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ON FUZZY SU-IDEAL TOPOLOGICAL STRUCTURE

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ABSTRACT. This paper discuss Fuzzy SU-ideal Topological Structure on SU-algebras, by connecting the two notions SU-algebras and Fuzzy Topology.

1. Introduction

The concept of a fuzzy set was introduced by Zadeh [**7**], and it is now a rigorous area of research with manifold applications ranging from engineering and computer science to medical diagnosis and social behavior studies. The study of fuzzy algebraic structures was initiated by Rosenfeld [**5**]. The notion of a fuzzy set provides a natural framework for generalizing many concepts of general topology to what might be called fuzzy topological spaces [**1**]. In [**2**], Foster combined the structure of fuzzy topological spaces with that of fuzzy groups to form the notion of fuzzy topological group.

In 1966, Imai and Iseki [**3**] introduced two classes of abstract algebras; BCK-algebras and BCI-algebra. It is known that the BCK-algebras are a proper sub class of the class of BCI-algebras. During 2011 Keawrahun and Leerawat [**6**] introduced new structured algebra: SU-Algebra. Recently Sukklin and Leerawat [**4**], discussed Fuzzy SU-subalgebras and Fuzzy SU-ideals.

With all these motivation, this paper, discusses the fuzzy SU-ideal topological structure on SU-algebras and investigate some of their properties.

2. Preliminaries

In this section, some basic definitions that are required are recalled in the sequel.

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Definition 2.1. *Let X be a non-empty set. A mapping $\mu : X \to [0,1]$ is called a fuzzy set of X.*

Definition 2.2. *The union of two fuzzy sets μ_1 and μ_2 of a set X, is defined to be a fuzzy set of X by $(\mu_1 \cup \mu_2)(x) = max\{\mu_1(x), \mu_2(x)\}$ for any $x \in X$.*

Definition 2.3. *The intersection of two fuzzy sets μ_1 and μ_2 of a set X, is defined to be a fuzzy set of X by $(\mu_1 \cap \mu_2)(x) = min\{\mu_1(x), \mu_2(x)\}$ for any $x \in X$.*

Definition 2.4. *Any fuzzy sets μ_1 and μ_2 of X, if $\mu_1 \subset \mu_2 \Rightarrow \mu_1(x) \leqslant \mu_2(x)$ for any $x \in X$.*

Definition 2.5. *Let μ be a fuzzy set of X. Then the complement of μ denoted by $\mu'$is defined to be $\mu'(x) = 1 - \mu(x)$ for any $x \in X$.*

Definition 2.6. *A fuzzy topology is a family τ of fuzzy sets in X which satisfies the following conditions:*
(1) $\overline{0}, \overline{1} \in \tau$ *where* $\overline{0} = \mu(x) = 0\ \forall x \in X$ *&* $\overline{1} = \mu(x) = 1$ *for any* $x \in X$.
(2) *If* μ_1 , $\mu_2 \in \tau$ *then* $\mu_1 \cap \mu_2 \in \tau$.
(3) *If* $\mu_i \in \tau$ *for each* $i \in I$ *then* $\bigcup_{i \in I} \mu_i \in \tau$ *where I is an indexing set.*

Remark 2.1. *If X is a set with a fuzzy topology τ then (X, τ) is called a fuzzy topological space and any element in τ is called a τ -open fuzzy set in X.*

Definition 2.7. *Let (X, τ) be a fuzzy topological space.Let μ be a fuzzy set in X. A fuzzy set $\nu \in \tau)$ is said to a neighbourhood of μ if there exists a τ-open fuzzy set α such that $\mu \subset \alpha \subset \nu$. i.e $\mu(x) \subset \alpha(x) \subset \nu(x)$ for any $x \in X$.*

Definition 2.8. *Let μ and ν be fuzzy sets in a fuzzy topological space (X, τ). Let $\mu \supset \mu$. Then ν is called an interior of μ if μ is a neighbourhood of ν. The union of all interior fuzzy sets of μ is again an interior of μ and is denoted by μ^0.*

Definition 2.9. *A SU-algebra $(X, *, 0)$ is a non-empty set X with a constant 0 and a binary operation $*$ satisfying the following axioms:*
(1) $((x * y) * (x * z)) * (y * z) = 0$,
(2) $x * 0 = x$,
(3) *if* $x * y = 0 \Rightarrow x = y\ \forall x, y, z \in X$.

Example 2.1. The following Caley's table

$*$	0	1	2	3
0	0	1	2	3
1	1	0	3	2
2	2	3	0	1
3	3	2	1	0

shows $(X = \{0, 1, 2, 3\}, *)$ is a SU-algebra.

Definition 2.10 (Fuzzy SU-sub algebra). *A fuzzy subset μ of a SU-algebra $(X, *, 0)$ is called a fuzzy SU-Subalgebra of X if $\mu(x * y) \geqslant min\{\mu(x), \mu(y)\}$ for any $x, y \in X$.*

Definition 2.11 (Fuzzy SU-Ideal). *A fuzzy subset μ of a SU-algebra $(X, *, 0)$ is called a fuzzy SU-Ideal of X if*
(1) $\mu(0) \geqslant \mu(x)$ *and*
(2) $\mu(x * z) \geqslant min\{\mu((x * y) * z), \mu(y)\}$ *for any* $x, y \in X$.

3. Fuzzy SU-ideal Topological Structure (FSTS)

This section introduces Fuzzy SU-ideal Topological Structure (FSTS) on a SU-Algebra. For the sake of simplicity the notations A_1, A_2, A_3 etc. have been used to represent the elements in τ. Also X is a SU-Algebra unless otherwise specified.

Definition 3.1 (Fuzzy SU-ideal Topological Structure (FSTS)). *Let X be a SU-algebra. (X, τ) is said to be a Fuzzy SU-ideal Topological Structure (FSTS) on a SU- algebra if there is a family τ of fuzzy SU-ideals in X which satisfies the following conditions:*
(1) $\overline{0}, \overline{1} \in \tau$
(2) *If* A_1 , $A_2 \in \tau$ *then* $A_1 \cap A_2 \in \tau$.
(3) *If* $A_i \in \tau$ *for each* $i \in I$ *then* $\bigcup_{i \in I} A_i \in \tau$ *where I is an indexing set.*

Remark 3.1. *Any element in τ is called a τ-open fuzzy set in the SU-Algebra X.*

Example 3.1. Consider the SU-algebra defined in Example 2.1. Define the fuzzy SU-ideals A_i , $i = 1, 2, 3, 4, 5, 6, 7, 8$ on X as follows.

$$A_1(x) = \begin{cases} .7 & ; = 0 \\ .5 & ; = 1 \\ .4 & ; = 2 \\ .3 & ; = 3 \end{cases} \quad A_2(x) = \begin{cases} .6 & ; = 0 \\ .4 & ; = 1 \\ .3 & ; = 2 \\ .2 & ; = 3 \end{cases} \quad A_3(x) = \begin{cases} .8 & ; = 0 \\ .6 & ; = 1 \\ .5 & ; = 2 \\ .4 & ; = 3 \end{cases}$$

$$A_4(x) = \begin{cases} .5 & ; = 0 \\ .3 & ; = 1 \\ .2 & ; = 2 \\ .1 & ; = 3 \end{cases} \quad A_5(x) = \begin{cases} .9 & ; = 0 \\ .7 & ; = 1 \\ .5 & ; = 2 \\ .4 & ; = 3 \end{cases} \quad A_6(x) = \begin{cases} .7 & ; = 0 \\ .6 & ; = 1 \\ .5 & ; = 2 \\ .4 & ; = 3 \end{cases}$$

Then $\left(X, \tau = \{\overline{0}, \overline{1}, A_1, A_2, A_3, A_4, A_5, A_6\}\right)$ is a FSTS on a SU-Algebra.

Definition 3.2 (Fuzzy neighbourhood). *Let (X, T) be a FSTS on a SU-Algebra on a SU-Algebra. A fuzzy set U in (X, τ), is called a fuzzy neighbourhood of a fuzzy set A if there exist an τ-open fuzzy set O such that $A \subset O \subset U$ i.e. $A(x) \leqslant O(x) \leqslant U(x)$ for any $x \in X$.*

Example 3.2. Consider the SU-algebra defined in Example 2.1 and the FSTS (X, τ) defined in Example 3.1. Then A_1 is a fuzzy neighbourhood of a fuzzy set A_2 i.e, $A_2(x) \leqslant A_4(x) \leqslant A_1(x)$.

Definition 3.3 (Fuzzy interior). *Let A and B be fuzzy sets in a FSTS on a SU-Algebra. (X, τ) and let $A \supset B$ then B is called a fuzzy interior of A iff A is a* *fuzzy neighbourhood of B. The union of all fuzzy interior sets of A is again a fuzzy interior of A and it is denoted by A^0.*

Example 3.3. Consider the SU-algebra defined in Example 2.1 and the FSTS (X, τ) defined in Example 3.1. Then A_5 is a fuzzy neighbourhood of a fuzzy sets A_2, A_4, A_4, A_6 and
$A_2(x) \leqslant A_4(x) \leqslant A_5(x), \ \forall\, x \in X,$
$A_3(x) \leqslant A_1(x) \leqslant A_5(x), \ \forall\, x \in X,$
$A_4(x) \leqslant A_1(x) \leqslant A_5(x), \ \forall\, x \in X,$
$A_6(x) \leqslant A_1(x) \leqslant A_5(x), \ \forall\, x \in X.$
From this follows that A_2, A_3, A_4, A_6 are fuzzy interiors of $A_5(x)$ and

$$A^0 = \cup\{A_2, A_3, A_4, A_6\} \ = max\{A_2(x), A_3(x), A_4(x), A_6(x)\} \ = A_3(x)$$

which is also interior of A_5.

Definition 3.4. *Let (X, τ) be a FSTS on X. A sequence of fuzzy sets*

$$\{A_n \ : \ n = 1, 2, 3, ...\}$$

in SU-algebra X and it is said to be eventually contained in a fuzzy set A iff there is an integer m such that $n \geqslant m \Rightarrow A_n \subset A$.

Definition 3.5. *Let (X, τ) be a FSTS on X. Let $\{A_n \ : \ n = 1, 2, 3, ...\}$ be a sequence of fuzzy SU-ideals in X. The sequence is said to converge to a fuzzy SU-ideal A in X iff it is eventually contained in each fuzzy neighbourhood of A.*

Example 3.4. Consider the SU-algebra defined in Example 2.11. Define the fuzzy SU-ideals A_i , $i = 1, 2, 3, 4, 5, 6, 7, 8$ on X as follows.

$$A_1(x) = \begin{cases} .7 & ; = 0 \\ .5 & ; = 1 \\ .4 & ; = 2 \\ .3 & ; = 3 \end{cases} \quad A_2(x) = \begin{cases} .6 & ; = 0 \\ .4 & ; = 1 \\ .3 & ; = 2 \\ .2 & ; = 3 \end{cases} \quad A_3(x) = \begin{cases} .8 & ; = 0 \\ .6 & ; = 1 \\ .5 & ; = 2 \\ .4 & ; = 3 \end{cases}$$

$$A_4(x) = \begin{cases} .5 & ; = 0 \\ .3 & ; = 1 \\ .2 & ; = 2 \\ .1 & ; = 3 \end{cases} \quad A_5(x) = \begin{cases} .9 & ; = 0 \\ .7 & ; = 1 \\ .5 & ; = 2 \\ .4 & ; = 3 \end{cases} \quad A_6(x) = \begin{cases} .7 & ; = 0 \\ .6 & ; = 1 \\ .5 & ; = 2 \\ .4 & ; = 3 \end{cases}$$

$$A_7(x) = \begin{cases} .4 & ; = 0 \\ .2 & ; = 1 \\ .1 & ; = 2 \\ 0 & ; = 3 \end{cases} \quad A_8(x) = \begin{cases} .6 & ; = 0 \\ .5 & ; = 1 \\ .3 & ; = 2 \\ .2 & ; = 3 \end{cases}$$

Then $\big(X, \tau = \{\overline{0}, \overline{1}, A_1, A_2, A_3, A_4, A_5, A_6, A_7, A_8\}\big)$ is a FSTS on a X and take

$$A = A_4(x) = \begin{cases} .5 & ; = 0 \\ .3 & ; = 1 \\ .2 & ; = 2 \\ .1 & ; = 3 \end{cases}$$

Consider the sequence $A_n = \{A_2, A_3, A_6, A_7\}$. Now

$$A_4(x) \leqslant A_8(x) \leqslant A_1(x) \text{ and } A_4(x) \leqslant A_8(x) \leqslant A_5(x).$$

Thus A_1, A_5 are neighbourhood of A and A_n is contained in A_1, A_5. Finally the sequence A_n converges to A.

THEOREM 3.1. *Let (X, τ) be a FSTS on X. A fuzzy set A is τ-open if and only if for each fuzzy set B contained in A, A is a fuzzy neighbourhood of B.*

PROOF. Suppose a fuzzy set A is τ-open. Let B be any fuzzy set contained in A. Since A is open, and $A \subset B$ we have $B \subset A \subset A$ and A is fuzzy neighbourhood of B.

Conversely, for each fuzzy set B contained in A, A is a fuzzy neighbourhood of B. Since $A \subset A$ by our assumption, A is a fuzzy neighbourhood of A. Hence there exits an open fuzzy set O such that $A \subset O \subset A$. Therefore $A = O$ and A are open. □

DEFINITION 3.6. *Let (X, τ) be a FSTS on a SU-Algebra. Let A be a fuzzy set in X. The set of all fuzzy neighbourhood $A \in \tau$, $\mathfrak{U}_A$ is defined to be the fuzzy neighbourhood system of A.*

THEOREM 3.2. *Let (X, τ) be a FSTS on a SU-Algebra. Let A be a fuzzy set in X. Let $\mathfrak{U}_A$ be the fuzzy neighbourhood system of a fuzzy set A. Then*
(1) *The finite intersections of members of $\mathfrak{U}_A$ belong to $\mathfrak{U}_A$*
(2) *Any fuzzy set of X which contain a member of $\mathfrak{U}_A$ belong to $\mathfrak{U}_A$*

PROOF. (1) Let (X, τ) be a FSTS on X. Let A be a fuzzy set in X. Let $\mathfrak{U}_A$ be a fuzzy neighbourhood system of A. Let $R, S \in \mathfrak{U}_A$ Hence R and S are fuzzy neighbourhood of A. Thus there exits open fuzzy sets R_0 and S_0 Such that $A \subset R_0 \subset R$ and $A \subset S_0 \subset S$ respectively. Hence $A \subset R_0 \cap S_0 \subset R \cap S$. Follows $R \cap S$ is a fuzzy neighbourhood of A. Hence the intersection of two members of $\mathfrak{U}_A$ is again a member of $\mathfrak{U}_A$. It automatically follows that the intersection of any finite number of members of $\mathfrak{U}_A$ is again a member of $\mathfrak{U}_A$
(2) Let R be a fuzzy set that contains a member of $\mathfrak{U}_A$ say U. Hence R contains a neighbourhood U of A, that is $U \subset R$, $U \in \mathfrak{U}_A$. Since U is a fuzzy neighbourhood of A, there exists a T-open fuzzy set O such that $A \subset O \subset U \subset R$. Thus $A \subset O \subset R$ and R is a fuzzy neighbourhood of A. Therefore $R \in \mathfrak{U}_A$. □

THEOREM 3.3. *Let (X, τ) be a FSTS on X. Let A be a fuzzy set in X. Then*
(1) *A^0 is open and is the largest open fuzzy set contained in A.*
(2) *The fuzzy set A is open iff $A = A^0$*

Proof. (1) Let (X,τ) be a FSTS on a SU-Algebra. Let A be a fuzzy set in X. By def of fuzzy interior, A^0 is again a fuzzy interior set of A. Hence there exist an T- open fuzzy set O such that $A^0 \subset O \subset A$ but O is an fuzzy interior set of A,$O \subset A^0$ Hence $A^0 = O$. Thus A^0 is open and is the largest open fuzzy set contained in A.
(2) Suppose the fuzzy set A is open. If A is open , then $A \subset A^0$ for A is an fuzzy interior set of A. Hence $A = A^0$.

Conversely , Suppose $A = A^0$ By definition, the union of all fuzzy interior sets of A is called the interior of A and is denoted by A^0. Thus A is a neighbourhood of A^0 and therefore fuzzy set A is open. □

Theorem 3.4. *If the fuzzy neighbourhood system of each fuzzy set in a FSTS (X,τ) is countable, then a fuzzy set A is open if and only if each sequence of fuzzy sets, $\{A_n, n = 1,2,3,...\}$ which converges to a fuzzy set B contained in A is eventually contained in A.*

Proof. Suppose A is open. Given each sequence of fuzzy sets ,$\{A_n, n = 1,2,3,...\}$ which converges to a fuzzy set B. Since A is open and B contained in A. Thus $A$is a neighbourhood of B. Hence $\{A_n, n = 1,2,3,...\}$ is contained in A.

Conversely, for each $B \subset A$, let $U_1, U_2, ..., U_n...$ be the neighbourhood system of B. Let $V_n = \cap_1^n\{U_i\}$. Then $V_1, V_2, ..., V_n...$ is a sequence which is eventually contained in each fuzzy neighbourhood of B. Hence there is an m such that for $n > m$, $V_n \subset A$. Thus V_n are fuzzy neighbourhood of B. Therefore A is open. □

Definition 3.7. *Let f be a function from X to Y. Let λ be a fuzzy set in Y. The inverse of function, f^{-1} is defined as*

$$\lambda_{f^{-1}}(x) = \lambda(f(x)) \;\; forall \;\; x \in X.$$

Let μ be a fuzzy set in X. The image of μ is defined as

$$\mu(y) = \begin{cases} sup_{x\in \; f^{-1}(y)} \; \mu(x), & if\, f^{-1}(y) \neq \emptyset \\ 0, & otherwise \end{cases}$$

Definition 3.8. *Let (X,τ) and (Y,σ) be a FSTS on SU-Algebra X and Y respectively . A function f from (X,τ) to (Y,σ) is called a F-continuous function if the inverse of each σ-open fuzzy set is τ-open fuzzy set.*

Theorem 3.5. *Let (X,τ) and (Y,σ) be a FSTS on SU-Algebra X and Y respectively and f be a function from X to Y. Then the function f is F-continuous if and only if the inverse image of every closed fuzzy set is closed.*

Proof. Suppose the function f is F-continuous. Then the inverse of each σ-open fuzzy set is τ-open. Let $\sigma\,'$ be the set of closed fuzzy set in Y. Then

$$\mu_{f^{-1}(\sigma\,')}(x) = \mu'_\sigma(f(x)) = \mu_{\sigma\,'}(f(x)) = 1-\mu_\sigma(f(x)) = 1-\mu_{f^{-1}(\sigma)}(x) = \mu'_{f^{-1}(\sigma\,')}(x).$$

Thus $f^{-1}(\sigma\,') = \{f^{-1}(\sigma)\}'$ for all x in X. Since f is F-continuous, the inverse of every closed fuzzy set is closed.

Conversely, let σ be the set of open fuzzy set in Y. Then $\mu_{f^{-1}(\sigma)}(x) = \mu_\sigma(f(x))$ for all x in X. Since the inverse of every closed fuzzy set is closed. Hence the inverse of every open fuzzy set is open. Therefore f is F-continuous. □

THEOREM 3.6. *Let (X,τ) and (Y,σ) be a FSTS on SU-Algebra X and Y respectively and f be a function from X to Y. Then for each fuzzy set A in X, the inverse of every neighbourhood of $f(A)$ is a neighbourhood of A if and only if for each fuzzy set A in X and each neighbourhood v of $f(A)$, there is neighbourhood w of A such that $f(w) \subset v$.*

PROOF. Let $\mathcal{A}$ be the fuzzy sets of X. Let $\mathcal{U}$, $\mathcal{I}$ be the family of neighbourhoods of fuzzy sets and their image. Let $A \in \mathcal{A}$. Suppose $v \in \mathcal{I}$, $w \in \mathcal{U}$ is the neighbourhood of $f(A)$ and A. Since the inverse of every neighbourhood of $f(A)$ is a neighbourhood of A. Thus $f(w) = f(f^{-1}(v)) \to 1$. If $f^{-1}(y)$ is not empty, then

$$\mu_{f(f^{-1}(v))}(y) = \underset{z\in f^{-1}(y)}{sup} \mu_{f^{-1}(v)}(z) = \underset{z\in f^{-1}(y)}{sup} \{\mu_v(f(z))\} = \mu_v(y)$$

for all y in Y. If $f^{-1}(y)$ is not empty, then $\mu_{f(f^{-1}(v))}(y) = 0$. Hence $\mu_{f(f^{-1}(v))}(y) \leqslant \mu_v(y)$ for all y in Y and $f(f^{-1}(v)) \subset v$. Thus $1 \Rightarrow f(w) \subset v$.

Conversely, let V be a neighbourhood of $f(A)$. Since there is a neighbourhood w of A such that $f(w) \subset v$. Hence $f^{-1}(f(w)) \subset f^{-1}(v) \to 2$. Then for any $x \in X$ we have

$$\mu_{f^{-1}(f(w))}(x) = \mu_{f(w)}(f(x)) = \underset{z\in f^{-1}(f(x))}{sup} \{\mu_w(z)\} \geqslant \mu_w(x).$$

Thus $w \subset f^{-1}(f(w))$ and $2 \Rightarrow w \subset f^{-1}(f(w)) \subset f^{-1}(v)$. Finally $f^{-1}(v)$ is a neighbourhood of w. □

THEOREM 3.7. *Let (X,τ) and (Y,σ) be a FSTS on SU-Algebra X and Y respectively and f be a function from X to Y. If the function f is F-continuous then for each fuzzy set A in X; the inverse of every neighbourhood of $f(A)$ is a neighbourhood of A:*

PROOF. Let $\mathcal{A}$ be the fuzzy sets of X. Let $\mathcal{I}$ be the family of neighbourhood of fuzzy set on $\mathcal{A}$. Let $A \in \mathcal{A}$ and $v \in \mathcal{I}$. Then A is a fuzzy set in X and V is a neighbourhood of $f(A)$. There is an open neighbourhood w of $f(A)$ such that $f(A) \subset w \subset v$ and $f^{-1}(f(A)) \subset f^{-1}(w) \subset f^{-1}(v) \to 1$. Since f is F -continuous, $f^{-1}(w)$ is open. Further on

$$\mu_{f^{-1}(f(A))}(x) = \mu_{f(A)}(f(x)) = \underset{z\in f^{-1}(f(x))}{sup} \{\mu_A(z)\} \geqslant \mu_A(x)$$

for all $x \in X$. Therefore $A \subset f^{-1}(f(A))$. Thus $1 \Rightarrow A \subset f^{-1}(f(A)) \subset f^{-1}(w) \subset f^{-1}(v)$ and $A \subset f^{-1}(w) \subset f^{-1}(v)$. Finally $f^{-1}(v)$ is a neighbourhood of A. □

THEOREM 3.8. *Let (X,τ) and (Y,σ) be a FSTS on SU-Algebra X and Y respectively. If for each fuzzy set A in X and each neighbourhood v of $f(A)$, there is neighbourhood w of A such that $f(w) \subset v$,then for each sequence of fuzzy sets $\{A_n,\ n = 1,2,3,...\}$ in X which converges to a fuzzy set A in X, the sequence $\{f(A_n),\ n = 1,2,3,...\}$ converges to $f(A)$.*

PROOF. Since v is a neighbourhood of $f(A)$, there is a neighbourhood w of A such that $f(w) \subset v$. Since $\{A_n, n = 1, 2, 3, ...\}$ in X which converges to A in X by definition of converges, $\{A_n, n = 1, 2, 3, ...\}$ is eventually contained in w. Then there is an m such that for $n \geqslant m$, $A_n \subset w$. Thus $f(A_n) \subset f(w)$ and $f(A_n) \subset f(w) \subset v$ for $n \geqslant m$ since v is a neighbourhood of $f(A)$. By definition of converges, $\{f(A_n), n = 1, 2, 3, ...\}$ is converges to $f(A)$. □

4. Conclusion

This paper dealt several interesting results by connecting the notions of fuzzy SU-ideal and fuzzy topology. It can be further extended to intuitionistic fuzzy and interval valued fuzzy sub structures on SU-algebras by connecting with respective fuzzy topological settings.

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