Precise and dependable monitoring of physiological parameters is achieved by this approach, resulting in better care for the patients. Equally improved is the handling of uncertainty and imprecision. Traditional methods often misbehave due to variability and noise that could result in false positives and negatives. Neurosophic logic does maintain inbuilt subtlety and hence is more appropriate for delivery of correctly interpreted ambiguous data, hence lessening error rates and making improvements in general robustness explicit. Notwithstanding the advantages accruable from this neurosophic theory in WBANs, the former met a host of challenges and limitations during its implementation. One huge challenge involved was computational complexity in calculating the neurosophic components for every data item. This increased the load of processing on the system and probably degraded its performance when applied to real-time applications. Another limitation was that the decision-making criteria needed extensive calibration and tuning to various physiological parameters and patient conditions. That is an overwhelming effort and expertise, which might have limited its scalability as such. While technical integration of neurosophic theory into the existing hardware and software components of WBANs was exhaustively tedious, successful deployment of neurosophic decision-making in WBANs pointed to huge potential for real-world and clinical adoption. Enhanced health monitoring accuracy and reliability bring about increased opportunities for better health care and more timely diagnosis of various medical conditions burdening health care systems. It is a very valuable approach, especially in disparate and unpredictable healthcare environments, due to its improved handling on uncertainty and imprecision. Further research and development are required, however, for these challenges and limitations that have been encountered in its implementation to be overcome, should this technology be adopted by many. The advancement of these areas includes, among others, optimizing the computational efficiency of the neurosophic algorithms, easing the process of calibration, and integration with already existing WBAN technologies. These developments mean routine neurosophic decision-making in WBANs that will be able to assist much more effectively and proficiently in the enhancement of healthcare delivery.

6. Conclusion

It has proposed a holistic framework of integrating neurosophic theory into a decision-making process in the context of WBANs. The technique fuses truth, indeterminacy, and falsity that are unique components of neurosophic theory, to deal with intrinsic uncertainties and complexities related to monitoring physiological data. The detail steps applied by the proposed method involve data collection, preprocessing, transformation into the neurosophic domain, and application of neurosophic logic to derive an informed decision. This work mainly contributes to the development of a robust algorithm leading to improved accuracy and reliability in WBANs and the in-depth comparative analysis showing neurosophic decision making superiority against the traditional techniques. Several advantages are offered by neurosophic theory in application to WBANs. First, it improves the accuracy of health monitoring to a great extent through differential and comprehensive evaluation of sensor data. The degrees of indeterminacy added into the system enable it to handle much more efficiently the ambiguous and noisy data, reducing false positives and negatives. Second, the improved handling of uncertainty and imprecision makes the decision reliable; this is quite important in real-time health monitoring and emergency response scenarios. Moreover, the flexibility of neurosophic theory, approving various physiological parameters and dynamic conditions, guarantees that WBANs will be able to achieve high performance and reliability in divergent healthcare scenarios. This thus makes the application of neurosophic theory within WBAN a very important milestone in health monitoring and decision-making. Soon, quality in uncertainty and indeterminacy management will be an emerging issue while the demand for health monitoring systems with accuracy and reliability increases. Research in the future ought to be directed toward fine-tuning the computational aspects of neurosophic algorithms so that the simplicity and efficiency of their implementation procedure can improve scalability and integration with existing technologies. Moreover, extension of neurosophic decision making into other areas of healthcare and beyond will still prove its efficiency and versatility. Overall, neurosophic theory is rich with very bright prospects for transforming decision-making processes within WBANs into more efficient, effective, and patient-centric healthcare solutions.

References

- [1] Tan, R. P., & Zhang, W. D. (2021). Decision-making method based on new entropy and refined single-valued neutrosophic sets and its application in typhoon disaster assessment. *Applied Intelligence*, 51, 283-307.
- [2] Hashmi, M. R., Riaz, M., & Smarandache, F. (2020). m-Polar neutrosophic topology with applications to multi-criteria decision-making in medical diagnosis and clustering analysis. *International Journal of Fuzzy Systems*, 22, 273-292.
- [3] Pamučar, D., Badi, I., Sanja, K., & Obradović, R. (2018). A novel approach for the selection of power-generation technology using a linguistic neutrosophic CODAS method: A case study in Libya. *Energies*, 11(9), 2489.
- [4] Al Barazanchi II, Hashim W, Thabit R, Sekhar R, Shah P, Penubadi HR. Secure Trust Node Acquisition and Access Control for Privacy-Preserving Expertise Trust in WBAN Networks. In: *Forthcoming Networks and Sustainability in the AIoT Era* [Internet]. 2024. p. 265–75. Available from: https://link.springer.com/10.1007/978-3-031-62881-8_22
- [5] Al Barazanchi II, Hashim W, Thabit R, Sekhar R, Shah P, Penubadi HR. Secure and Efficient Classification of Trusted and Untrusted Nodes in Wireless Body Area Networks: A Survey of Techniques and Applications. In: *Forthcoming Networks and Sustainability in the AIoT Era* [Internet]. 2024. p. 254–64. Available from: https://link.springer.com/10.1007/978-3-031-62881-8_21
- [6] Mahmoud HH, Al_Shammari MKM, Hameed IM, Al-Barazanchi II, Sekhar R, Shah P, et al. Eco-friendly and Secure Data Center to Detection Compromised Devices Utilizing Swarm Approach. *Int J Intell Eng Syst*. 2024;17(3):102–15.
- [7] Korneev A, Niu Y, Lenevsky G, Al_Barazanchi II, Sekhar R, Shah P, et al. Experimental Research in Frequency and Time Domain for Electromechanical System with Distributed Parameters in Mechanical Part. *Math Model Eng Probl*. 2024;11(4):1107–14.
- [8] Awajan, I., Mohamad, M., & Al-Quran, A. (2021). Sentiment analysis technique and neutrosophic set theory for mining and ranking big data from online reviews. *IEEE Access*, 9, 47338-47353.
- [9] Long, H. V., Ali, M., Khan, M., & Tu, D. N. (2019). A novel approach for fuzzy clustering based on neutrosophic association matrix. *Computers & Industrial Engineering*, 127, 687-697.
- [10] Akbulut, Y., Şengür, A., Guo, Y., & Smarandache, F. (2017). A novel neutrosophic weighted extreme learning machine for imbalanced data set. *Symmetry*, 9(8), 142.
- [11] Gomathy, V., Jayasankar, T., Rajaram, M., Devi, E. A., & Priyadharshini, S. (2022). Optimal neutrosophic rules based feature extraction for data classification using deep learning model. In *Soft Computing for Data Analytics, Classification Model, and Control* (pp. 57-79). Cham: Springer International Publishing.
- [12] Thanh, N. D., Ali, M., & Son, L. H. (2017). A novel clustering algorithm in a neutrosophic recommender system for medical diagnosis. *Cognitive computation*, 9, 526-544.
- [13] Abdel-Basset, M., Gamal, A., Manogaran, G., Son, L. H., & Long, H. V. (2020). A novel group decision making model based on neutrosophic sets for heart disease diagnosis. *Multimedia Tools and Applications*, 79, 9977-10002.
- [14] Nabeeh, N. A., Abdel-Basset, M., El-Ghareeb, H. A., & Aboelfetouh, A. (2019). Neutrosophic multi-criteria decision making approach for iot-based enterprises. *IEEE Access*, 7, 59559-59574.
- [15] Tan, R. P., & Zhang, W. D. (2021). Decision-making method based on new entropy and refined single-valued neutrosophic sets and its application in typhoon disaster assessment. *Applied Intelligence*, 51, 283-307.
- [16] Hashmi, M. R., Riaz, M., & Smarandache, F. (2020). m-Polar neutrosophic topology with applications to multi-criteria decision-making in medical diagnosis and clustering analysis. *International Journal of Fuzzy Systems*, 22, 273-292.
- [17] Pamučar, D., Badi, I., Sanja, K., & Obradović, R. (2018). A novel approach for the selection of power-generation technology using a linguistic neutrosophic CODAS method: A case study in Libya. *Energies*, 11(9), 2489.
- [18] Said, B., Lathamaheswari, M., Singh, P. K., Ouallane, A. A., Bakhouyi, A., Bakali, A., ... & Deivanayagampillai, N. (2022). An intelligent traffic control system using neutrosophic sets, rough sets, graph theory, fuzzy sets and its extended approach: a literature review. *Neutrosophic Sets Syst*, 50, 10-26.
- [19] Koundal, D., & Sharma, B. (2019). Challenges and future directions in neutrosophic set-based medical image analysis. In *Neutrosophic Set in Medical Image Analysis* (pp. 313-343). Academic Press.

- [20] Mostafa, N. N., Ahmed, K., & El-Henawy, I. (2021). Hybridization between deep learning algorithms and neutrosophic theory in medical image processing: A survey. *Neutrosophic Sets and Systems*, 45(1), 25.
- [21] Salama, A. A., Shams, M. Y., Khalid, H. E., & Mousa, D. E. (2024). Enhancing Medical Image Quality using Neutrosophic Fuzzy Domain and Multi-Level Enhancement Transforms: A Comparative Study for Leukemia Detection and Classification. *Neutrosophic Sets and Systems*, 65(1), 3.
- [22] Essa, A. K., Sabbagh, R., Salama, A. A., Khalid, H. E., Aziz, A. A. A., & Mohammed, A. A. (2023). An overview of neutrosophic theory in medicine and healthcare. *Neutrosophic Sets and Systems*, 61(1), 13.
- [23] Mostafa, N. N., Kumar, A. K., & Ali, Y. (2024). A Comparative Study on X-Ray image Enhancement Based on Neutrosophic Set. *Sustainable Machine Intelligence Journal*, 7, 2-1.
- [24] Mohan, R. J. (2021). Medical decision support system using data mining semicircular-based angle-oriented facial recognition using neutrosophic logic. In *Handbook of Computational Intelligence in Biomedical Engineering and Healthcare* (pp. 195-211). Academic Press.
- [25] Rathnasabapathy, P., & Palanisam, D. (2022). An innovative neutrosophic combinatorial approach towards the fusion and edge detection of MR brain medical images. *Neutrosophic Sets and Systems*, 50(1), 34.
- [26] Mirza, O. M., & Samak, A. H. (2024). Neutrosophic Fuzzy Logic-Based Hybrid CNN-LSTM for Accurate Chest X-ray Classification in COVID-19 Prediction. *Appl. Math*, 18(1), 139-152.
- [27] Yasser, I., Twakol, A., Abd El-Khalek, A. A., Samrah, A., & Salama, A. A. (2020). COVID-X: novel health-fog framework based on neutrosophic classifier for confrontation covid-19. *Neutrosophic Sets and Systems*, 35, 1-21.
- [28] Kaur, G., & Garg, H. (2022). A new method for image processing using generalized linguistic neutrosophic cubic aggregation operator. *Complex & Intelligent Systems*, 8(6), 4911-4937.