# Extension to Fuzzy Logic Representation: Moving Towards Neutrosophic Logic - A New Laboratory Rat

A.Q.Ansari
Department of Electrical Engineering
Jamia Millia Islamia
New Delhi, India
aqansari@ieee.org

Ranjit Biswas
Department of Computer Science
Jamia Hamdard (Hamdard Univ.)
New Delhi, India
ranjitbiswas@yahoo.com

Swati Aggarwal *
Department of Computer Science
ITM University
Gurgaon, India
swati1178@gmail.com
*Corresponding author

*Abstract*— **Real world problems have been effectively modeled using fuzzy logic that gives suitable representation of real-world data/information and enables reasoning that is approximate in nature. It is quite uncommon that the inputs captured by the fuzzy models are 100% complete and determinate. Though, humans can take intelligent decisions in such situations but fuzzy models require complete information. Incompleteness and indeterminacy in the data can arise from inherent non-linearity, time-varying nature of the process to be controlled, large unpredictable environmental disturbances, degrading sensors or other difficulties in obtaining precise and reliable measurements. Neutrosophic logic is an extended and general framework for measuring the truth, indeterminacy and falsehood-ness of the information. It is effective in representing different attributes of information like inaccuracy, incompleteness and ambiguous, thus giving fair estimate about the reliability of information. This paper suggests extending the capabilities of fuzzy representation and reasoning system by introducing Neutrosophic representation of the data and Neutrosophic reasoning system.**

***Keywords*— *Fuzzy logic data representation; Neutrosophic logic data representaion; Neutrosophic logic reasoning system***

## I. INTRODUCTION

Real world information is full of uncertainties, gaps and inconsistent information. This uncertainty can be encountered in varied forms like uncertainty in outcome of tossing a coin; whether it will be a head or tail is an example of classical bivalence where uncertainty disappears on the completion of event. Or else accurate description of the statement "Rose is red"; has fuzzy uncertainty associated with it as it is difficult to define red colour due to various possible shades of the same colour applicable. Similarly during information fusion, multiple tools and sources like sensors, databases, humans, and intelligent sources; are employed for deriving synergy in the information from multiple sources; in which every component has its own individualistic limitation and constraint, thus gaps or inconsistency in the information derived is very much expected. Vagueness and ambiguity in a dynamic distributed environment requires generalized computational effort, conflicting with requirements of immediate response. So, in nutshell real world modelling is a challenging problem due to heterogeneity of uncertainty in sources, their models and characterization. Human beings are able to deal with this uncertainty because of their capability to compose uncertain facts and knowledge into an analysis structure that is inexact in nature.

Fuzzy logic proposed by Prof. L.A. Zadeh [1] has been widely used in various decision making models proposed by different researchers [2],[3],[4],[5],[6],[7], [8], [9], [10], [11]. This paper suggests using neutrosophic logic which is an extension to the already existing fuzzy logic, for modeling real world data and information.

Section II, briefly summarizes popular logics given by different researchers right from the inception of fuzzy logic, that are used for representing uncertainties and ambiguities in the real data and information. Section III is dedicated to the basic understanding of neutrosophic logic and its components. Underlying principles of neutrosophic geometry, it's relation to other logics and their corresponding mathematical correlation is discussed in section IV. Simple example of obstacle avoidance by robot is dealt in section V, where fuzzy logic representation is compared with neutrosophic logic representation. As neutrosophy is relatively a nascent concept, so its possibilities of future exploration and future work are discussed in section VI & VII.

## II. CHRONICLE OF DIFFERENT LOGICS

This section gives the short review of the commonly used logics that are used to represent the fuzziness, imprecision and uncertainty in the data acquired. The treatment here explores the relationship between them, citing other works where relevant.

Prof. Zadeh had revolutionized the field of logics by proposing a novel multi-valued logic, Fuzzy logic in 1965 where each element in fuzzy set had a degree of membership [1]. Decision framework using fuzzy logic uses type-1 fuzzy sets that represent uncertainty by numbers in the range [0, 1].Since its inception, fuzzy logic has emerged as a powerful representation method in handling vague estimates [2], [3], [11], [12].

Interval-valued fuzzy set (IVFS) treats the set membership as an interval and were proposed as a natural extension to fuzzy sets. These were introduced independently by Zadeh [13], Grattan-Guiness [14], Jahn [15], Sambuc [16], in the seventies, in the same year. According to Prof. Zadeh imperfect information is information that is imprecise, uncertain, incomplete, unreliable, vague or partially true [17] can best be described by type-2 fuzzy sets [7], and it has also found extensive applications in information system models [18], [19], [20], [21].

Belnap in 1977 defined four-valued logic [22] to cope with multiple information sources, with parameters truth (T), false (F) , unknown (U), and contradiction (C). Belnap's logic has also fascinated researchers and several works have been reported [23], [24], [25].

Rough set theory that represents imprecision by a boundary region of a set, and not by a partial membership, like in fuzzy set theory was proposed by the Pawlak [26]. Rough set representation has also found decision making applications in different domains [27], [28], [29], [30].

Fuzzy logic was extended by K. Atanassov [31] to Intuitionistic fuzzy sets (IFS) where each element of the universe has both a degree of membership $\mu$ and one of non membership $v$ such that $\mu + v \leq 1$. Modelling of imprecision in real world using intuitionistic fuzzy set representation has also found profound application in different decision making models [32], [33], [34], [35]. To allow more degree of freedom and flexibility in representing uncertainty, interval valued intuitionistic fuzzy sets (IVIFS) were proposed [36].Different domains have been experimented for modeling uncertainty using IVIFS [37], [38], [39].

Vague sets defined by Gau and Buehrer in 1993 [40] are characterized by a truth and false membership functions. Vague set is a set of objects, each of which has a grade of membership whose value is a continuous subinterval of [0, 1]. Similarity of vague sets to IFS has been proved by Bustince and Burillor [41].

### *A. Neutrosophic Logic*

Quite recently, Neutrosophic Logic was proposed by Florentine Smarandache [42] which is based on non-standard analysis that was given by Abraham Robinson in 1960s. Neutrosophic Logic was developed to represent mathematical model of uncertainty, vagueness, ambiguity, imprecision, incompleteness, inconsistency, redundancy and contradiction. All the factors stated are very integral to human thinking, as it is very rare that we tend to conclude/judge in definite environments, imprecision of human systems could be due to the imperfection of knowledge that human receives (observation) from the external world.

## III. Preliminaries

In this section, we now present basic definition of the theory of Neutrosophic logic and Neutrosophic sets (NS).

### *A. Neutroosphic Logic*

A logic in which each proposition is estimated to have the percentage of truth in a subset *T*, the percentage of indeterminacy in a subset *I*, and the percentage of falsity in a subset *F*, where:

*T, I, F* are standard or non-standard real subsets of $]^{-}0, 1^{+}[$,

with $\sup T = t\_sup$, $\inf T = t\_inf$, (1)
$\sup I = i\_sup$, $\inf I = i\_inf$, (2)
$\sup F = f\_sup$, $\inf F = f\_inf$, and (3)
$n\_sup = t\_sup + i\_sup + f\_sup$, (4)
$n\_inf = t\_inf + i\_inf + f\_inf$. (5)
is called Neutrosophic Logic [42].

The sets *T, I, F* are not necessarily intervals, but may be any real sub-unitary subsets: discrete or continuous; single-element, finite, or (countable or uncountable) infinite; union or intersection of various subsets; etc. They may also overlap. We use a subset of truth (or indeterminacy, or falsity), instead of a number only, because in many cases we are not able to exactly determine the percentages of truth or of falsity but approximate them: for example a proposition is between 30-40% true and between 60-70% false, even worst: between 30-40% or 45-50% true (according to various analyzers), and 60% or between 66-70% false. A subset may have one element only in special cases of this logic [43], [44], [45], [46].

### *B. Neutrosophic logic is a generalized logic*

The existing information representation and decision theories gives decent results, but the problem is that these theories work with dataset/information having specific attributes. Now there is a need in generation of more generalised representation techniques and reasoning theories that should work with all kinds of data whether precise or imprecise, complete or incomplete, clear or ambiguous; certain or uncertain. This section elaborates on the fact that Neutrosophic logic is a generalized logic with other prominent logics as its subsets.

When the sets are reduced to an element only respectively, then $t\_sup = t\_inf = t$, $i\_sup = i\_inf = i$, $f\_sup = f\_inf = f$, and $n\_sup = n\_inf = n = t+i+f$

Hence, the neutrosophic logic generalizes:

i. *Boolean Logic* (for $n = 1$ and $i = 0$, with $t, f = 0/1$)
ii. M*ulti Valued Logic* (for $0 \leq t, i, f \leq 1$)
iii. *Fuzzy Logic (for $n = 1$ and $i = 0$, and $0 \leq t, i, f \leq 1$)*
iv. *Intuitionistic Fuzzy Set, for ($t+i+f=1$ and $0 \leq i < 1$)*

## IV. Neutrosophic sets and their geometry

A neutrosophic set is defined on a universe of discourse (UOD) and maps the elements of the UOD into a set of real numbers which denotes the truth, indeterminacy and falsity membership of UOD elements in the set. In other words it is a function mapping UOD elements to triplet membership values of $x$ $(t, i, f)$, where $t$ , $i$ and $f$ corresponds to values given by truth, indeterminacy and falsity membership functions. This is similar to the definition of membership function employed for fuzzy sets, but with a difference. Fuzzy sets admit a continuum of memberships between 0 and 1, we therefore have, $\mu(x): X \text{->} [0,1]$, where $X$ is the universe of discourse.

*Neutrosophic set:* Let $X$ be a space of points (objects), with a generic element in $X$ denoted by $x$. A neutrosophic set $A$ in $X$ is characterized by a truth-membership function $T_A$, a indeterminacy-membership function $I_A$ and a falsity-membership function $F_A$. $T_A(x)$; $I_A(x)$ and $F_A(x)$ are real standard or nonstandard subsets of ] -0,1+[ . That is

$$T_A(x): X \rightarrow ]^-0,1^+[$$
$$I_A(x): X \rightarrow ]^-0,1^+[$$
$$F_A(x): X \rightarrow ]^-0,1^+[ \qquad (6)$$

( $]a,b[$ represents the set of numbers that are either less than or equal to $a$, or greater than or equal to $b$)

As shown in fig: 1, a neutrosophic set can be given an interesting geometrical interpretation. Considering a universe defined by neutrosophic set comprising of truth function, indeterminacy function and falsity function; geometrically it can be represented using three axis representations, where each axis represents one subset. To represent three functions, RGB (red, blue, green) colour scheme is used; *x- axis* represents truth membership function values denoted by red colour, *y- axis* represents falsity membership function values denoted by green colour and *z- axis* represents indeterminacy membership function value. Though there is no restriction on the sum of $T_A(x)$, $I_A(x)$ and $F_A(x)$ so $^-0 \leq T_A(x) + I_A(x) + F_A(x) \leq 3^+$, but for practical purposes, the limit of each $T_A(x)$, $I_A(x)$ and $F_A(x)$ is restricted to standard interval of $[0, 1]$. Considering this interval, an imaginary unit cube can be constructed using these three axes as shown in fig: 1.

### A. *Analytical comparison of neutrosophic logic to other logics*

This unit cube representation is capable of representing the fact that neutrosophic logic is a generalized representation of the representation given by other logics.

If we consider the vertices of the cube in figure 1, following generalizations can be derived:

*Vertex 1:* ($t=0, i=0, f=0$) represents determinate paradox

*Vertex 2:* ($t=1, i=0, f=0$) represents tautologies in classical set which have the truth value

*Vertex 3:* ($t= 1, i=0, f= 1$) represents dialetheism which are true contradictions, some paradoxes can be denoted this way

*Vertex 4:* ($t= 0, i= 0, f=1$) represents classical set with $f$=1 and $t$=0

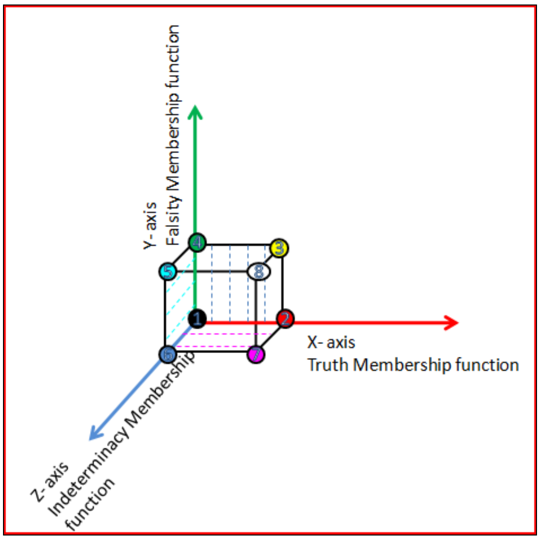


Fig. 1. Neutrosophic geometry

*Vertex 5:* ($t= 0, i=1, f=1$) represents contradictions which have the value indeterminacy and falsity, both set to 1.

*Vertex 6:* ($t=0, i=1, f=0$) represents complete indeterminate world, in which nothing can be ascertained about truth or falsity of any proposition

*Vertex 7:* ($t= 1, i= 1, f=0$) represents contradictions which have both truth and indeterminacy value set to 1.

*Vertex 8:* ($t=1, i= 1, f=1$ ) represents paradox, which have truth value ($t$=1 , $i$= 1, $f$=1 ). Indeed paradox is the only proposition true and false in the same time in the same world, and indeterminate as well.

Next the six planes bounded by the cube are discussed:
Assuming $n=t+i+f$

*Plane 1:* 3-4-5-8: ($0 \leq t \leq 1, 0 \leq i \leq 1, f=1$)

*Plane 2:* 1-4-5-6: ($t=0, 0 \leq i \leq 1, 0 \leq f \leq 1$)

*Plane 3:* 1-2-7-6: ($0 \leq t \leq 1, 0 \leq i \leq 1, f=0$)

*Plane 4:* 2-3-8-7: ($t=1, 0 \leq i \leq 1, 0 \leq f \leq 1$)

Plane 1,2,3,4 represents the pseudoparadoxist logic, based on pseudoparadoxes ($0 < i < 1, t + f > 1$)

*Plane 5:*1-2-3-4: ($0 \leq t \leq 1, i=0, 0 \leq f \leq 1$) represents intuitionistic set, which supports incomplete set theories and incomplete known elements belonging to a set. (for $0<n<1$ and $i=0, 0 \leq t, i, f < 1$)

**It also represents fuzzy set** (for $n=1$, and $i=0, 0 \leq t, i, f \leq 1$)

Also it represents the paraconsistent logic sets (for $n > 1$ and $i = 0$, with both $t, f < 1$)

*Plane 6*:5-6-7-8: ($0 \le t \le 1$, $i=1$, $0 \le f \le 1$): represents extreme faillibilism set where $i=1$, which says that uncertainty belongs to every proposition (for $i > 0$).

In general points in the 3-D cube space represents the multi-valued logic (for $0 \le t, i, f \le 1$); in which the propositions may take many values beyond simple truth and falsity values which are functionally determined by the values of their components; like Lukasiewicz considered three values (1, 1/2, 0) [47] Post considered m values and they varied in between 0 and 1 only [48].

Also the faillibilism set can also be represented within the cube, which says that uncertainty belongs to every proposition (for $i > 0$).

As there is no restriction on the sum of $T_A(x)$, $I_A(x)$ and $F_A(x)$ so $^-0 \le T_A(x) + I_A(x) + F_A(x) \le 3^+$, neutrosophic logic let each component *t, i, f* be even boiling over 1 (overflooded) or freezing under 0 (underdried): thus is able to make distinctions between relative truth and absolute truth, and between relative falsity and absolute falsity. For example: tautology where $t > 1$, it is called "overtrue". Similarly, a proposition may be "overindeterminate" (for $i > 1$, in some paradoxes), "overfalse" (for $f > 1$, in some unconditionally false propositions); or "undertrue" (for $t < 0$, in some unconditionally false propositions), "underindeterminate" (for $i < 0$, in some unconditionally true or false propositions), "underfalse" (for $f < 0$, in some unconditionally true propositions). This is because we should make a distinction between unconditionally true ($t > 1$, and $f < 0$ or $i < 0$) and conditionally true propositions ($t \le 1$, and $f \le 1$ or $i \le 1$).Also neutrosophic logic generalizes the paradoxist logic, based on paradoxes where $i > 1$ and the tautological logic, that is based on tautologies where $i < 0$ & $t > 1$.

Neutrosophic logic is far better representation of real world data/executions due to the following reasons:

a. Fuzzy logic though ensures multiple belongingness of a particular element to multiple classes with varied degree but capturing of neutralities due to indeterminacy is missing, further data representation using fuzzy logic is limited by the fact that membership and non-membership value of an element to a particular class should sum up to 1.

b. Similarly other allied logics like Lukasiewicz logic [47] considered three values (1, 1/2, 0), Post [48] considered m values, etc, but all are constrainted that values can vary in between 0 and 1 only. No extension beyond 1 or value less than 0 is permitted.

c. Intuitionistic fuzzy logic though deals with indeterminacy parameter related to a particular element, but this fact is still limited with the condition that, for any element *x*, indeterminacy value (*x*)=1 – [membership value(*x*)+ non-membership value(*x*)]. Also there is no provision of distinguishing between relative and absolute truth/indeterminacy/falsity.

d. In a rough set, an element *x* that is on the boundary-line can be classified neither as a member of a particular class nor of its complement with certainty but this element can be very well represented by neutrosophic logic , $x\,(T,I,F)$ with $T,I,F$ being standard or non-standard subsets of the nonstandard interval $]^-0, 1^+[$.

## V. Representation and Reasoning based on Neutrosophic Logic vs. Fuzzy Logic vs. Boolean Logic

This section deals with a simple example of obstacle avoidance by robot from the field of mobile robotics and two representations and reasoning types, one using fuzzy logic and other using neutrosophic logic.

Suppose that the goal of our experiment is to control a mobile robot as shown in fig. 2 using simple algorithm. Here the robot is equipped with single sensor that estimates the distance between robots current position and obstacle. The controller coordinating the movement of robot; would take distance between the current position and the obstacle (*d*) as the input and outputs ($\alpha$) which is the steering angle of the robot's wheel. So essentially this problem reduces to one input/one output controller, in which inputs and output would be defined as linguistic variables.

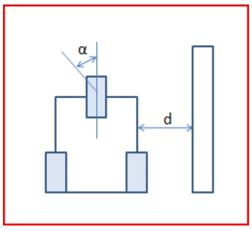


Fig. 2. Mobile robot

### A. Fuzzy representation and reasoning

If fuzzy logic approach is followed then following linguistic rules would be formed:

Rule 1: IF the distance between the robot and the obstacle is less than 10 cm, THEN turn to the left (α is negative)

Rule 2: IF the distance between the robot and the obstacle is more than 10 cm, THEN turn to the right (α is positive)

Rule 3: IF the distance between the robot and the obstacle is nearly 10 cm, THEN keep the direction (α is around 0)

So for input linguistic variable distance: three values are defined: more than 10 cm, nearly 10 cm and less than 10 cm. For the steering angle also three values are defined: negative for negative angles, zero for keeping direction i.e going straightforward and positive for positive angles.

The universe of discourse for the distance and the steering angle is shown in fig. 3.The chosen input and output membership functions have triangular and monotonous shapes.

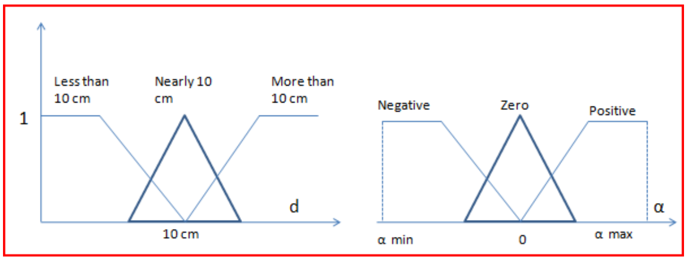


Fig. 3. Universe of discourse for the distance and the steering angle

With fuzzy controller, intelligent behaviour is expected. Control value is obtained by applying fuzzy implication [49].

For example, suppose that the sensor judges 6 cms for the distance, so 6 cms belongs to fuzzy set 'less than 10 cms' with truth degree of 0.7 (70%) and has truth degree of 0.2 (20%) for the fuzzy set 'nearly 10 cm', as shown in fig. 4.

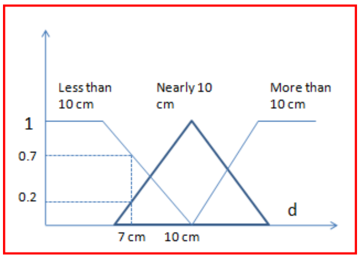


Fig. 4. Fuzzification step

Once the input is captured and truth degree in various fuzzy sets is found, rules are applied:

The antecedent part of Rule 1 and Rule 3 is satisfied with degree 70 % and 20 %. Rule 2 would not be used as its premise is not satisfied.

Rule 1 has firing strength 70 %, meaning that the steering angle has to be negative 70 % and Rule 3 has firing strength 20 %, indicating that robot has to keep the direction with this degree of truth.

Modulation techniques like centre of gravity (linear modulation) or mean of maxima (modulation by clipping), can be applied on the two generated output fuzzy sets for generating the crisp value of the command. Centre of gravity method is shown in fig. 5.

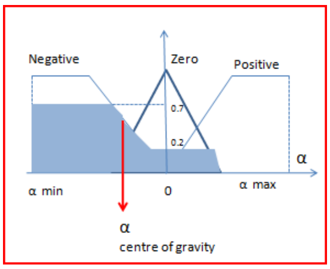


Fig. 5. Fuzzy inference and defuzzification

*B. Neutrosophic representation and reasoning*

Proposed neutrosophic representation and reasoning system would be a special system which would be more generalized and indeterminacy tolerant in it's working as compared to fuzzy counterparts. These Neutrosophic reasoning systems would differ substantially according to the nature of the control problems that they are supposed to solve. Here we are restricting ourselves to the explanation of neutrosophic reasoning for the simple problem from the field of mobile robotics.

The advantage of using neutrosophic logic in reasoning system is that it is very uncommon that the data acquired by the system would be 100% complete and determinate. Incompleteness and indeterminacy in the data can arise from inherent non-linearity, time-varying nature of the process to be controlled, large unpredictable environmental disturbances, degrading sensors or other difficulties in obtaining precise and reliable measurements. Humans can take intelligent decisions in such situations. Though this knowledge is also difficult to express in precise terms, an imprecise linguistic description of the manner of control can usually be articulated by the operator with relative ease.

Neutrosophic reasoning systems similar to their fuzzy counterparts would be capable of utilizing knowledge obtained from human operators. So to deal with such situations wherein there is possibility of indeterminacy and incompleteness in the data acquired, neutrosophic representation and reasoning system is proposed. It is suggested to extend the capabilities of fuzzy representation and reasoning system by introducing neutrosophic representation and reasoning system.

The universe of discourse for the distance and the steering angle in neutrosophic reasoning system is shown in fig. 6. Here, the difference is that apart from truth membership functions for various sets as in fuzzy logic, it also supports the designing of indeterminacy and falsity membership functions; that helps to capture the percentage of the indeterminacy in the data captured and also the non-membership to a particular set. The incompleteness and indeterminacy in the data acquired could arise from poor vision of the sensor due to insufficient light or in general it could be due to inherent non-linearity, time-varying nature of the process to be controlled, large unpredictable environmental disturbances, degrading sensors or other difficulties in obtaining precise and reliable measurements.

The chosen input and output truth/ indeterminacy and falsity membership functions have triangular and monotonous shapes.

For the current robot problem: following are the input membership functions defined:

a. less than 10 cm –truth membership function, less than 10 cm –indeterminacy membership function, less than 10 cm –falsity membership function

b. nearly 10 cm–truth membership function, nearly 10 cm–indeterminacy membership function, nearly 10 cm–falsity membership function

c. more than 10 cm–truth membership function, more than 10 cm– indeterminacy membership function, more than 10 cm– falsity membership function

And following are the output membership function defined:

a. Negative –truth membership function, Negative –indeterminacy membership function, Negative –falsity membership function

b. Zero–truth membership function, Zero – indeterminacy membership function, Zero – falsity membership function

c. Positive–truth membership function, Positive – indeterminacy membership function, Positive– falsity membership function

Algorithm of the proposed neutrosophic reasoning system is as stated below:

*Step1:* Record the measurements of all the variables that represent relevant conditions of the controlled process in this case it is the distance '$d_1$' between the robot and the obstacle.

*Step2:* The acquired measurements are then converted to appropriate neutrosophic sets to capture the measurement truth, falsity and indeterminacy using truth, falsity and indeterminacy membership functions respectively. This step is called as neutrosophication step. Same has been shown in part-a of fig. 6.

If the captured distance is $d_1$, then it is mapped to the input neutrosophic sets. As shown in part-a of fig. 6, so distance $d_1$ belongs to neutrosophic set:

a. less than 10 cm-- truth membership function by $t_1$%, nearly 10 cm-- truth membership function by $t_2$%, where $t_1 > t_2$.

b. less than 10 cm-- indeterminacy membership function by $i_1$%, nearly 10 cm-- indeterminacy membership function by $i_2$%, where $i_1 > i_2$.

c. less than 10 cm-- falsity membership function by $f_1$%, nearly 10 cm-- falsity membership function by $f_2$%, where $f_1 > f_2$.

*Step3:* Neutrosophied measurements are then used by the reasoning system to evaluate the control rules stored in the neutrosophic rule base. This evaluation will result in a neutrosophic set or several neutrosophic sets which would be defined on the universe of possible actions.

If the neutrosophic approach is followed then for input and output truth membership functions, the neutrosophic rules will be of the form:

Rule1: IF the distance between the robot and the obstacle is less than 10 cm-truth membership function, THEN negative-truth membership function.

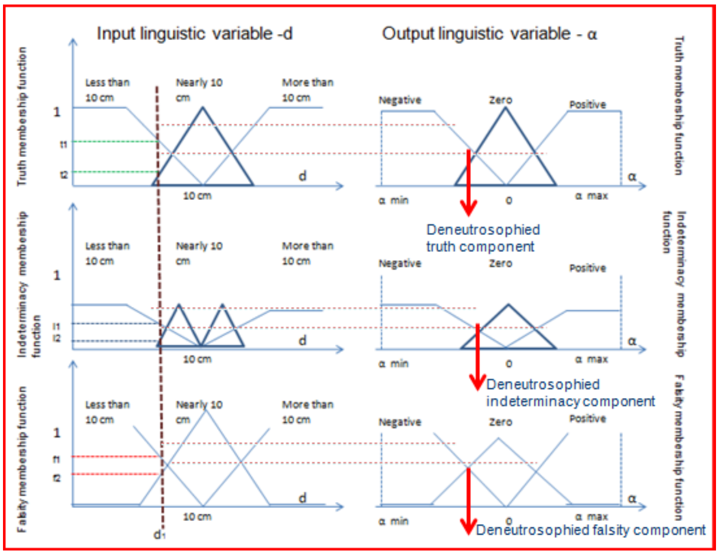


Fig. 6. Universe of discourse for the (a) distance and (b) the steering angle

Rule 2: IF the distance between the robot and the obstacle is more than 10 cm- truth membership function, THEN positive-truth membership functions.

Rule 3: IF the distance between the robot and the obstacle is nearly 10 cm--truth membership function, THEN zero-truth membership functions.

Similarly rules will be formed for indeterminacy and falsity input-output membership functions. To keep the discussion relatively simple, here we are giving explanation for deriving output value for the truth component; output indeterminacy and falsity component values can be derived in the same way.

According to the captured $d_1$, the antecedent part of Rule 1 and Rule 3 is satisfied with degree $t_1$% and $t_2$ % respectively. Rule 2 would not be used as its premise is not satisfied.

Rule 1 has firing strength $t_1$ %, it means that the steering angle has to be negative $t_1$ % and Rule 3 has firing strength $t_2$ %, indicating that robot has to keep the direction with this degree of truth.

Modulation techniques like centre of gravity (linear modulation) or mean of maxima (modulation by clipping), can be applied on the two generated output neutrosophic sets for generating the crisp true value component of the command. This process is called as de-neutrosophication.

In the same way, indeterminacy and falsity values can also be obtained. Final output generated is represented as Negative $(t, i, f)$, where $t$ corresponds to the truth value generated and $i$ and $f$ for indeterminacy and falsity values.

For the results generated by neutrosophic reasoning system, a confidence value can be set for the truth component. For example if for truth component the confidence value set>= 50%, then for the truth exceeding the confidence threshold, the associated indeterminacy and falsity values should be considered insignificant; else the result generated for the given instance has significant proportion of indeterminacy and/or falsity associated with it and would call for human expert intervention for final interpretation.

$$i/f = \begin{cases} \text{Insignificant} \quad \text{if} \quad t >= 50\% \\ \text{Significant} \quad \text{if} \quad t < 50\% \end{cases}$$

Though trivial, this example is introduced to give a general idea of neutrosophic reasoning.

The importance of using Neutrosophic logic in reasoning systems is its effective representation of information. Neutrosophic data representation not only reflects the degree of truthness and falsity of information but also conveys the degree of indeterminacy associated, because of which it gives a clear picture about the reliability of the data. Also the three parameters of truthness, indeterminacy and falsity are independent of each other that further augment to the freedom of expression. Besides this, the reasoning system generates the output by taking into consideration the falsity and indeterminacy associated with the input data captured, unlike fuzzy systems.

## VI. Possible application areas and Conclusion

Whenever the object descriptions are vague or the data acquired about the object is imprecise; precise mathematical representations of such objects is not possible. So this paper explores the geometric representation of various worlds in section IV, which have varying degree of preciseness, inexactness and indeterminacy infused in them; all represented by generalized logic: Neutrosophic logic. This representation may further be extended to provide a foundation framework for the development of neutrosophic geometric modelling which will be useful for both creative design and computer vision applications.

Section V compares neutrosophic representation and reasoning system with the fuzzy representation and reasoning system by explaining the simple robot problem, which correctly justifies that neutrosophic logic is an extension to the existing fuzzy systems in their working and are much more capable of representing and processing ambiguities and indeterminacies infused in the real world.

As it is clear that all theories that proposes logical interpretations cannot ever be freed of paradoxes [56], it becomes utter mandatory and clear that a generalized logic is required that represents two extremes (true and false) and is also capable of encompassing continuous spectrum of neutralities, that can happen due to various levels of overlapping imprecision and misunderstandings; which as of date is best represented by Neutrosophic logic.

Since as revealed in the section III that Neutrosophic logic includes varied range of logics, so there seems a possibility of potential conversion of logic specific systems to more generalized and indiscriminate logical systems that can exhibit different logical behaviors depending on the nature of the problem being solved; which is possible by integrating neutrosophic logic in systems.

So definitely neutrosophic logic holds its chance to be experimented and utilized for real world executions and human psychology simulations. Neutrosophic logic can find application in the areas like Web intelligence, medical informatics, bioinformatics, decision making, relational databases, image processing, preference structures, expert systems, soft computing techniques etc. where the information is very commonly inconsistent, incomplete, uncertain and imprecise.

## VII. Future Work

Neutrosophic logic is an extended and general framework to measure the truth, indeterminacy, and falsehood-ness that closely resembles human psychological behaviour. This paper discusses the theoretical aspects of applying neutrosophic logic in real world problems, practical aspects of the same can be tried in different domains. Also to augment the capabilities of this generalized logic, the hybridization with other soft computing techniques like evolutionary computing- genetic algorithm, neural networks, can be tried and experimented.

## References


[1] L. A. Zadeh, "Fuzzy sets," *Inf. Control*,vol. 8, pp. 338-353, 1965.

[2] L.A. Zadeh, "Fuzzy logic = computing with words," *IEEE Trans. on Fuzzy Syst.,*vol. 4, pp. 103–111, 1996.

[3] L.A. Zadeh, "Toward a theory of fuzzy information granulation and its centrality in human reasoning and fuzzy logic," *Fuzzy Sets and Syst.*, vol. 90, no. 2, pp. 111–127, 1997.

[4] R.R. Yager, "Decision making with fuzzy probability assessments," *IEEE Trans. on Fuzzy* Syst., vol. 7, pp. 462–467, 1999.

[5] R.R. Yager, "A general approach to uncertainty representation using fuzzy measures," in *Proc. 14th Int. Florida Artificial Intelligence Research Society Conf. (FLAIRS-01)*, 2001, pp. 619–623.

[6] J.J. Buckley, "Fuzzy probability and statistics," *Series: Studies in Fuzziness and Soft Computing*, vol. 196, Springer, 2003.

[7] L.A. Zadeh, "Generalized theory of uncertainty (GTU) – principal concepts and ideas,", *Computational statistics & Data Analysis*, vol. 51, pp. 15–46, 2006.

[8] L.A. Zadeh, "Computation with imprecise probabilities," in *Proc. 7th Int. Conf. on Applications of Fuzzy Systems and Soft Computing (ICAFS 2008)*, 2008, pp. 1–3.

[9] R.A. Aliev, " Modelling and stability analysis in fuzzy economics," *Applied and Computational Mathematics an International Journal*, vol. 7, no. 1, pp. 31–53, 2008.

[10] L.A. Zadeh et al., " Decision theory with imprecise probabilities, " in *Contract on Application of Fuzzy Logic and Soft Computing to Communications*, *Planning and Management of Uncertainty*, Berkeley, Baku, 2009.

[11] R.A. Aliev et al., "Unprecisiated information-based approach to decision making with imperfect information," in *Proc.9th Int. Conf. on Application of Fuzzy Systems and Soft Computing (ICAFS-2010)*, 2010, pp. 387–397.

[12] S.G. Tzafestas et al., “Fuzzy Logic Applications in Engineering Science,” *Microprocessor based and Intelligent Systems Engineering,* vol. 29, Springer, Netherlands, 2006, pp. 11–30.

[13] L. Zadeh, “The concept of a linguistic variable and its application to approximate reasoning-I,” *Inform. Sci.,*vol. 8, pp. 199–249, 1975.

[14] I. Grattan-Guiness, “Fuzzy membership mapped onto interval and many-valued quantities,” *Z. Math. Logik. Grundladen Math*, vol. 22, pp. 149-160, 1975.

[15] K. U. Jahn, “Intervall-wertige Mengen,” *Math.Nach*, vol. 68, pp. 115-132, 1975.

[16] R. Sambuc, “Fonctions Φ-floues. Application l’Aide au Diagnostic en Pathologie Thyroidienne,” Ph. D. Thesis, Univ. Marseille, France, 1975.

[17] L.A. Zadeh, “Computing with words and perceptions—a paradigm shift,” in *The 2009 IEEE Int. Conf. on Information Reuse and Integration*, 2009.

[18] R. R. Yager, “Fuzzy subsets of type II in decisions,” *J. Cybern.*, vol. 10, pp. 137–159, 1980

[19] J. L. Chaneau, M. Gunaratne, and A. G. Altschaeffl, “An application of type-2 sets to decision making in engineering,” in *Analysis of Fuzzy Information*, vol. 2, Artificial Intelligence and Decision Systems, J. C. Bezdek, Ed. Boca Raton, FL: CRC, 1987.

[20] R. I. John, “Type 2 fuzzy sets: An appraisal of theory and applications,” *Int. J. Uncertainty, Fuzziness, Knowledge-Based Syst.*, vol. 6, no. 6, pp.563–576, Dec. 1998.

[21] J. M. Mendel, “Advances in type-2 fuzzy sets and systems,” *Inf.Sc.*, vol. 177, no. 1, pp. 84-110, 2007.

[22] N. Belnap, “A Useful Four-Valued Logic,” in *Modern Uses of Multiple-Valued Logics*, D.Reidel, ed., pp. 8-37, 1977.

[23] Y. Kaluzhny, A. Y. Muravitsky, “A knowledge representation based on the Belnap's four-valued logic,” *Journal of Applied Non-Classical Logics*, vol. 3, no. 2, pp. 189-203,1993.

[24] S.Chopra, R. Parikh, “An inconsistency tolerant model for belief representation and belief revision,” *Proc.16th Int. joint conf.on Artifical intelligence*, vol.1, Morgan Kaufmann Publishers Inc., 1999.

[25] A. P. Pynko, “Functional completeness and axiomatizability within Belnap's four-valued logic and its expansions,” *Journal of Applied Non-Classical Logics*, vol. 9, no. 1, pp. 61-105, 1999.

[26] Z. Pawlak, “Rough sets,” *International Journal of Computer and Information Sciences*, vol. 11, no.5, pp. 341-356, 1982.

[27] Z. Pawlak, “Rough set approach to knowledge-based decision support,” *European journal of operational research*, vol. 99, no.1 pp. 48-57, 1997.

[28] Z. Pawlak, “Rough set theory and its applications to data analysis,” *Cybernetics & Systems*, vol. 29, no.7 pp. 661-688, 1998.

[29] M. Kryszkiewicz, “Rough set approach to incomplete information systems,” *Information sciences*, vol. 112, no. 1, pp. 39-49, 1998.

[30] A. Skowron, “Rough sets perspective on data and knowledge,” *Handbook of data mining and knowledge discovery*, Oxford University Press, Inc., 2002.

[31] K.T. Atanassov, “Intuitionistic fuzzy sets,” *Fuzzy sets and Systems*, vol. 20, no.1, pp. 87-96, 1986.

[32] G. Deschrijver, E. E. Kerre, “On the position of intuitionistic fuzzy set theory in the framework of theories modelling imprecision,” *Information Sciences*, vol. 177, no.8 , pp. 1860-1866, 2007.

[33] S.K. De et al., “An application of intuitionistic fuzzy sets in medical diagnosis,” *Fuzzy Sets and Systems*, vol. 117, no. 2, pp. 209-213, 2001.

[34] D. F. Li, “Multiattribute decision making models and methods using intuitionistic fuzzy sets,” *Journal of Computer and System Sciences*, vol. 70, no.1, pp. 73-85, 2005.

[35] H.W. Liu, G. J. Wang, “Multi-criteria decision-making methods based on intuitionistic fuzzy sets,” *European Journal of Operational Research*, vol. 179, no. 1, pp. 220-233, 2007.

[36] K. T. Atanassov, G. Gargov, “Interval valued intuitionistic fuzzy sets,” *Fuzzy sets and systems*, vol. 31, no.3, pp. 343-349, 1989.

[37] I.K. Vlachos, G.D. Sergiadis, “Intuitionistic fuzzy information–Applications to pattern recognition,” *Pattern Recognition Letters*, vol. 28, no.2, pp. 197-206, 2007.

[38] J. Ye, “Multicriteria fuzzy decision-making method based on a novel accuracy function under interval-valued intuitionistic fuzzy environment,” *Expert Systems with Applications*, vol. 36, no.3, pp. 6899-6902, 2009.

[39] Z. Wang et al., “An approach to multiattribute decision making with interval-valued intuitionistic fuzzy assessments and incomplete weights,” *Information Sciences*, vol. 179, no.17, pp. 3026-3040, 2009.

[40] W. L. Gau, D. J. Buehrer, “Vague Sets,” *IEEE Trans. Systems Man Cybernet*, vol. 23. No. 2, pp. 610-614, 1993.

[41] H. Bustince, P. Burillo, “Vague sets are intuitionistic fuzzy sets,” *Fuzzy sets and systems*, vol. 79, no.3, pp. 403-405, 1996.

[42] F. Smarandache, “Linguistic Paradoxists and Tautologies,” *Libertas Mathematica*, University of Texas fat Arlington, vol. 19, pp. 143-154, 1999.

[43] F. Smarandache, “ A Unifying Field in Logics: Neutrosophic Logic, in Multiple-Valued Logic,” *An International Journal*, vol. 8, no. 3, pp. 385-438, 2002

[44] F. Smarandache , “ Neutrosophy, A New Branch of Philosophy, in Multiple-Valued Logic,” *An International Journal*, vol. 8, no. 3,2002, pp. 297-384.

[45] F. Smarandache , editor *Proc. 1st Int. Conf. on Neutrosophy, Neutrosophic Logic, Neutrosophic Set, Neutrosophic Probability and Statistics*, University of New Mexico, Gallup Campus, Xiquan, Phoenix, 2002, pp. 147.

[46] F. Smarandache, “Definition of Neutrosophic Logic – A Generalization of the Intuitionistic Fuzzy Logic,” *Proc.3rd Conf. European Society for FuzzyLogic and Technology, EUSFLAT 2003*, Zittau, Germany; University of Applied Sciences at Zittau/Goerlitz, 2003, pp. 141-146.

[47] J. Lukasiewicz, “O logice tr`ojwarto´sciowej,” *Ruch Filozoficzny*, vol. 5, pp. 169–171,1920.

[48] E.L. Post, “Introduction to a general theory of propositions,” *Amer. J. Math*, vol. 43, pp. 163–185, 1921.

[49] E. H. Mamdani, S. Assilian, “An experiment in linguistic synthesis with a fuzzy logic controller,” *Int. J. Man- Mach. Stud.*, vol. 7, pp. 1–13, 1975.