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Neutrosophic complex $\alpha\psi$ connectedness in neutrosophic complex topological spaces

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Abstract: Neutrosophic topological structure can be applied in many fields, viz. physics, chemistry, data science, etc., but it is difficult to apply the object with periodicity. So, we present this concept to overcome this problem and novelty of our work is to extend the range of membership, indeterminacy and non-membership from closed interval [0, 1] to unit circle in the neutrosophic complex plane and modify the existing definition of neutrosophic complex topology proposed by [17], because we can't apply the existing definition to some set theoretic operations, such as union and intersection. Also, we introduce the new notion of neutrosophic complex $\alpha\psi$ -connectedness in neutrosophic complex topological spaces and investigate some of its properties. Numerical example also provided to prove the nonexistence

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1. Introduction

In 1965, Zadeh [25] introduced fuzzy sets, after that there have been a number of developments in this fundamental concept. Atanassov [3] introduced the notion of intuitionistic fuzzy sets, which is generalized form of fuzzy set. Using the generalized concept of fuzzy sets, D. Coker [5] introduced the notion of intuitionistic fuzzy topological spaces. F. Smarandache [21, 22] introduced and studied neutrosophic sets. Applications of neutrosophic sets has been studied by many researchers [1, 2, 14]. Shortly, Salama et.al [19] introduced and studied Neutrosophic topology. Since then more research have been identified in the field of neutrosophic topology [4, 8, 11, 15, 18, 23], neutrosophic complex topology [10], neutrosophic ideals [17], etc. Kuratowski [9] introduced connectedness between sets in general topology. Thereafter various weak and strong form of connectedness between sets have been introduced and studied, such as b-connectedness [7], p-connectedness between sets [20], GO-connectedness between sets [19]. Parimala et.al, [16] initiated and investigated the concept of neutrosophic-closed sets. Wadei Al-Omeri [24], presented the concept of generalized closed and pre-closed sets in neutrosophic topological space and extended their discussions on pre- $T_{1/2}$ space and generalized pre-$T_{1/2}$. They also initiated the concept of generalized neutrosophic connected and of their properties.

R. Devi [17] brought the concept complex topological space and investigated some properties of complex topological spaces. Topological set with real values are not sufficient for the complex plane, this led to define this proposed concept. Every neutrosophic complex set contains a membership, indeterminacy and non-membership function in neutrosophic complex topology and each membership function in neutrosophic complex set contain amplitude and phase term. Similarly, indeterminacy and non-membership functions in neutrosophic complex set contain amplitude and phase terms. The null neutrosophic complex set has 0 as amplitude and phase value in membership and indeterminacy and 1 as amplitude and phase value in non-membership. The unit neutrosophic complex set has 1 as amplitude and phase value in membership and indeterminacy and 0 as amplitude and phase value in non-membership. The only open and closed set in neutrosophic complex topological space is 0 and 1. The remaining neutrosophic complex sets are not both open and closed. If it is both open and closed sets then it can't be a connected in neutrosophic complex topology. In this work, we define the concepts of neutrosophic complex $\alpha\psi$ -connectedness between neutrosophic complex sets in neutrosophic complex topological spaces and also study some of its properties.

2. Preliminaries

We recall the following basic definitions in particular the work of R. Devi [17] which are useful for the sequel.

Definition 2.1. Let $X \neq \phi$ and I be the unit circle in the complex plane. A neutrosophic complex set (NCS) A is defined as $A = \{< x_1, P_A(x_1), Q_A(x_1), R_A(x_1) >: x_1 \in X\}$ where the mappings $P_A(x_1), Q_A(x_1), R_A(x_1)$ denote the degree of membership, the degree of indeterminacy and the degree of non-membership for each element x_1 in X to the set A, respectively, and $0 \le P_A(x) + Q_A(x) + R_A(x) \le 3$ for each $x_1 \in X$. Here $P_A(x_1) = T_A(x_1)e^{j\mu_A(x_1)}$, $Q_A(x_1) = I_A(x_1)e^{j\sigma_A(x_1)}$, $R_A(x_1) = F_A(x_1)e^{j\nu_A(x_1)}$ and $T_A(x_1), I_A(x_1), F_A(x_1)$ are amplitude terms, $\mu_A(x_1), \sigma_A(x_1), \upsilon_A(x_1)$ are the phase terms.

***Definition* 2.2.** Two NCSs A and B are of the form $A = \{< x_1, P_A(x_1), Q_A(x_1), R_A(x_1) >: x_1 \in X\}$ and $B = \{< x_1, P_B(x_1), Q_B(x_1), R_B(x_1) >: x_1 \in X\}$.Then

$A \subseteq B$ if and only if $P_A(x) \le P_B(x), Q_A(x) \ge Q_B(x)$ *and* $R_A(x) \ge R_B(x)$.

$\overline{A} = \{< x_1, R_A(x_1), Q_A(x_1), P_A(x_1) >: x_1 \in X\}$.

$A \cap B = \{< x_1, P_A(x_1) \wedge P_B(x_1), Q_A(x_1) \vee Q_B(x_1), R_A(x_1) \vee R_B(x_1) >: x_1 \in X\}$.

$A \cup B = \{< x_1, P_A(x_1) \vee P_B(x_1), Q_A(x_1) \wedge Q_B(x_1), R_A(x_1) \wedge R_B(x_1) >: x_1 \in X\}$

Where

$P_A(x_1) \vee P_B(x_1) = (T_A \vee T_B)(x_1)e^{j(\mu_A \vee \mu_B)(x_1)}$, $P_A(x_1) \wedge P_B(x_1) = (T_A \wedge T_B)(x_1)e^{j(\mu_A \wedge \mu_B)(x_1)}$,

$Q_A(x_1) \wedge Q_B(x_1) == (I_A \wedge I_B)(x_1)e^{j(\sigma_A \wedge \sigma_B)(x_1)}$,

$Q_A(x_1) \vee Q_B(x_1) == (I_A \vee I_B)(x_1)e^{j(\sigma_A \vee \sigma_B)(x_1)}$,

$$R_A(x_1) \wedge R_B(x_1) = (F_A \wedge F_B)(x_1)e^{j(\upsilon_A \wedge \upsilon_B)(x_1)}$$

$$R_A(x_1) \vee R_B(x_1) = (F_A \vee F_B)(x_1)e^{j(\upsilon_A \vee \upsilon_B)(x_1)}$$

Definition 2.3. A subset A of a neutrosophic complex topological space (X,τ) is called

i. A neutrosophic complex semi-generalized closed (briefly, NCsg-closed) set if complex semi closure of (A) $\subseteq U$ whenever $A \subseteq U$ and U is semi-open in (X,τ);

ii. A neutrosophic complex ψ -closed set if complex semi closure of (A) $\subseteq U$ whenever $A \subseteq U$ and U is neutrosophic complex semi-generalized open in (X,τ);

iii. A neutrosophic complex $\alpha\psi$ -closed (briefly, N C $\alpha\psi$ CS) set if complex ψ closure (A) $\subseteq U$ whenever $A \subseteq U$ and U is neutrosophic complex α -open in (X,τ).

Definition 2.4. Two neutrosophic complex sets A and B of X are said to be q-complex coincident (ACqB for short) if and only if there exist an element y in X such that $A(y) \cap B(y) \neq \phi$.

Definition 2.5. For any two neutrosophic complex sets A and B of X, $A \subseteq B$ iff A and B^C are not q-coincident (B^C is the usual complement of the set B).

Remark 2.6. Every neutrosophic complex closed (resp. neutrosophic complex open) set is neutrosophic complex $\alpha\psi$ - closed (resp. neutrosophic complex $\alpha\psi$ - open) but the converse may not be true.

3. On neutrosophic complex $\alpha\psi$ - connectedness between neutrosophic complex sets

In this section, modified definition of neutrosophic complex topology and definition of neutrosophic complex $\alpha\psi$ - connectedness between sets are presented, some of its properties also investigated and counter examples are also provided.

Definition 3.1. A neutrosophic complex topology (NCT) on a nonempty set X is a family _ of NCSs in X satisfying the following conditions:

(T1) $0, 1 \in \tau$ where $0 = \langle x, 0e^{j0}, 1e^{j1}, 1e^{j1} \rangle, 1 = \langle x, 1e^{j1}, 0e^{j0}, 0e^{j0} \rangle$

(T2) $A \cap B \in \tau$ for any $A, B \in \tau$;

(T3) $\cup A_i \in \tau$ for any arbitrary family $\{A_i : i \in J\} \subseteq \tau$

Definition 3.2. A neutrosophic complex topological space (X,τ) is said to be neutrosophic complex $\alpha\psi$ -connected between neutrosophic complex sets A and B if there is no neutrosophic complex $\alpha\psi$ -closed neutrosophic complex $\alpha\psi$ -open set F in X such that $A \subset F$ and ¬(FCqB).

Theorem 3.3. If a neutrosophic complex topological space (X,τ) is neutrosophic complex $\alpha\psi$ - connected between neutrosophic complex sets A and B, then it is neutrosophic complex connected between A and B.

Proof: If (X,τ) is not neutrosophic complex connected between A and B, then there exists an neutrosophic complex closed open set F in X such that $A \subset F$ and ¬(F qB). Then every neutrosophic complex closed open set F in X is a neutrosophic complex $\alpha\psi$ closed neutrosophic complex $\alpha\psi$ open set F in X. If F is an neutrosophic $\alpha\psi$ -closed $\alpha\psi$ -open set in X such that $A \subset F$ and ¬(FqB) then (X,τ) is not neutrosophic $\alpha\psi$ -connected between A and B, which contradicts our hypothesis. Hence (X,τ) is a neutrosophic complex connected between A and B.

Remark 3.4. Following example clears that the converse of the above theorem may be false.

Example3.5.

Let X = {a,b} and $U = \{< a, 0.5e^{0.5j}, 0.4e^{0.4j}, 0.4e^{0.4j} >, < b, 0.6e^{0.6j}, 0.4e^{0.4j}, 0.4e^{0.4j} >\}$, $A = \{< a, 0.2e^{0.2j}, 0.7e^{0.7j}, 0.7e^{0.7j} >, < b, 0.3e^{0.5j}, 0.6e^{0.6j}, 0.6e^{0.6j} >\}$ and $B = \{< a, 0.5e^{0.5j}, 0.4e^{0.4j}, 0.4e^{0.4j} >, < b, 0.4e^{0.4j}, 0.5e^{0.5j}, 0.5e^{0.5j} >\}$ be neutrosophic complex sets on X. Let $\tau = \{0_\sim, 1_\sim, U\}$ be a neutrosophic complex topology on X. Then (X,τ)

is neutrosophic complex connected between A and B but it is not neutrosophic complex $\alpha\psi$ -connected between A and B.

Theorem 3.6. A NCT (X,τ) is neutrosophic complex $\alpha\psi$ - connected if and only if it is neutrosophic complex $\alpha\psi$ - connected between every pair of its non-empty neutrosophic complex sets.

Proof: **Necessity**: Let A, B be any pair of neutrosophic complex subsets of X. Suppose (X,τ) is not neutrosophic complex $\alpha\psi$ - connected between neutrosophic complex sets A and B. Then there exists a neutrosophic complex $\alpha\psi$ - closed complex $\alpha\psi$ - open set F of X such that A is a subset of F and ¬(FCqB). Since neutrosophic complex sets A and B are neutrosophic non-empty, it follows that F is a neutrosophic non - empty proper neutrosophic complex $\alpha\psi$ - closed complex $\alpha\psi$ - open set of X. Hence (X,τ) is not neutrosophic complex $\alpha\psi$ - connected.

Sufficiency: Suppose (X,τ) is not neutrosophic complex $\alpha\psi$ - connected. Then there exist a neutrosophic non empty proper neutrosophic complex $\alpha\psi$ - closed complex $\alpha\psi$ - open set F of X. Consequently (X,τ) is not neutrosophic complex $\alpha\psi$ - connected between F and F^C, a contradiction.

Remark 3.7. If a neutrosophic topological space (X,τ) is neutrosophic complex $\alpha\psi$ - connected between a pair of its neutrosophic complex subsets, it is not necessarily that (X,τ) is neutrosophic complex $\alpha\psi$ - connected between every pair of its neutrosophic complex subsets, as the following example shows.

Example 3.8.

Let X = {a,b} and $U=\{<a,0.5e^{0.5j},0.4e^{0.4j},0.4e^{0.4j}>,<b,0.6e^{0.6j},0.4e^{0.4j},0.4e^{0.4j}>\}$,

$A=\{<a,0.4e^{0.4j},0.3e^{0.3j},0.3e^{0.3j}>,<b,0.6e^{0.6j},0.4e^{0.4j},0.4e^{0.4j}>\}$

$B=\{<a,0.5e^{0.5j},0.2e^{0.2j},0.2e^{0.2j}>,<b,0.4e^{0.4j},0.4e^{0.4j},0.4e^{0.4j}>\}$

$C=\{<a,0.2e^{0.2j},0.7e^{0.7j},0.7e^{0.7j}>,<b,0.3e^{0.3j},0.6e^{0.6j},0.6e^{0.6j}>\}$ and

$D=\{<a,0.5e^{0.5j},0.4e^{0.4j},0.4e^{0.4j}>,<b,0.4e^{0.4j},0.5e^{0.5j},0.5e^{0.5j}>\}$ be neutrosophic sets on X. Let $\tau=\{0_\sim,1_\sim,U\}$ be a neutrosophic complex topology on X. Then (X,τ) is a neutrosophic complex connected between neutrosophic complex sets A and B but it is not neutrosophic complex connected between neutrosophic complex sets C and D. Also (X,τ) is not neutrosophic complex $\alpha\psi$ - connected.

Theorem 3.9. An NCT (X,τ) is neutrosophic complex $\alpha\psi$ - connected between neutrosophic complex sets A and B if and only if there is no neutrosophic complex $\alpha\psi$ - closed complex $\alpha\psi$ - open set F in X such that $A\subset F\subset B^C$.

Proof. **Necessity**: Let (X,τ) be an neutrosophic complex $\alpha\psi$ - connected between neutrosophic complex sets A and B. Suppose on the contrary that F is an neutrosophic complex $\alpha\psi$ - closed complex $\alpha\psi$ - open set in X such that $A\subset F\subset B^C$. Now $F\subset B^C$ which implies that ¬(FCqB). Therefore F is a neutrosophic complex $\alpha\psi$ - closed complex $\alpha\psi$ - open set in X such that $A\subset F$ and ¬(FCqB). Hence (X,τ) is not neutrosophic complex $\alpha\psi$ - connected between neutrosophic complex sets A and B, which is a contradiction.

Sufficiency: Suppose on the contrary that (X,τ) is not a neutrosophic complex $\alpha\psi$ - connected between neutrosophic complex sets A and B. Then there is a neutrosophic complex $\alpha\psi$ - closed complex $\alpha\psi$ - open set F in X such that $A\subset F$ and ¬(FCqB). Now, ¬(FCqB) which implies that $F\subset B^C$. Therefore F is a neutrosophic complex $\alpha\psi$ - closed complex $\alpha\psi$ - open set in X such that $A\subset F\subset B^C$, which contradicts our assumption.

Theorem 3.10. If a NCT (X,τ) is neutrosophic complex $\alpha\psi$ - connected between neutrosophic complex sets A and B, then A and B are neutrosophic non-empty in complex plane.

Proof. Let (X,τ) be a neutrosophic complex $\alpha\psi$ - connected between neutrosophic complex sets A and B. Suppose the neutrosophic complex sets A or B or both are empty set then the intersection of A and B is empty, which is contradiction to the definition of connectedness. The only open and closed sets in neutrosophic complex sets are 0 and 1. We know that every neutrosophic complex connected space is a $\alpha\psi$ - connected between A and B. Therefore (X,τ) is not a neutrosophic complex $\alpha\psi$ - connected between neutrosophic complex sets A and B. This leads to the contradiction to the hypothesis.

Theorem 3.11. Let (X,τ) be a NCT and A,B be two neutrosophic complex sets in X. If ACqB then (X,τ) is a neutrosophic complex $\alpha\psi$ - connected between A and B.

Proof. If B is any neutrosophic complex $\alpha\psi$ - closed complex $\alpha\psi$ - open set of X such that A and B^C are not q-coincident and A is a subset of B. This is contradiction to the given statement A is complex q-coincident with B. Therefore (X,τ) is neutrosophic complex $\alpha\psi$ - connected between A and B.

Remark 3.12. Example 3.13 shows that the converse of the above theorem may not hold.

Example 3.13.

Let X = {a,b} and $U=\{<a,0.2e^{0.2j},0.6e^{0.6j},0.6e^{0.6j}>,<b,0.3e^{0.3j},0.5e^{0.5j},0.5e^{0.5j}>\}$, $A=\{<a,0.4e^{0.4j},0.3e^{0.3j},0.3e^{0.3j}>,<b,0.3e^{0.3j},0.6e^{0.6j},0.6e^{0.6j}>\}$ and $B=\{<a,0.2e^{0.2j},0.5e^{0.5j},0.5e^{0.5j}>,<b,0.5e^{0.5j},0.4e^{0.4j},0.4e^{0.4j}>\}$ be neutrosophic complex sets on X. Let $\tau=\{0_{\sim},1_{\sim},U\}$ be a neutrosophic complex topology on X. Then (X,τ) is neutrosophic complex $\alpha\psi$ -connected between neutrosophic sets A and B but ¬(AqB).

4. On subspace of neutrosophic complex topology and subset of neutrosophic complex set

Theorem 4.1. If a NCT (X,τ) is a neutrosophic complex $\alpha\psi$ - connected between neutrosophic complex sets A and B such that A and B are subset of A_1 and B_1 respectively, then (X,τ) is a neutrosophic complex $\alpha\psi$ - connected between A_1 and B_1.

Proof. Let (X,τ) be a neutrosophic complex $\alpha\psi$ - connected between neutrosophic complex sets A and B such that A and B are subset of A_1 and B_1 respectively. Suppose (X,τ) is not a neutrosophic complex $\alpha\psi$ - connected between A1 and B1. Then there exist a set A_1 such that A_1 a subset of complement of B_1 and intersection of A and B_1 is empty. Also intersection of A and B is empty since A is a subset of A_1 and A_1 is a subset of complement of B_1. This is contradiction to the assumption that (X,τ) is a neutrosophic complex $\alpha\psi$ - connected between neutrosophic complex sets A and B. Hence (X,τ) is a neutrosophic complex $\alpha\psi$ - connected between A_1 and B_1.

Theorem 4.2. A NCT (X,τ) is a neutrosophic complex $\alpha\psi$ -connected between neutrosophic complex sets A and B if and only if it is neutrosophic complex $\alpha\psi$ - connected between NC$\alpha\psi$ cl(A) and NC$\alpha\psi$ cl(B).

Proof. **Necessity**: Let (X,τ) be a neutrosophic complex $\alpha\psi$ - connectedness between A and B. On the contrary, (X,τ) is not a neutrosophic complex $\alpha\psi$ - connected between NC$\alpha\psi$ cl(A) and NC$\alpha\psi$ cl(B). We know that every neutrosophic complex set A and B are subset of NC$\alpha\psi$ cl(A) and NC$\alpha\psi$ cl(B), respectively. Therefore there does not exist neutrosophic complex $\alpha\psi$ - connected between A and B. Follows from Theorem 4.1, because A is a subset of NC$\alpha\psi$ cl(A) and B is a subset of NC$\alpha\psi$ cl(B).

Sufficiency: Suppose (X,τ) is not a neutrosophic complex $\alpha\psi$ - connected between neutrosophic complex sets A and B. Then there is a neutrosophic complex $\alpha\psi$ - closed complex $\alpha\psi$ - open set F of X such that $A \subset F$ and ¬(FCqB). Since F is a neutrosophic complex $\alpha\psi$ -closed and $A \subset F$, NC$\alpha\psi$ cl(A)$\subset F$. Now, ¬(FCqB) which implies that $F \subset B^C$ Therefore F = NC$\alpha\psi$ int(F) $\subset$ NC$\alpha\psi$ int(B^C) = (NC$\alpha\psi$ cl(B))^C. Hence (FCqN$\alpha\psi$ cl(B)) and X is not a neutrosophic complex $\alpha\psi$ - connected between NC$\alpha\psi$ cl(A) and NC$\alpha\psi$ cl(B).

Theorem 4.3. Let (Y,τ_Y) be a subspace of a NCT (X,τ) and A;B be neutrosophic complex subsets of Y. If (Y,τ_Y) is a neutrosophic complex $\alpha\psi$ - connectedness between A and B then so is (X,τ)

Proof. Suppose, on the contrary, that (X,τ) is not a neutrosophic complex $\alpha\psi$ -connected between neutrosophic sets A and B. Then there exist a neutrosophic complex $\alpha\psi$ -closed complex $\alpha\psi$ -open set F of X such that $A \subset F$ and ¬(FCqB). Put $F_Y = F \cap Y$. Then F_Y is neutrosophic complex $\alpha\psi$ -closed complex $\alpha\psi$ -open set in Y such that $A \subset F_Y$ and ¬(F_YCqB). Hence (Y,τ_Y) is not a neutrosophic complex $\alpha\psi$ -connected between A and B, a contradiction.

Theorem 4.4. Let (Y,τ_Y) be a neutrosophic complex subspace of a NCT (X,τ) and A, B be neutrosophic subsets of Y. If (X,τ) is a neutrosophic complex $\alpha\psi$ -connected between neutrosophic complex sets A and B, then so is (Y,τ_Y) .

Proof. If (Y,τ_Y) is not a neutrosophic complex $\alpha\psi$ -connected between neutrosophic complex sets A and B, then there exist a neutrosophic complex $\alpha\psi$ - closed complex $\alpha\psi$ -open set F of Y such that $A \subset F$ and ¬(FCqB). Since Y is a neutrosophic complex closed open in X, F is a neutrosophic complex $\alpha\psi$ -closed complex $\alpha\psi$ -open set in X. Hence X cannot be neutrosophic complex $\alpha\psi$ -connected between neutrosophic complex sets A and B, a contradiction.

5. Conclusions

Neutrosophic topology is an extension of fuzzy topology. Neutrosophic complex topology is an extension of neutrosophic topology and complex neutrosophic set. In neutrosophic complex set, membership degree stands for truth value with periodicity, indeterminacy stands for indeterminacy with periodicity and non-membership stands for falsity with periodicity. In this paper, we modified the definition proposed by [17] and we presented the new concept of neutrosophic complex $\alpha\psi$ - connectedness between NCSs in NCTs using new definition and some properties of neutrosophic complex $\alpha\psi$ - connectedness is investigated along with numerical example. Also this work encourages that in future, this concept can be extended to various connectednesses and analyse the properties with application.

Conflicts of Interest: The authors declare no conflict of interest.

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