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Neutrosophic approach for enhancing quality of signals

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Abstract

Information in a signal is often followed by undesirable disturbance which is termed as noise. Preventing noise in the signal leads to signal integrity, which also leads to better signal quality. The previous related works have the major issues while reducing noise in signals regarding assumptions, frequency and time domain, etc. This paper proposes a new Neutrosophic approach to reduce noises and errors in signal transmission. In the proposed method, confidence function is used as the truth membership function, which is associated with sampled time intervals. Then, we define a Dependency function at each time interval for the frequency of transmitted signal. Finally, a Falsehood function, which indicates the loss in information due to amplitude distortion, is defined. This function shows how much information has been lost. Our objective is to minimize the falsehood function using several neutrosophic systems. Experimental results show 1% decrease in loss compared to the original signal without PAM. It is shown the decrease of 0.1% if the frequency is shifted to a higher range.

Keywords Neutrosophic sets · Signal processing · Noises and errors

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Abbreviations

FSK	Frequency Shift Keying
PAM	Pulse Amplitude Modulation
T, I, F	Truth, Indeterminacy and Falsity
FS	Fuzzy Set
IFS	Intuitionistic Fuzzy Set
NS	Neutrosophic Set
SS	Soft set
DM	Decision Maker
DoM	Domain
DNM	Demoplastic Neutropic Melanoma
PC	Personal Computer
HFSs	Hesitant Fuzzy Sets
INSs	Intuitionistic Neutrosophic set
SVNS	Single Valued Neutrosophic sets
MCDM	Multi-Criteria Decision Making
EDAS	Evaluation based on Distance from Average Solution
AHP	Analytic Hierarchy Process
EMG	Electromyogram
SN	Signal to Noise
TF	Transfer function
BWT	Bionic Wavelet transform
SSNR	Spectral Signal to Noise Ratio
SNR	Signal to Noise Ratio
ECG	Electrocardiography
DWT	Discrete wavelet transform
TOFD	Time of flight diffraction
c, d, f	Confidence, dependencies and falsehood
SOM	Self-Organizing Map
SRMR	Speech-to-reverberation modulation energy ratio

1 Introduction

A signal is defined as an electrical or electromagnetic current that is capable of carrying data from a device or network to another. Each signal incorporates data fed into the signal using certain modulation techniques [132]. Signals can be analog/continuous and digital/quantized. Sound, motion, images, videos etc. are some examples of signals. A signal system takes input and output signals along with mathematical representation of characteristics like frequency and time upon which the signal system depends. Information in a signal is often followed by undesirable disturbance which is termed as noise [17]. Preventing noise in the signal leads to signal integrity, which also leads to better signal quality. When the desired signal is separated from noise, it leads to signal recovery. Signal quality refers to the quality of how good the information is received [67]. It depends on the interference existing in a signal. Since noise leads to loss of data. Lesser the noise, better the signal quality. Signal quality depends on several factors like signal towers (cellular towers for example), tower load, traffic, cosmic events, low energy, physical barriers, competing signals, weather, signals going through other components. Hence, there is a **need to strengthen the quality of signals** in transmission.

In the past years, there have been **several methods proposed to enhance the signal quality**. Sinderby et al. [92] used the double subtraction technique to enhance signal quality in esophageal recordings of diaphragm electromyogram. Considering the bipolar electrode position with respect to the diaphragm centre, the active region of diaphragm is filtered to different degrees, such that the filtering effects are reduced using the double subtraction technique. Gannot [32] proposed a signal enhancement technique using Beamforming and Non-stationarity with respect to speech signals. A sensor array was considered to ensure arbitrary transfer functions for signal enhancement. The algorithm was applied to speech enhancement in a reverberating room. Czyżewski and Królikowski [24] came up with a neuro-rough hybridisation technique applied to audio signals for processing. The idea is to estimate statistics of corrupting noises by analysing signals, after which noise estimation may enable the determination of masking thresholds for noise inaudibility.

Johnson [45] proposed the Bionic Wavelet transform (BWT) for speech signal enhancement. Vullings et al. [122] suggested an Adaptive Kalman Filter for ECG signal enhancement. Bayesian framework was used to develop a sequential averaging filter that may flexibly vary the number of complexes based on the ECG signal characteristics. This filter has the form of adaptive Kalman filter and Bayesian evidence function is maximised for measuring noise covariances. Rahman et al. [85] proposed Wavelet transform for Enhancement of Electrocardiogram signal by noise filtration. Praveen et al. [84] performed signal quality enhancement using the Time of flight diffraction (TOFD) technique. Discrete wavelet transform (DWT) thresholding has been used to de-noise TOFD signals from Austenitic Steel welds. Veras et al. [121] suggested speech quality enhancement by using the technique spectral subtraction, which deals with late components and reverberation effect. Bouserhal et al. [21] presented adaptive filtering and artificial bandwidth extension techniques for speech quality enhancement, since the limited bandwidth of bone and tissue may lead to degradation of quality of speech signal. Artificial Bandwidth Extension technique may degrade overall performance of the system [83]. Du et al. [30] performed signal quality improvement for Human Motion Analysis.

In signal processing, information is regularly questionable or uncertain in the sense that every single genuine datum is not really fresh, exact, and deterministic as a result of their fluffy nature. A large portion of these issues were explained by various hypotheses, right off the bat by Fuzzy Set (FS) [132], Intuitionistic Fuzzy Set (IFS) [17], and **Neutrosophic Set** (NS) [95, 96, 123]. In NS, all components have a degree of truth, indeterminacy and falsity between [0, 1], which depicts the interval which consist of range of discrete values [26]. NS has been applied to various problems in decision making [28] such as in supplier selection [5, 18, 20], linear programming problems [2, 19], Strategic Planning [3], Big Data Analysis [4, 6], e-government website evaluation [7], smart city [1], link prediction [118], stock analysis [43], and others [8, 9, 11–13, 15, 22, 23, 25, 27, 42, 50, 59, 60, 69–71, 74–79, 81, 82, 89, 111, 116, 119, 124, 126–131, 133].

Regarding signal processing, Guo et al. [36] suggested a novel neutrosophic approach to image denoising using γ-median-filtering operation. The idea is to decrease the set indeterminacy for noise removal. Mohan et al. [63, 64] proposed nonlocal neutrosophic approach for denoising magnetic resonance images (MRI) using Wiener Filtering. Mohan et al. [65] proposed an image denoising technique using neutrosophic approach and Wiener filtering operation to decrease set indeterminacy for noise removal. The authors again in [66] analysed the performance of neutrosophic approach to remove Rician noise from magnetic resonance image. Mohan et al. [61, 62, 67] compared the filtering methods for removing Rician noise from MR images based on NS.

Neutrosophic approach has been used effectively in the past for eliminating noise from images. Jha et al. [44] proposed a novel neutrosophic image segmentation technique using dice coefficients on basis of Max-Min normalization, activation functions and membership functions. Guo et al. [34] suggested another image segmentation approach based on neutrosophic c-means clustering and indeterminacy filtering. Similarly, a color image segmentation approach was offered by Guo et al. [35] using neutrosophic adaptive mean shift clustering. Other image segmentation techniques involve wavelet and data-driven neutrosophic fuzzy clustering [125] and discrete wavelet transform [16]. Texture based image segmentation using neutrosophic clustering [51] has also been proposed. Neutrosophic logic also finds its applications in medical imaging. It has been used in segmentation of breast ultrasound images [58, 72]. While there are several image segmentation techniques involving neutrosophic sets, the domain pertaining to enhancing the quality of signals still remains unexplored. Therefore in this paper, we introduce a new neutrosophic approach that would enhancing quality of signals.

The previous related works have the following major issues while reducing noise in signals: Studies are based on assumptions like double subtraction and reduced influences over the signal but not proposition in reducing noises in absolute forms. Most of the studies are confined only to frequency domain; therefore, they did not address any resolution about the time domain. In other related works, noises were assumed to be non-stationary which alters the accuracy. Most importantly, most of the previous works has many assumptions; due to this, they have ignored source signal interference and also some signals were lost during transmission. For instance, many digital communication systems like FSK and PAM did not deal with transmission impairments occurring while a signal is propagating through a particular channel. The noise and error at the receiver's end and during the transmission of a signal varies. In addition, signal strength varies from one end to the other end varies substantially while transmitting. Due to this, parametric values of noise error reduced at the receiver's end differs. In order to resolve this conflict, Neutrosophic approach should be used as it has the potentiality of being a general framework for uncertainty analysis in datasets. For more details of the related works, see Table 7 in Appendix.

This paper **proposes a new Neutrosophic approach to reduce noises and errors in signal transmission**. The **contribution of this paper** is stated as follows. Three membership functions are defined to account for the truth, indeterminacy and falsehood of a system. Each of these three functions takes discrete values in the interval [0,1]. Confidence function is used as the truth membership function, which is associated with sampled time intervals. It is because for the entire transmission and receiving process, it should be always confident that time taken by the signal will be negligible compared to the distance. Then, we define a Dependency function at each time interval for the frequency of transmitted signal. This can be checked in different signal stations between the source and destination. In order to recover digital signal at the receiving end, frequency depends on the Nyquist rate. Therefore, if the energy or frequency of the signal drops below the Nyquist rate, Confidence function decreases which need to amplify the signal. Finally, a Falsehood function, which indicates the loss in information due to amplitude distortion, is defined. This function shows how much information has been lost. Our objective is to minimize the falsehood function. To minimize the errors, we use several neutrosophic systems.

The rest of the article is structured as follows: Section 2 presents the proposed work. Section 3 describes the result and discussion as well as comparative analysis with exiting work and lastly, conclusions and further works are explored in Section 4.

2 Proposed work

2.1 Ideas

Let the Neutrosophic set (A) be defined using three components as $A \Rightarrow \{c, d, f\}$ where c - > confidence, d - > dependency, f - > falsehood. All the three components are intended to be degrees of neutralities with values in the set [0, 1]. In this paper, we propose an ideal spectrum for signal transmission over the channel using carrier systems. This can be better understood by the following analogy: “A is the opposite of Anti A”. Here, the term Anti A refers to $\underline{A}$ or its complement, not negation. However, if we use a term “Non A” instead of Anti A, it has a different meaning but still it is not the negation of A. Thus, we denote “Non A” as “Neut A” to define neutrality throughout this paper. This concept is the basis of Neutrosophic philosophy wherein nothing is defined as false or negation of any system. **We define neutralities (Neut A) as consistent logic** to characterize many logical statements defined as Confidence (c), Dependency (d) and Falsehood(f). C depends on whether “Neut A” is neutral or not, D indicates if “Neut A” is “Non A” and whether it is dependent on A or “Anti A”, F depends on if “Neut A” is very false or not. In practical situations, it is not possible for “Neut A” to be false, as it represents a null system. Therefore, we do not define any Falsehood function for our model.

In signal transmission, it is impossible to get the perfect message signal in the source as well as destination. Both sampling and quantization are used to break down the signal into corresponding amplitude and frequency components. Here, **we define the time domain as the truth membership function or confidence function** (F). As the time domain does not change during the transmission of signal, we use the Confidence to denote the truth membership function. The reason is that, in any signal processing the time domain is consistent throughout communication for which we have used Confidence as a membership function (which as per the Neutrosophic theory is “Truth membership function”). In addition, we define the quantized amplitude levels as the indeterminacy function or dependency function (D) because amplitude levels are mostly indeterminate because of noise interference and depend on a lot of factors during transmission.

Finally, as the frequency domain is just the reciprocal of the time domain and hence the falsehood function is Anti of the truth membership function. We use Confidence, Dependency and Falsehood instead of standard definitions as they are relatable and easy to understand. Therefore, we define Falsehood function F to be the frequency domain set. Our overall **objective is to minimize the amplitude and frequency loss** over the entire time span of signal transmission. In this paper, we focus on Signal Systems on the classical domain interval of [0, 1]. Let X be the universe of discourse, or the domain of the signal being transmitted. Then, Neutrosophic set N is as follows:

$$N = \{< c(x), d(x), f(x) >\} \mid c{\in}C; d{\in}D; f{\in}F \mid \forall x{\in}X \Big\} \tag{1}$$

where $c(x)$ is degree of confidence for x, $d(x, y)$ is degree of dependencies between two components, $f(x)$ is degree of falsehood over component x. X is the universe of discourse, and N is the Neutrosophic set.

2.2 Correlating signal and systems with neutrosophic theory

2.2.1 Sampling

Before transmission of any signal, it is important to digitize it so that the message could be transmitted through long distances with very less noise interference and ensuring data consistency [52]. This is a crucial part of signal transmission as it necessary to have uninterrupted communication throughout the globe. The first step towards digitization of a signal is called sampling. Here, we take different samples of the time-varying signal at different times to convert the signal into discrete time domain signal. Sampling is usually done in the Nyquist Rate so that the corresponding signal can be recovered at the receiver end. The Nyquist Theorem states the sampling frequency (f_c) should be at least twice the largest frequency component of the message signal (f_m). Mathematically, it can be represented as:

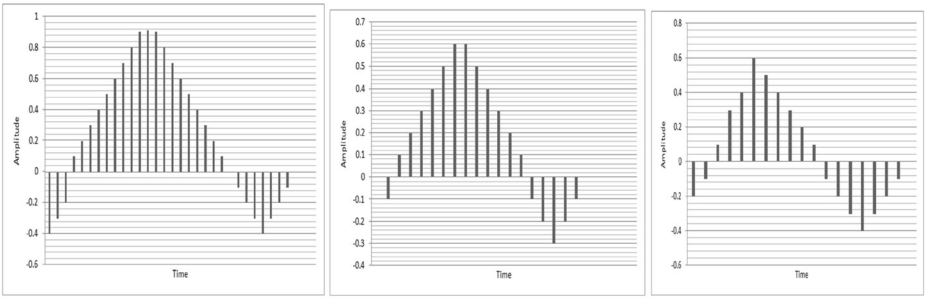
$$f_c \geq 2 * f_m \tag{2}$$

During signal transmission, there can be **many distortions**. Some of them are:

a). *Aliasing:* If the sampling frequency f_s are less than the Nyquist rate, then the corresponding higher and lower frequency band components overlap. In this case, it is the message components are distorted unable to be retrieved in receiver end.
b). *Jitter:* This occurs due to imprecise time domain sampling due to deviation.
c). *Noise:* Various noises including analog, digital, thermal sensor noise etc. can be introduced unknowingly due to bad media or equipment.
d). *Non-linearity:* Non-linearity applied in the signal transmission while sampling can have a dramatic effect over transmission.
e). *Quantization:* Signal loss due to imprecise quantization levels for different signals can also affect the transmission.

In order to reduce these distortions, it is important to sample the signal properly, check the medium of transmission and the intermediate equipment used to reduce unwanted noise. From Fig. 1 (a, b and c), while a signal is delivered from the source (or even coherent source); the signal is assumed perfectly sinusoidal. However, at the receiver's end we may not receive the same perfectly sinusoidal signal due to above distortions. In order to change from consistent time to discrete time domain, we may use ideal sampling, which is practically not possible as no equipment can sample at an infinitely small-time interval. Practically, we use **Flat-top sampling method**, which is less affected by noise and distortions. This method uses a specific time interval and samples all components within that interval. Because the top of the samples is flat, their amplitudes are constant at a specific interval. Noise can be easily removed if the samples have a flat top. It is often called staircase sampling due to its resemblance to a staircase.

In order to change over a flag from consistent time to discrete time, a procedure called examining is used. Examining is the process of acquiring flat top samples out of a given signal (Fig. 2 and Table 1). A flag represents a particular flat top time interval called as λ. Flat-top sampling safeguards the entire data in the flag even if there are slight changes due to noise. However, we need to check at the most extreme intervals of the frequency domain to ensure a better end-to-end communication. It is important to notice that while transitioning from higher to lower flag or vice versa, in the above curve, there is minimum loss in data transmission,



(a) (b) (c)

Fig. 1 **(a, b, c).** Different Sampling Methods Adopted for Digital Signals. **(a).** Ideal sampling; **(b).** Flat top sampling; **(c).** Natural Sampling

which indicates better support for varying pitches. This phenomenon is called **association** in which on leaving each segment in the first flag and select a low testing recurrence. If the flag contains high recurrence segments, we should test the flag at a higher rate to abstain from losing data in the flag (Fig. 3). If the flag at the recurrence or the sampling rate is less than the Nyquist rate then the frequency components will overlap resulting in a ceaseless time flag, which shows association. Association happens in light of the face that flag frequencies can cover if the testing recurrence is too low. The exhibition of testing the first flag in the figure below is made out of three sinusoidal signals, each with an alternate recurrence and adequacy [56].

During sampling, we divide the time domain into different time quanta λ, resulting in some form of indeterminacy in the signal as loss in message is introduced. We also have to assume that the sampling rate is equal or greater than the Nyquist rate so that the signal can be regenerated at the receiver side. Table 1 denotes different encoding levels defined for the

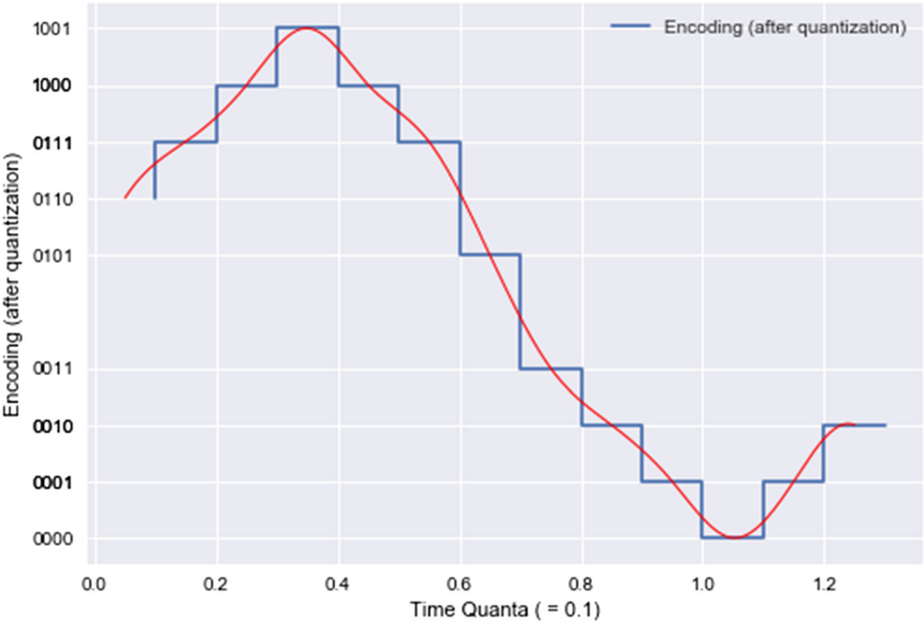
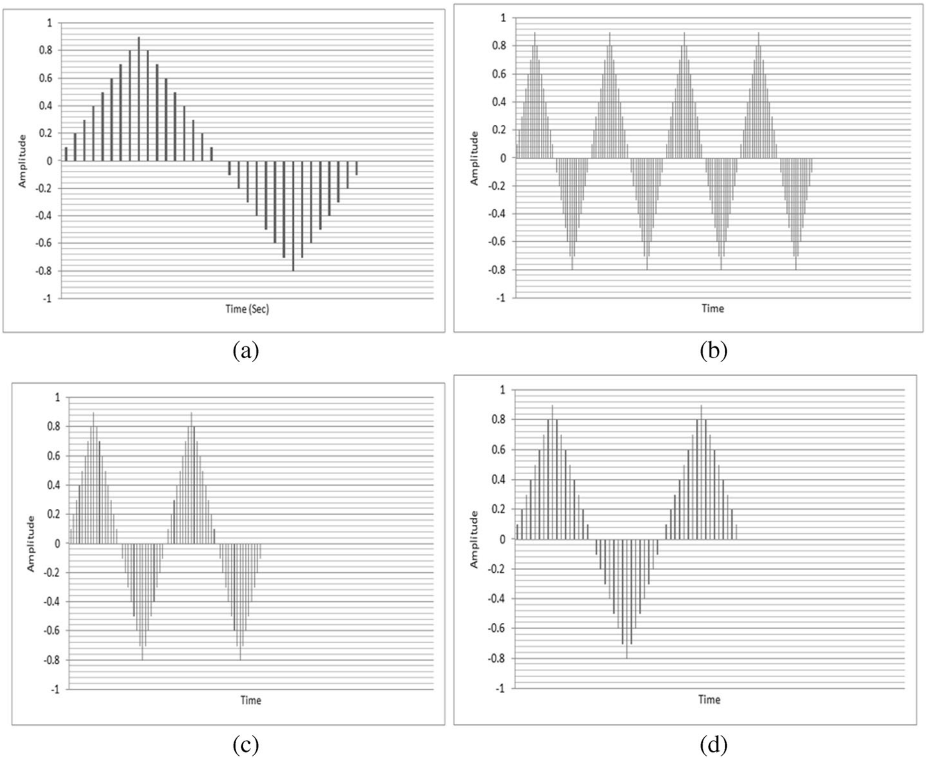


Fig. 2 Encoding after quantization

Table 1 Encoding of Different Amplitude in each time Quanta

Time Quanta ($\lambda = 0.1$)	Encoding (after quantization)
0.1	0110
0.2	0111
0.3	1000
0.4	1001
0.5	1000
0.6	0111
0.7	0101
0.8	0011
0.9	0010
1.0	0001
1.1	0000
1.2	0001
1.3	0010

amplitude levels for digital transmission of the signal. These amplitudes were encoded during the experimentation through "spectrum analyzer" in our research, and hence we incorporated the results for defining the "Confidence" vector. Since Neutrosophic set is based upon three membership functions, so it has to be within the range of [0,1]. But if we bluntly apply the



(a) (b) (c) (d)

Fig. 3 Different Sinusoidal Waves with different ranges of frequencies. **(a)** 3 bit depth, 1 cycle; **(b)** 3 bit depth, 6 cycle; **(c)** 3 bit depth, 22.5 KHz sample rate**; (d)** 3 bit depth, 43,500 Hz sample rate crisp value from 0 to 1, the training and testing will go yielding out indefinite results. Hence, Nyquist rate has been used to bound the crisp values.

Here, **we use the Confidence function to represent the samples taken**, as we are content that the time domain will not change throughout the entire course of transmission. We know that frequency is the reciprocal of time interval. Therefore, we can say **frequency is anti-time, which is the Neutrosophic philosophy**. Then we define the Falsehood function in term of frequencies of each time interval.

2.2.2 Quantization

In order to make a discrete time signal into a digital time signal, we quantize the amplitude levels to take on only certain levels. This helps representing the samples in [0, 1]. We can use binary numbers to represent these quantized samples and send them through a digital channel using PAM modulation [52]. Binary signals are easy to interpret, detect and manipulate. However, to represent higher amplitude signals, a large number of binary digits is needed. For preserving the original message signal, the number of quantization levels should be increased. Let N be the number of quantization levels. We can represent 2^N states. If quantization is not done, the amplitudes can take values from 0 to infinity and therefore cannot be represented in digital form. All digital systems use quantization to transmit their signals by adding another layer of indeterminacy in the form of amplitude levels. The parameters set by the station are taken and used to define the Dependency or Indeterminacy function (Fig. 4).

Therefore, every digital system samples the transmission signal in the time axis by using flat-top sampling. Then, the **sampled signal is digitized using a technique called**

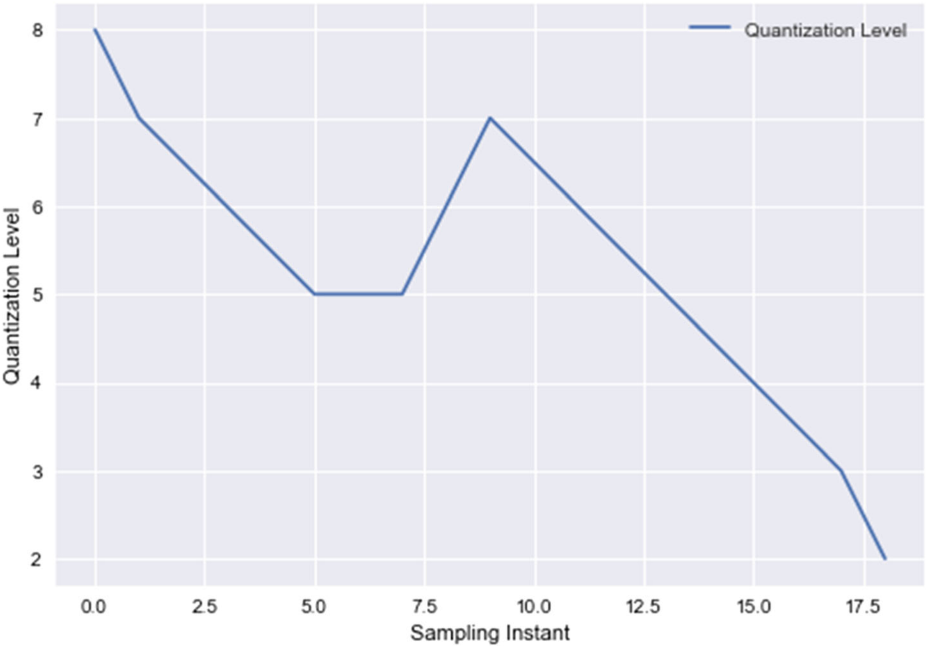


Fig. 4 Representation of Sampling and Quantization in Signal Processing

quantization, which assigns discredited the amplitude levels. Quantization usually helps in lossy data compression algorithms where the purpose is to manage distortion within the limits of the bit rate supported by a communication channel. To achieve this, we **use Rate-distortion optimization technique**, which involves a huge amount of digitized signal data to represent the output of a quantizer. Quantization can be applied on audio signals with varying noise and error easily. Quantization can be viewed as the path towards changing over basic signs or information casing into a propelled course of action, which can be appreciated by electronic devices (Table 2). Due to advances in computational technology, we can use programming to manipulate digital signals and visualize them properly as all systems work on two states i.e. binary states. It is now even possible to represent large information systems such as pictures, voice, video etc. in digital form and transmit through channel mediums at large places without interruption. We are also capable of harnessing the power of parallel computing for transmission of signals through parallel threads ensuring faster communication.

2.2.3 Encoding

Encoding is the process of representing the quantized samples into binary digits to be transmitted in the channel or medium (Fig. 5 and Table 3). Therefore, if there is some error or noise which affects the signal in between transmission, the binary encoding of resulting signal will be affected as well. To reduce this, we **use Frequency Shift Keying** (FSK) technique to **shift the frequency** in various frequency ranges and use **Confidence and Dependency vectors** to define the Falsehood in each part. This is done by applying a Gaussian filter over the frequency domain of the signal to make the transitions smoother. The one-dimensional Gaussian filter to produce the Falsehood function is given as:

$$g(x) = \sqrt{\frac{a}{n} e^{-ax^2}} \tag{3}$$

where x denotes the time in the propagated signal, coming from the Confidence and Dependency vectors. Here, the **Neutrosophic approach is used in FSK** in the sense that shifting frequency does not affect the original message. This is the analogy to be taken that "A is the opposite of Anti A". That is, frequency shifting is just the opposite of time shifting. Alternatively, they are just reciprocals of each other.

Table 2 Quantization for sampling Instant

Sampling Instant	Quantization Level
0	8
1	7
3	6
5	5
7	5
9	7
11	6
13	5
15	4
17	3
18	2

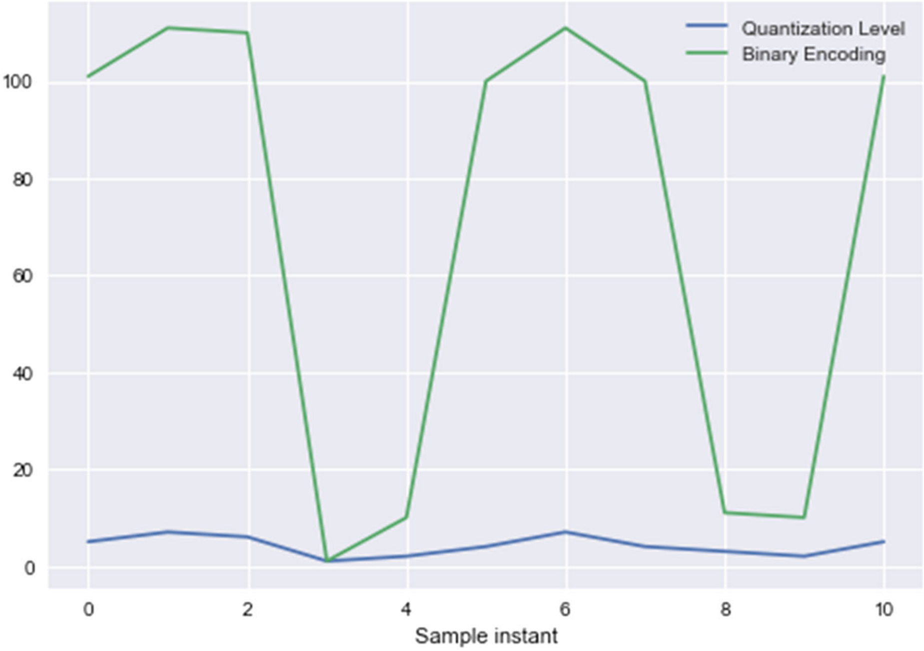


Fig. 5 Representation of sampling instant and binary encoding

It is found that using Morphological filters after quantization helps in encoding the signal in a better form without any error [88]. Fig. 6 shows the pipeline of our entire system.

2.3 Applying new neutrosophic approach in signal loss

A Neutrosophic process is based on the philosophy that there are no or few assumptions to consider while optimizing any solution [54, 73]. We define that there are no false segments in transmission signal and therefore any kind of noise can affect our signal when it reaches the destination. The proposed model assumes that the signal transmitted is a standard signal such as a sinusoidal wave and follows Dirichlet's conditions on Fourier analysis.

Table 3 Binary Encoding of each quantized sample

Sample instants ($\lambda = 1$)	Quantization Level	Binary Encoding
0	5	101
1	7	111
2	6	110
3	1	001
4	2	010
5	4	100
6	7	111
7	4	100
8	3	011
9	2	010
10	5	101

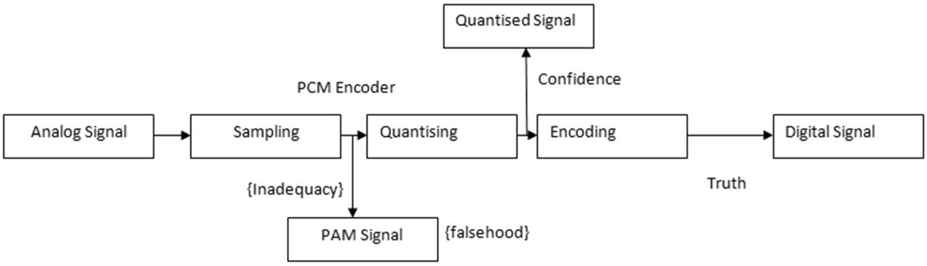


Fig. 6 General Pipeline of Signal Processing

In Fig. 7, the Nyquist rate is taken to be 50 Hz. In the first figure, the input is a full sinusoidal wave with sampling frequency 100 Hz, which is greater than the Nyquist rate. This indicates there is no loss in terms of frequency in this, and therefore the Falsehood function F is undefined. The sampling rate is 50 Hz, which is equal to Nyquist rate. It is not subjected to any loss but may be prone to other kinds of noises. The sampling rate is 25 Hz, which is lower than the Nyquist rate. Hence, we **define the Falsehood function to account for the errors in the**

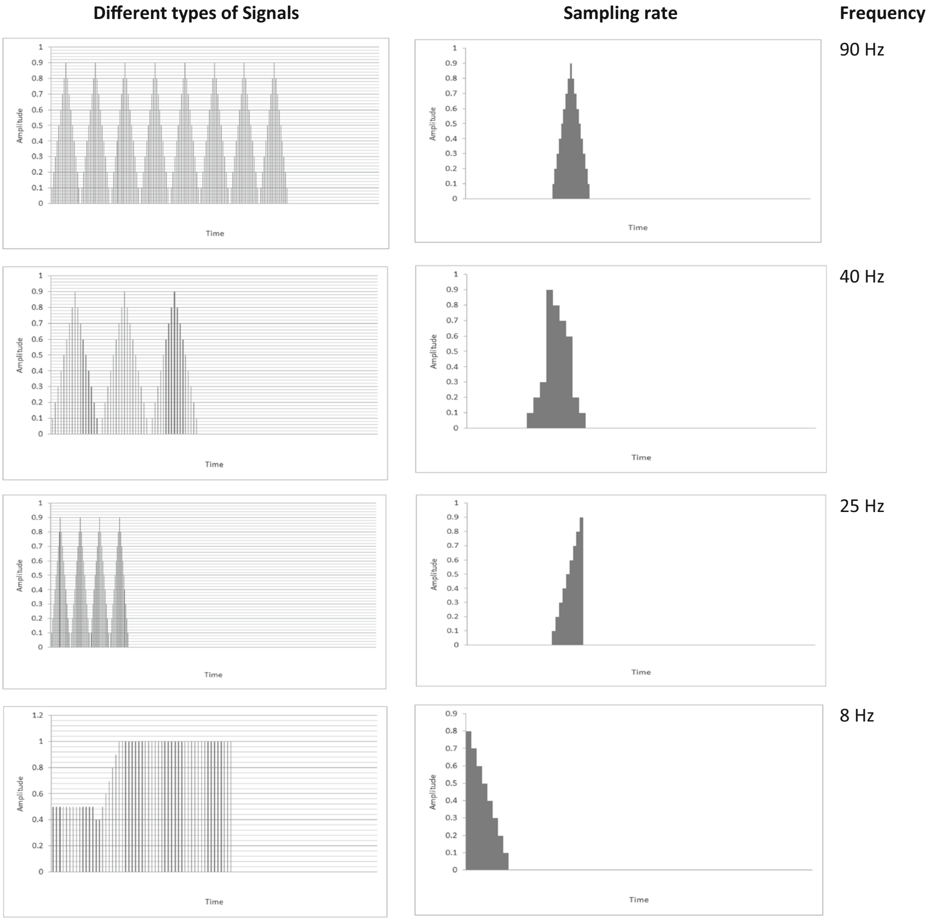


Fig. 7 Sampling outputs for different types of signals with noises

frequency domain. Likewise, the sampling rate is much lower than the Nyquist rate, which therefore penalizes the original signal a lot, in which case we need to use a strong carrier for better optimization of the original signal.

Let $Z_i \in [Y_L, Y_U]$, where Y_L represents the minimum amplitude of message signal and Y_U represents the maximum amplitude and i represents the discrete signal variable such frequency or amplitude. We **define the confidence set as the time interval set**, or simply put, the set of all sampled time intervals. We choose this as the confidence set because throughout the entire transmission, time interval will not change at all, as time is an internal factor and cannot be manipulated. We **define the dependency set as the quantized levels of amplitude** after we apply the rate-distortion quantizer technique to quantize all amplitude set as amplitude of the signal may vary due to different noises in the channel. Thus, it depends on the channel and other factors contributing to amplitude distortion.

We also define **the falsehood set to be the frequency components of the digitized signal**. As frequency is an intricate factor of the signal and is the reciprocal of time itself, frequency is defined over the time span of the signal transmission.

In Fig. 8, it is clear that we define the Confidence Set after quantization. The message signal is first passed through a device called Sampler in Stage 1, which samples the time domain and use it to define the Confidence set [31, 120]. In Stage 2, the sampled signal is passed through a device called S/H quantizer, which quantifies the amplitude domain into various quantization levels with step level α. We use it to define the Dependency set for further investigations. We **define the Correlation coefficients** for Neutrosophic sets as follows:

$$C_{NS}(A,B) = \frac{1^{*}}{n} \sum_{i=1}^{n} \frac{min[C_A(x), C_B(x)] + min[D_A(x), D_B(x)] + min[F_A(x), F_B(x)]}{\sqrt{C_A(x)C_B(x)} + \sqrt{D_A(x), D_B(x)} + \sqrt{F_A(x), F_B(x)}} \tag{4}$$

where the symbol "min" is the minimum operation. Using above definition, we conclude the following properties about the correlation coefficients.

$$0 \le C_{NS}(A,B) \le 1 \tag{5}$$

$$C_{NS}(A,B) = C_{NS}(B,A) \tag{6}$$

$$C_{NS}(A,B) = 1 \text{ if and only if } A = B \tag{7}$$

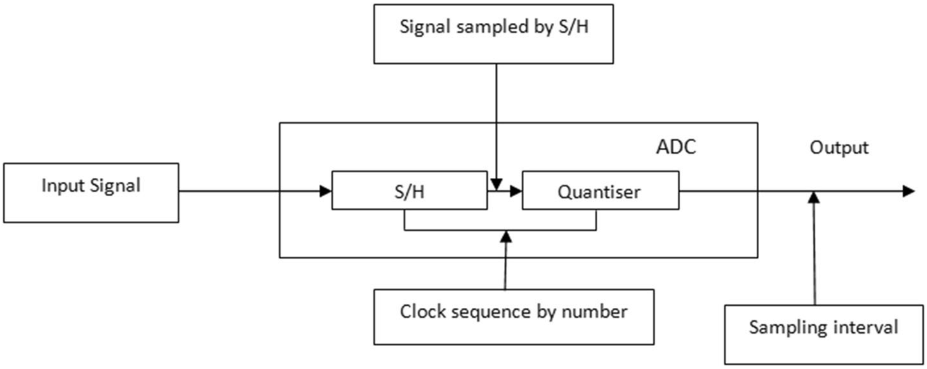


Fig. 8 Confidence Set after quantization

Now, after defining confidence, dependency and falsehood observations, let us **define a metric for computing the average amplitude over a time span** denoted as $\mu_x \in \{\mu_{lower}, \mu_{upper}\}$. Here, μ_{lower} and μ_{upper} denotes the average amplitude of the lower band and upper band of signal over time T, where T is the time period. For noise cancellation, we need to compute $\mu_x$and μ_y, which denote the average frequency and amplitude over the entire time span of transmission. By computing this, we get to know the average loss in frequency and amplitude and we can compare it with the original message and the received message. We compute these values after applying the confidence and dependency components with that of the carrier and then justifying the degree of falsehood.

Assume $Z_{xi} \in \{Y_{lower}, Y_{upper}\}$ do not have an absolute value between [0,1]. We take the upper bound Y_{upper} as 1 and the lower bound Y_{lower} as 0. We now **define the new Neutrosophic approach for signal** as:

$$L_{xi} = \frac{\sigma_x^2}{d^2} \tag{8}$$

$$d = \left(Y_{upper} - Y_{lower}\right)/2 \tag{9}$$

where L is the loss of the transmitted signal and σ is the variance in error of the Confidence vector after transmitting the signal samples. As the error can occur in any time, we take a cumulative sum of all the time domains to define the total loss. Here, d denotes the time span during which the error occurs. According to the Shannon theorem and applying the estimated Neutrosophic for signal loss, we **define the signal loss** as,

$$L_{xs} = \frac{\sigma_x^2}{d^2} + \frac{\mu_x^2}{d^2} \tag{10}$$

where σ_x^2 and μ_x are the standard deviation and mean of frequency and amplitude after noise respectively. In eq. (10), as the exact loss cannot be calculated over the entire time span, we calculate the mean and deviation of the cumulative errors occurred and hence we get an approximate model for the loss. According to the Neutrosophic loss theory [96], the loss on signal is defined:

$$L_{xi} = \frac{SNR_x^2}{d^2}, x \in [0, 1] \tag{11}$$

$$SNR = \frac{Z_{x1}}{L_{xs}} \tag{12}$$

The above approach reduces any impairment that may have been added to the original carrier frequency. Here, Neutrosophic Loss defines the true loss according to our proposed algorithm and is calculated by taking the Signal to Noise ratio (SNR) between the original quantized signal values and Shannon's signal loss (Noise) values. The quantized values are calculated using Neutrosophic approach by computing the Confidence, Dependency and Falsehood sets, incorporating neutrosophication in the loss. Neutrosophic sampling plan can be reduced by limiting quality level. For this, we propose the following steps to minimize the noise and maintain the results using confidence, dependency and falsehood components.

1. Minimization by unpacking the Neutrosophic set:
   $Z_x \in \{Y_{lower}, Y_{upper}\} \in [0, 1]$ Provided $Z_x \in \{Y_{approxlow}, Y_{approxhigh}\}$
2. Tabulating the results and analyzing the carrier signal and the receiving signal.

The proposed algorithm is given as follows:

```
Input: Normalized signal parameters (amplitude, frequency) in range [0,1]
Output: Neutrosophic Loss $L_{xi}$
  1. Select a signal.
  2. Calculate the upper bound and lower bound from amplitude and frequency after
     quantization and calculate Shannon's Loss (approximate) by equations (8-9):
         $L_{xi} = \frac{\sigma_x^2}{d^2}$
         $d = (Y_{upper} - Y_{lower})/2$
  3. Obtain two parameters below:
     a. $Z_{xi} \in \{Y_{lower}, Y_{upper}\}$
     b. $A_{xi} \in \{Y_{approxlow}, Y_{approxhigh}\}$
  4. Apply Neutrosophic operations:
     a. $M_{xi} = \rho\left\{\widehat{Y_{lower}} \leq \widehat{Y_{upper}};\ \underline{Z_{xi}} \in \{\widehat{Y_{lower}} \leq \widehat{Y_{upper}}\}\right\}$
     b. $S_{xi} \in \{Y_{lower}, Y_{upper}\}$;
     c. $P_{xi} \in \{Y_{approxlow}, Y_{approxhigh}\}$
  5. Calculate neutrosophic memberships {c, d, f} from the results obtained in step 4
     a. ⍰ $=$ ⍰⍰⍰$(\widehat{Y_{approxlow}}(t), \widehat{Y_{approxhigh}}(t))$
     b. ⍰ $=$ ⍰⍰⍰$(Time(\widehat{Y_{lower}}(t), \widehat{Y_{upper}}(t)))$
     c. $f = max\ (freq(\widehat{Y_{lower}}(t), \widehat{Y_{upper}}))$
  6. Calculate Neutrosophic Loss using {c, d} calculated in Step 5 and Shannon's Loss in Step
     2 by equation (10):
         $L_{xi} = \frac{SNR_x^2}{d^2}, x \in [0,1]$
```

3 Experiments

In this section, we present the experimental results on the sampled and encoded data for a Sinusoidal wave (Fig. 9) where the sampling interval λ is 0.1, the quantization step-level Δ is

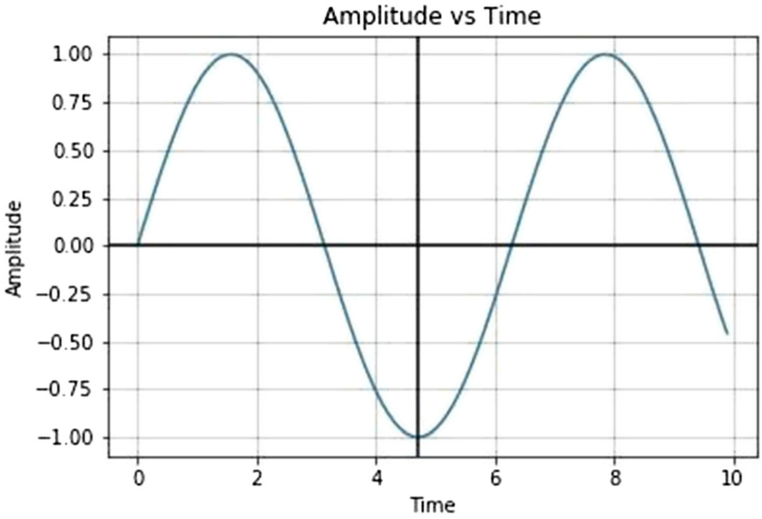


Fig. 9 Sinusoidal Wave Passing through Origin

1 (which creates 8 quantization levels). We find that the Loss is around 0.9% even after noise interferes with the signal. The parameters used were selected after doing many tests and finetuning the model and the best of all were selected. Here, we assume that the Confidence function returns a value of 1 as the source is at a finite distance from the destination. From Table 4, for two-time intervals of the same signal, we can compute the upper band amplitude and lower band amplitude and calculate the loss. The first column represents the time interval sampled from the received signal. The second column represents the asymmetry between the upper band and lower band in terms of amplitude. From the table, we see the difference of the lower and upper bounds along with the Confidence vector Z_{xi} and Dependency vector Z_{x2}. The upper and the lower bounds vary from 33% and are decreased down to 0.05%. The loss in amplitude and frequency also goes down at each time step, which is better than the existing results.

Table 4 Results after calculation of Loss using the proposed algorithm

Z_{x1}	Z_{x2}	Y_{lower}	Y_{upper}	Loss
0.1	N/A	N/A	N/A	N/A
0.2	[77, 119]	0.0114	0.9503	0.0927
0.3	[11,08]	0.0121	0.8892	0.0922
0.4	[0.,18]	0.0128	1.010	0.0951
0.5	[07, 19]	0.0134	1.0101	0.0978
0.6	[09,13]	0.014	1.0101	0.0954
0.7	[04, 09]	0.0142	1.0101	0.0971
0.8	[05,12]	0.0148	1.010	0.0971
0.9	[15, 53]	0.0173	1.010	0.0928
0.02	[53, 126]	0.0192	1.010	0.0928
0.03	[95, 96]	0.0197	1.010	0.0971
0.05	[22, 97]	0.024	1.0101	0.0958
0.06	[38, 53]	0.038	1.0101	0.0958
0.08	[21, 63]	0.0152	0.9287	0.0925
0.09	[92, 130]	0.0189	0.9548	0.0955

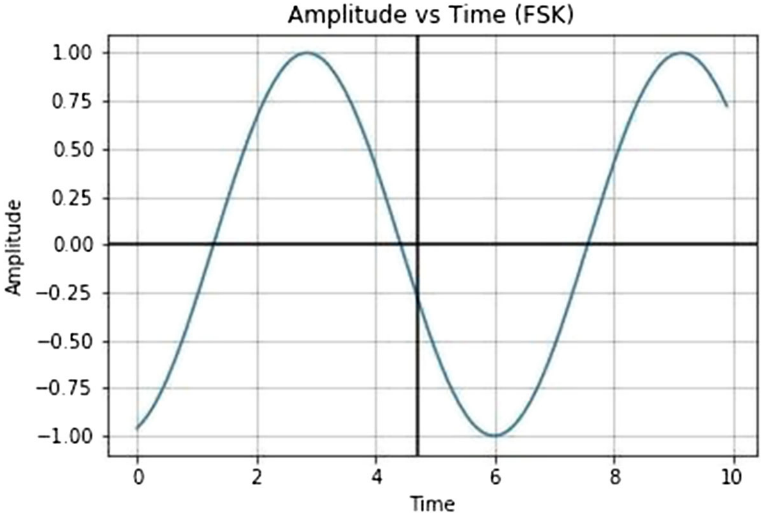


Fig. 10 Frequency Shift of Sinusoidal Wave

Even if the datasets may vary from stations to stations and there may be some uncertainty of suitable sample size used by the vendors and correspondingly a different range of upper and lower bound values, the proposed method has the results of Confidence Vector Z_{x1} and Dependency Vector Z_{x2} being huge improvement over other signal processing and noise reductions methods. Let us shift the frequency range by 5 units more using Frequency Shift Keying (FSK) as shown in Fig. 10, we found that the loss is minimized as the amplitude does not change with time or frequency. Table 5 shows how the loss changes with respect to frequency shift. By applying the proposed approach on wave after sampling, quantizing and encoding, the loss goes down by 0.5%, which indicates that as the source moves towards from the destination i.e. the energy of the wave gets more over time. This tells us the Neutrosophic system has high Confidence (> 1) if the frequency is larger and the amplification of the signal can be done effectively.

Table 5 Results after calculation of Loss using the proposed Algorithm in FSK

Z_{x1}	Z_{x2}	Y_{lower}	Y_{upper}	Loss
0.6	N/A	N/A	N/A	N/A
0.7	[78, 88]	0.0114	0.9503	0.0846
0.8	[103, 109]	0.0121	0.8892	0.0946
0.9	[5.,23]	0.0128	1.010	0.0874
1.0	[22, 129]	0.0134	1.0101	0.0832
1.1	[14, 38]	0.014	1.0101	0.0847
1.2	[09, 14]	0.0142	1.0101	0.0964
1.3	[87, 133]	0.0148	1.010	0.0871
1.4	[109, 128]	0.0173	1.010	0.0847
0.06	[60, 128]	0.0192	1.010	0.0823
0.07	[08,13]	0.0197	1.010	0.0812
0.08	[87, 133]	0.024	1.0101	0.0876
0.09	[14, 128]	0.038	1.0101	0.0932
0.1	[18, 62]	0.0152	0.9287	0.0948
0.12	[27, 122]	0.0189	0.9548	0.0966

Here, Z_{x1} represents the Confidence vector, that is, the maximum quantized amplitude value after sampling. Z_{x2} represents the Dependency vector denoting the observed time interval of sampling. Y_{lower} and Y_{upper} denote the maximum and minimum amplitude values in the observed time interval. The last column represents the final Neutrosophic Loss. For example, for the time interval [77, 119] (Dependency Vector), the sampled amplitude value is 0.1 (Confidence). Y_{lower} is 0.0114 denoting the lowest amplitude in the interval [77, 119] and Y_{upper} is 0.9503 denoting the highest amplitude value. Finally, the neutrosophic signal loss computed is 0.0927 or 9%.

Here the Dependency vector (Z_{x2}) values are shifted by 5 units using FSK and the Loss is calculated denoting there is least error in calculating Loss and proves that neutrosophic approach works well after applying transformations such as FSK.

We also present the results after using a carrier wave with the original signal using PAM modulation technique. We found a tremendous 1% decrease in loss when using a carrier signal as it uses a high frequency carrier wave. This shows that the proposed approach has greater tendency towards decreasing loss due to noise and error in bits when transmitting through digital channels. Fig. 11 and Table 6 show the results after applying PAM techniques.

In Table 6, by applying PAM techniques to the carrier signal and transforming accordingly, the Loss is found to be considerably low denoting that the neutrosophic approach excels the PAM-generated signals.

In Fig. 12, we generate an ideal spectrum of signal transmission over the channel using carrier systems on the Neutrosophic Sets, which is insusceptible of noise. The original message has been tampered using noise. However, by using the proposed method, it is able to generate a smooth transition between error regions that are transmitted easily. This could be done at every station. The message signal passes through to reduce all kinds of noises due to channel such as UV rays and other signals. The new method can be used for any kind of digital communication over large distances as well.

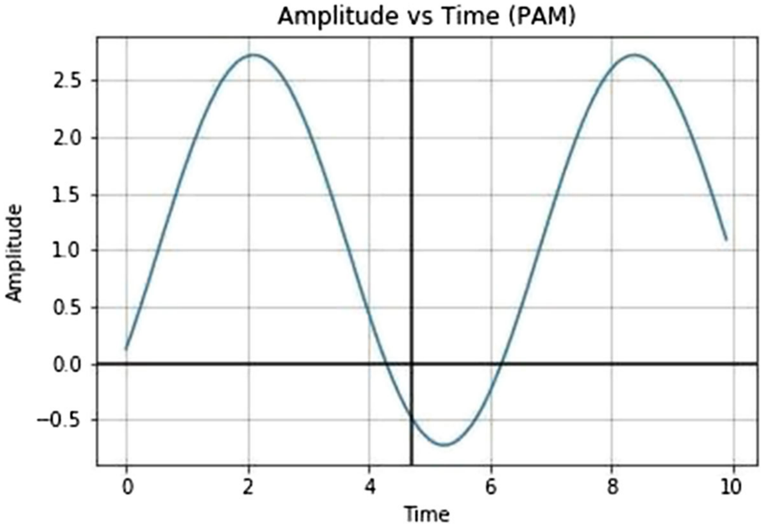


Fig. 11 PAM Modulation of Sinusoidal Wave

Table 6 Results after calculation of Loss using the proposed Algorithm in PAM

Z_{x1}	Z_{x2}	Y_{lower}	Y_{upper}	Loss
0.1	N/A	N/A	N/A	N/A
0.3	[78, 88]	0.1563	0.9648	0.0064
0.5	[103, 109]	0.1587	0.8962	0.0094
0.7	[5.,23]	0.1599	1.126	0.0087
0.9	[22, 129]	0.1633	1.256	0.0087
1.1	[14, 38]	0.1656	1.354	0.0089
1.3	[09, 14]	0.1689	1.387	0.0097
1.5	[87, 133]	0.1752	1.412	0.0097
1.7	[109, 128]	0.1811	1.423	0.0082
1.9	[60, 128]	0.1868	1.489	0.0083
2.1	[08,13]	0.1898	1.5369	0.0081
2.3	[87, 133]	0.1935	1.725	0.0083
2.5	[14, 128]	0.1956	1.741	0.0085
−0.1	[18, 62]	−0.121	−0.568	0.00974
−0.3	[27, 122]	−0.156	−0.756	0.00934

Based on the previous works, a quantitative analysis may be presented as follows:

1. In the experiment conducted by Sinderby et al. [92], it was found that the double subtraction technique was able to yield a variation in spectrum center-frequency value within a range of positive and negative of 10%. There was an increment in the signal to noise ratio by 2 dB. The experiment also led to increasing in number of samples by 50%. These signals were accepted by signal quality index.
2. In the experiment conducted by Gannot et al. [32], there is an increasing in average SNR and noise reduction by 10 dB. A small improvement of 1–2 dB in the measure of SNR was seen of enhanced signal quality.

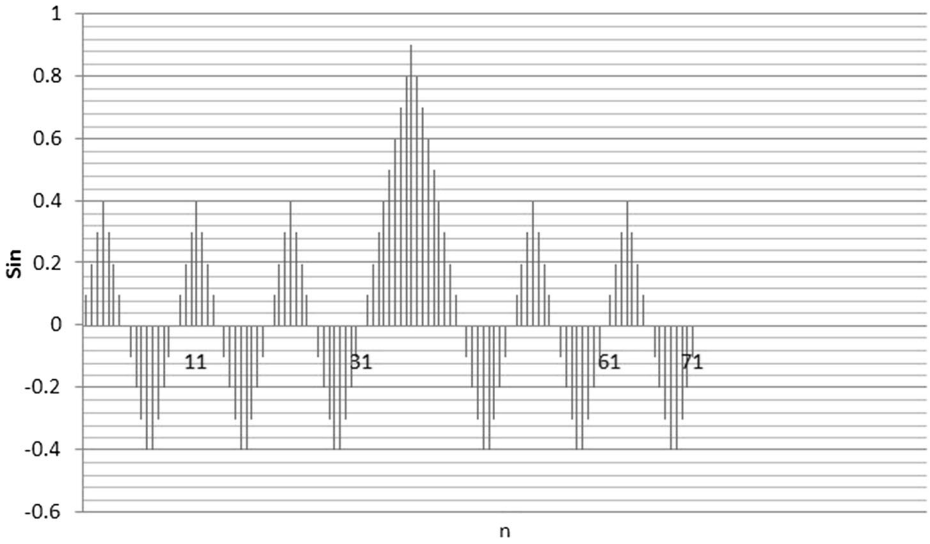


Fig. 12 Final results for Sinusoidal Wave

3. In the experiment conducted by Czyzewski et al. [24], the approaches considered are scalar quantization and vector quantization. Calculating the Spectral flatness measure and Unpredictability measure, it was found that vector data quantization is much more superior in terms of efficiency than the scalar data quantization. Quality of the algorithm is based on selection of the appropriate metric. Unpredictability measure leads to decision accuracy.
4. In the experiment conducted by Johnson et al. [45], it has been observed that thresholding leads to enhanced signal quality, and is compared to other speech enhancement techniques like Ephraim Malah filtering, iterative Wiener filtering, etc. The SNR and SSNR improvements are comparable to Ephraim Filtering, where the Bionic Wavelet Transform gives the best results for noisiest environments that range from -10 dB to -5 dB. The experiment also incorporates subjective measurement using mean Opinion Score at noise environments to yield enhanced signal quality. However, it still less than Ephraim Malah filtering and iterative Wiener filtering, but is significantly better than the scaled wavelet method.
5. In the experiment conducted by Vullings et al. [122], the filter is evaluated using TWA signals, Fetal ECG signals and Neonatal ECG. For TWA signals, the optimal value for which performance of the filter is good exists at -20 dB. Fetal movement leads to a decrease in noise covariance such that noise amplitude remains same but signal amplitude increases. Neonatal ECG enables the newly arriving data to have more impact such that Kalman gain is increased; thus, leading to a better estimation of ECG signals. In the experiment conducted, neonatal ECG signal occurs around 55 s.
6. In the experiment conducted by Rahman [85], it is evident from the analysis that when standard deviation of noise is small in the range 0.044 mV to 0. 09 mV, the best filtration technique is Fast Fourier Transform. When the standard deviation for noise is higher in the range 0.44 mV to 0.9 mV, the best filtration technique was found to be six times the filtering system. Thus, we find that iteration relies on the standard deviation of noise. The quality of filtration is evaluated by percentage rms difference method (PRD) which is smallest as percent of distortion for a high SNR.
7. In the experiment conducted by Praveen [84], DWT thresholding was used for denoising Time of flight diffraction (TOFD) signals. The signals denoised using 36 db were compared to the SNR values obtained for 4db. It is suggested that higher order wavelets provide greater SNR values in comparison to lower order wavelets.
8. In the experiment conducted by Veras [121], it has been validated that the proposed technique is suitable for speech quality enhancement. The suggested algorithm is capable of increasing the metrics for quality assessment CD, LLR, FWSS, SRMR and Q score mapped to Mean Opinion Score by 6%, 2%, 43%, 31% and 15% respectively. Further it has decreased the Word Error rate by 0.9%. Both the datasets considered experience an increased Q-score mapped to Mean Opinion Score by 60% and 50% respectively. Moreover, for real data, Word Error Rate reduces by 14.6%.
9. In the experiment conducted by Bouserhal et al. [21], it is evident how limited bandwidth degrades the quality of speech. Bandwidth extension may not be enough to solve the problem, and therefore the experimental analysis has been conducted using adaptive filtering and a non-linear bandwidth extension method. Both objective and subjective tests have been conducted and both show significant enhancement of signal quality. Statistical results for 95% confidence interval between objective evaluation for different stages is found to be significant ($0.0001 < \rho < 0.01$, $\rho = 0.9413$). Similarly, statistical

results for 95% confidence interval between objective evaluation for different stages is found to be significant ($\rho < 0.0001$ and $\rho = 0.9782$).

10. In the experiment conducted by Du et al. [30], seventeen algorithms were taken into consideration out of which twelve were capable of limiting the calculation time. The proposed technique has been known to address Noise reduction, drift signal prediction estimation, yaw correction during motion analysis. Simple filter algorithms like Low pass filter, high pass filter remove measurement biases, but compensation algorithms like Drift and Offset Compensator and Compensation Method with Temperature or Accelerometer and Magnetometer Data can be used for noise reduction by compensating for gyroscopic errors. Compensation algorithms require resource combination but provide efficiency.

In the proposed method, we can observe how the loss decreases. The proposed algorithm has good performance as shown in the experiments above and is able for signal transmission.

4 Conclusion

In this paper, we proposed a new Neutrosophic approach to reduce noises and errors in signal transmission. Three membership functions are defined to account for the truth, indeterminacy and falsehood of a system. Confidence function was used as the truth membership function, which is associated with sampled time intervals. Dependency function was defined at each time interval for the frequency of transmitted signal. This can be checked in different signal stations between the source and destination. Finally, a Falsehood function was defined to indicates the loss in information due to amplitude distortion. The signal loss is minimized by taking safe sampling rates and quantization levels.

In the experiments, we created an ideal spectrum for signal transmission over any channel by carrier systems such as PAM, which resulted in 1% decrease in loss compared to the original signal without PAM. We also used FSK and described its relationship as to Neutrosophic philosophy with reference to frequency and time domain and observed a decrease of 0.1% if the frequency is shifted to a higher range. This shows the feasibility and applicability of the proposed method.

Our research can be further modified by introducing other factors and optimization techniques. This research has great practical implications on signal transmission and should be adopted for communication without interruptions. Future expansion could lean toward real applications for better demonstration [10, 14, 29, 33, 37–41, 46–49, 53, 55, 57, 68, 80, 86, 87, 90, 91, 93, 94, 97–110, 112–115, 117].

Compliance with ethical standards

Conflict of interest The authors declare that they do not have any conflict of interests.

Human and animal studies This research does not involve any human or animal participation. All authors have checked and agreed the submission.

Appendix

Table 7 Comparative analysis

No.	Authors	Techniques	Results	Parameters	Limitations
1.	Sinderby et al. [92]	Double subtraction technique to enhance signal quality in esophageal recordings of diaphragm electromyogram (EMGdi)	The study resulted in variation of EMG power spectrum center-frequency, increase in signal to noise ratio	Frequency, Signal to Noise Ratio, Signal Quality Index	Change in electrode configuration may lead to alteration in the distance between electrode pairs for the double subtraction, reduced influence of relative changes in the position of the diaphragm centre with respect to the electrode array, study based on assumptions
2.	Sharon Gannot [32]	Signal enhancement technique using Beamforming and Nonstationarity	Microphone speech enhancement algorithm, Increase in SNR and self cancellation leads to better signal quality	Signal to Noise Ratio, Noise Reduction, Averaged Signal to Noise ratio, frequency	Study is confined only to frequency domain therefore no information about the time domain, noise has been assumed to be non-stationary which may alter the accuracy. Assumption that received signals are delayed versions of source signal ignore interference and some signals may get lost during transmission.
3.	Czyżewski and Królikowski [24]	Neuro-rough hybridisation technique applied to audio signals for processing	Hybridisation SOM based quantization and rough set inference is much more accurate in comparison to systems lacking hybridisation. Soft computing techniques improve overall efficiency.	Noise estimation (spectral flatness measure, unpredictability measure), Efficiency	High computational complexity involved in training of neural networks.
4.	Johnson [45]	Bionic Wavelet transform (BWT) for speech signal enhancement	Results are provided for white Gaussian noise as well as other realistic noise environments, Techniques like thresholding, filtering, spectral subtraction lead to enhanced signal quality	Signal to Noise Ratio, Segmental Signal to Noise ratio, Mean Opinion Score	Experiments do not validate that the method is best out of all the methods considered for experimental analysis, therefore it is just a survey
5.	Vullings et al. [122]	Adaptive Kalman Filter for ECG signal enhancement.	In the absence of priori knowledge the filter with adaptive noise estimation performs similar to the filter with optimized fixed noise covariance.	Noise Covariance, Noise Estimation, Signal to Noise Ratio	Kalman filters find their use only in linear state transitions, assumes linear dynamics and Gaussian Probability Distribution Function. Kalman filter may have a slow reaction speed in rapid change situations, Inaccuracy in estimation of measurement noise
6.	Rahma et al. [85]	Wavelet transform for Enhancement of Electrocardiogram signal by noise filtration	For small value of noise standard deviation, best filtration is Fast Fourier Transform, however for large values of standard deviation of noise, best filtration is six time the filtration system	Noise, Frequency, Signal to Noise Ratio	DWT coefficients may not be capable of distinguishing signal shifts and may lead to poor directionality, there may be absence of phase information.

Table 7 (continued)

No.	Authors	Techniques	Results	Parameters	Limitations
7.	Pravee et al. [84]	Signal quality enhancement using the Time of flight diffraction (TOFD) technique	Higher order wavelets have been observed to provide greater SNR improvement with respect to the lower order wavelets.	Signal to Noise ratio, Efficiency	Difficult to perform detection, and identify position and size the signal, TOFD is incapable of detecting the amplitude of diffracted signals for low level sensitivity, if the level is set to high a lot of diffracted signals are exhibited, there may be several mask defects and spurious indications.
8.	Veras et al. [121]	Speech quality enhancement by using the technique spectral subtraction	The metrics involved validate that the algorithm increases the estimated metrics for quality assessment and decreases Word Error Rate for the datasets	Time, Frequency, Speech-to-reverberation modulation energy ratio (SRMR), Cepstral Distance, Log Likelihood Ratio	Residual noise and roughening of speech due to the noisy phase,
9.	Bouserhal et al. [21]	Adaptive filtering and artificial bandwidth extension techniques for speech quality enhancement	Objective and Subjective Evaluation show enhanced signal quality.	Signal to Noise Ratio, Frequency	Adaptive filtering techniques may assume the process dynamics to be linear and may provide only a point estimate, may address only processes with additive unimodal noise. Artificial Bandwidth Extension technique may degrade the overall performance of the system
10.	Du et al. [30]	Study on Signal Quality Improvement Algorithms for Human Motion Analysis Systems	All the algorithms were capable of enhancing the signal quality by reducing signal errors.	Time, Frequency, Temperature, Accuracy	Kalman filter based algorithms may require information from other sensors and work with algorithms for specific applications. Adaptive Based algorithms may require a reference model and some of these algorithms must be used with specific sensors. Simple Filter algorithms are used for single simple function may need to be combined with other algorithms for better result.

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