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*sg**- CLOSED SETS AND *sT*$_a$–SPACES IN INTUITIONISTIC FUZZY TOPOLOGICAL SPACES

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The aim of this paper is to introduce and study different properties of sg^*-closed sets and sT_a-spaces in intuitionistic fuzzy topological space.

KEY WORDS : Intuitionistic Fuzzy (IF) sets, IF semi closed sets, *sg*-closed sets, gs-closed sets, *sg**- closed sets and sT_a-separation axiom, etc.

INTRODUCTION

Atanassov introduced the theory of intuitionistic fuzzy sets in 1983 [1, 2] and intuitionistic fuzzy topology by Coker in 1997 [5]. In this paper we introduce the concept intuitionistic fuzzy sg^*- closed sets. Intuitionistic fuzzy sT_a- space is also introduced with the help of intuitionistic fuzzy sg^*- closed sets. Throughout this paper we denote (X, τ_1), (Y, τ_2) (or simply X, Y) as intuitionistic fuzzy topological spaces on which no separation axioms are assumed unless explicitly stated.

PRELIMINARIES

Definition 2.1 [1, 2]. Let X be a nonempty fixed set. An intuitionistic fuzzy (IF for short) set A in X is given by a set of ordered triples $A = \{< x, \mu_A(x), \nu_A(x) > : x \in X\}$, where $\mu_A(x), \nu_A(x) : X \to [0, 1]$ are functions such that $0 \le \mu_A(x) + \nu_A(x) \le 1$, $\forall\, x \in X$. The numbers $\mu_A(x)$ and $\nu_A(x)$ represent the degree of membership and degree of non-membership for each element $x \in X$ to $A \subset X$, respectively.

Definition 2.2 [5]. Let $\alpha, \beta \in [0, 1]$ and $\alpha + \beta \le 1$.An IF point $x_{(\alpha, \beta)}$ in X is an IF set in X defined by

$$x_{(\alpha, \beta)}(y) = (\alpha, \beta), \text{ if } y = x \text{ and } (0, 1) \text{ if } y \ne x.$$

In this case, x is called the support of $x_{(\alpha, \beta)}$ and α and β are called the value and the non value of $x_{(\alpha, \beta)}$, respectively.

Definition 2.3 [5]. Let $x_{(\alpha, \beta)}$ be an IF point in X such that $\alpha, \beta \in (0, 1)$ and $A = \{< x, \mu_A(x), \nu_A(x) > : x \in X\}$ be an IF set in X, $x_{(\alpha, \beta)}$ is said to be properly contained in A ($x_{(\alpha, \beta)} \in A$ for short) if and only. If $\alpha < \mu_A(x)$ and $\beta > \nu_A(x)$.

Definition 2.4. An IF set A of an IF topological space (X, τ) is said to be

(a) IF semi closed if there exists a IF closed set U such that int $(U) \subseteq A \subseteq U$ [6].

(b) IF g-closed if cl $(A) \subseteq O$ whenever $A \subseteq O$ and O is an IF open set [8].

(c) IF gs-closed if scl $(A) \subseteq O$ whenever $A \subseteq O$ and O is an IF open set [7].

(d) IF sg-closed if scl $(A) \subseteq$ O whenever $A \subseteq O$ and O is an IF semi open set [9].

(e) IF g^*-closed set if cl $(A) \subseteq O$ whenever $A \subseteq O$ and O is an IF g-open set [3].

Result 2.1. Every IF closed (open) set is IF semi closed [6], IF-g closed [8] (respectively semi open, g-open) set but the converse may not be true [9].

Definition 2.5 [10]. Two IF sets A and B in an IF topological space (X, τ) are called q-separated if cl $(A) \cap B = 0_\sim = A \cap$ cl (B).

IF sg^*-CLOSED SETS

In this section, the concept sg^*-closed set in IF topological space is introduced and its different properties are studied.

Definition 3.1: An IF set A of an IF topological space (X, τ) is said to be an IF sg^*-closed set if scl $(A) \subseteq O$ whenever $A \subseteq O$ and O is an IF sg-open set.

Every IF semi closed set is IF sg^*- closed but the converse is not true as shown in following example.

Example 3.1. Let $X = \{a, b\}$ be an non empty set and $A = < x, (a/0.5, b/0.3), (a/0.5, b/0.7) >$, $B = < x, (a/0.6, b/0.4), (a/0.4, b/0.6) >$ are two IF sets of X. Then the family $\tau = \{0_\sim, 1_\sim, A, B\}$ is an IF topology on X. Then the IF set C defined by $C = < x, (a/0.2, b/0.4), (a/0.8, b/0.6) >$ is IF sg^* closed but is not IF semi closed as $C \subseteq A^c$, where $A^c = < x, (a/.5, b/.7), (a/.5, b/.3) >$ is IF semi closed but int $(A^c) = A \not\subset C$.

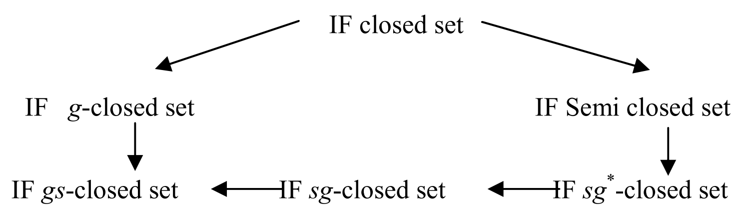
Theorem 3.1. Every IF sg^*- closed is IF semi g-closed.

Proof: Let A be an IF sg^*-closed set and O an IF open set in an IF topological space (X, τ) such that $A \subseteq O$. Since O is IF open, O is IF g-open. A being g^*-closed set, Cl $(A) \subseteq O$, whenever $A \subseteq O$ and O is an IF g-open. Hence, Cl $(A) \subseteq O$, whenever $A \subseteq O$ and O is an IF open set. Thus A is an IF semi g-closed set.

But the converse is not true as shown in the following example.

Example 3.2. Let $X = \{a, b\}$ be an non empty set and $A = < x, (a/0.4, b/0.5), (a/0.6, b/0.5) >$. Then the family $\tau = \{0_\sim, 1_\sim, A\}$is an IF topological on X. Then the IF set $B = < x, (a/0.7, b/0.5), (a/0.3, b/0.5) >$ is IF semi g-closed. But B is not IF sg^*-closed.

Remark 3.1. The relationship of IF sg^*-closed set with other types of closed sets are as follows



Remark 3.2. Union of two IF sg^*- closed sets may not be IF sg^*-closed which can be shown from the following example.

Example 3.3. In example 3.1 let $D = < x, (a/0.4, b/0.2), (a/0.5, b/0.8) >$. Then D is also IF sg^*-closed. Now $C \cup D = < x, (a/0.4, b/0.4), (a/0.5, b/0.6) >$ is not IF semi g^*- closed. Since $C \cup D \subseteq B$, where B is an IF sg-open set but scl $(C \cup D) \not\subset B$.

Theorem 3.2. Union of two IF sg^*-closed set is IF sg^*-closed iff Union of two IF semi closed sets is IF sg^*- closed.

Proof : Let union of two IF sg^*-closed set is IF sg^*-closed, A and B are two IF semi closed sets then A and B are IF sg^*-closed and so $A \cup B$ is IF sg^*-closed.

Conversely, let union of two IF semi closed sets is IF sg^*-closed set. Let A and B are two IF sg^*- closed sets such that scl $(A) = C$, scl $(B) = D$, where C, D are IF semi closed sets. Then scl $(A) = C \subseteq O$, scl $(B) = D \subseteq O$ whenever $A \subseteq O$, $B \subseteq O$ and O is IF sg-open. Now $C \cup D \subseteq O$. Since $C \cup D$ is IF sg^*-closed, therefore scl $(C \cup D) \subseteq O$ and this is true for all IF sg-open sets O containing $C \cup D$. Hence the theorem is proved.

Theorem 3.3. Let A is IF sg^*-closed and $A \subseteq B \subseteq$ scl (A), then B is IF sg^*-closed.

Proof : Let $B \subseteq O$ and O is IF sg-open. Since $A \subseteq B$ so $A \subseteq O$, now since A is IF sg^*-closed scl $(A) \subseteq O$. By hypothesis $B \subseteq$ scl (A), so scl $(B) \subseteq$ scl (A). Hence scl $(B) \subseteq O$. Thus B is IF sg^*-closed.

Definition 3.2. An IF set A of an IF topological space (X, τ) is said to be an IF sg^*- open set iff A^c is IF semi g^*-closed.

Theorem 3.4. An IF set A is IF sg^*-open iff $F \subseteq$ sint (A), whenever F is IF semi g-closed and $F \subseteq A$.

Proof : Let A is IF sg^*-open and F is IF semi g-closed such that $F \subseteq A$. Then A^c is IF sg^*-closed and contained in the IF semi g-open set F^c. Since A^c is IF sg^*-closed therefore scl $(A^c) \subseteq F^c$. Now scl $(A^c) =$ (sint $(A))^c$, where sint (A) is IF semi-open and (sint $(A))^c$ is IF semi-closed. Hence (sint $(A))^c \subseteq F^c$, *i.e.* $F \subseteq$ sint (A).

Conversely, if F is IF semi g-closed and $F \subseteq$ sint (A), whenever $F \subseteq A$. It follows that $A^c \subseteq F^c$ and (sint $(A))^c =$ scl $(A^c) \subseteq F^c$, where F^c is IF semi g-open. Hence A^c is IF sg^*-closed and A is IF sg^*-open.

Theorem 3.5. Let A is IF sg^*-open and sint $(A) \subseteq B \subseteq A$, then B is IF sg^*-open.

Proof : Let $F \subseteq B$ and F is IF sg-closed. Since $B \subseteq A$ so $F \subseteq B$, now since A is IF sg^*-open $F \subseteq$ sint (A). By hypothesis sint $(A) \subseteq B$, so $F \subseteq$ sint $(A) \subseteq$ sint (B). Thus B is IF sg^*-open.

Definition 3.3. Two IF sets A and B in an IF topological space (X, τ) are called semi separated if scl $(A) \cap B = 0_\sim = A \cap$ scl (B).

Theorem 3.6. Union of two semi separated IF sg^*-open sets is IF sg^*-open.

Proof : Let A and B be semi separated IF sg^*-open sets. Then we have scl $(A) \cap B = 0_\sim = A \cap$ scl (B). If F is an IF semi closed set such that $F \subseteq A \cup B$, then $F \cap$ scl $(A) = (A \cup B) \cap$ scl $(A) = (A \cap$ scl $(A)) \cup (B \cap$ scl $(A)) = A \cup 0_\sim = A$. Similarly $F \cap$ scl $(B) = B$. Now by theorem 3.4 $F \cap$ scl $(A) =$ sint (A) and $F \cap$ scl $(B) =$ sint (B). Hence $F = F \cap (A \cup B)$

$= (F \cap A) \cup (F \cap B) \subseteq (F \cap \text{scl}(A)) \cup (F \cap \text{scl}(B)) \subseteq \text{sint}(A) \cup \text{sint}(B) \subseteq \text{sint}(A \cup B)$. Hence by theorem 3.4 $A \cup B$ is IF semi g^*-open.

Theorem 3.7. An IF set A is IF sg^*-closed iff scl $(A) \cap A^c$ does not contain any non-null IF sg-closed set.

Proof : Let A is IF sg^*-closed and F is IF semi g-closed such that $F \subseteq (\text{scl}(A) \cap A^c)$, then F^c is IF semi g-open and $A \subseteq F^c$, it follows from definition 3.1 that scl $(A) \subseteq F^c$, implies $F \subseteq (\text{scl}(A))^c$, So $F \subseteq (((\text{scl}(A))^c \cap (\text{scl}(A) \cap A^c)) = 0_\sim$.

Conversely, let the given condition be satisfied. Let $A \subseteq O$, where O is IF sg-open set. If scl (A) is not an IF sub set of O, then scl $(A) \cap O = 0_\sim$. But scl $(A) \cap O^c$ is a non-null IF sg-closed set contained in scl $(A) \cap A^c$, a contradiction. So A is IF sg^*-closed.

Theorem 3.8. An IF set A is IF sg^*-closed iff scl $(A) \cap A^c$ is IF sg^*-open.

Proof : Let A is IF sg^*-closed and F is IF semi g-closed such that $F \subseteq (\text{scl}(A) \cap A^c)$, then by theorem 3.7 $F = 0_\sim$. Hence $F \subseteq \text{sint}(\text{scl}(A) \cap A^c)$ and by theorem 3.4 scl $(A) \cap A^c$ is IF sg^*-open.

Conversely, let scl $(A) \cap A^c$ be IF sg^*-open and $A \subseteq O$, where O is IF sg-open set. Then $O^c \subseteq A^c$ and $(\text{scl}(A)) \cap O^c \subseteq (\text{scl}(A)) \cap A^c$. Thus is an IF sg-closed sub set of scl $(A) \cap A^c$, since scl $(A) \cap A^c$ is IF sg^*-open, therefore by theorem 3.4 $(\text{scl}(A) \cap O^c) \subseteq \text{sint}(\text{scl}(A) \cap A^c) = 0_\sim$. This is possible if scl $(A) \subseteq O$. Thus A is IF sg^*-closed.

Notation 3.1. Let (X, τ) be an IF topological space and IFSGC (X) (respectively IFSGO (X)) be the family of all IF semi g-closed (respectively IF semi g-open) sets of X.

Theorem 3.9. In an IF topological space (X, τ) if IFSGC (X) = IFSGO (X) and every IF sg-closed is IF semi closed then every IF subset of X is IF sg^*-closed.

Proof : Let A is an IF sub set of X and $A \subseteq O$ and O is an IF sg-open. Since IFSGC (X) = IFSGO (X), O is IF sg-closed also. According to hypothesis O is IF semi closed. Hence scl $(A) \subseteq$ scl $(O) = O$ and A is an IF sg^*-closed set.

Theorem 3.10. In an IF topological space (X, τ) if every IF subset of X is IF sg^*-closed then IFSGC (X) = IFSGO (X).

Proof : Suppose that every IF subset of X is IF sg^*-closed. Let $A \in$ IFSGO (X), now since every IF sg^*-closed set is IF semi g-closed set, $A \in$ IFSGC (X). Thus IFSGO $(X) \subseteq$ IFSGC (X). Again if $A \in$ IFSGC (X) then $A^c \in$ IFSGO $(X) \subseteq$ IFSGC (X) and hence $A \in$ IFSGO (X). Consequently, IFSGC $(X) \subseteq$ IFSGO (X). Hence IFSGO (X) = IFSGC (X).

IF SEMI T_a- SPACES

In this section, a new notion, called IF semi T_a – space with the help of IF sg*-closed sets is defined and some of its properties are studied.

Definition 4.1. An IF topological space (X, τ) is said to be an IF semi T_a- space iff every IF sg^*-closed set is IF semi closed.

Theorem 4.1. For every IF point $x_{(\alpha, \beta)}$ in X, either $x_{(\alpha, \beta)}$ is IF semi g-closed or its complement $\{x_{(\alpha, \beta)}\}^c$ is sg^*-closed in IF topological space (X, τ).

Proof : Let $x_{(\alpha, \beta)}$ is not IF semi g-closed in (X, τ). Then $\{x_{(\alpha, \beta)}\}^c$ is not IF semi g-open and $1_\sim$ is the only IF semi g-open set containing $\{x_{(\alpha, \beta)}\}^c$. Therefore scl$\{x_{(\alpha, \beta)}\}^c \subseteq 1_\sim$ holds and so $\{x_{(\alpha, \beta)}\}^c$ is IF semi g^*-closed.

Definition 4.2. An IF semi g^*-closure operator of an IF set A in an IF topological space (X, τ) is defined as $\text{scl}^*(A) = \cap \{F : A \subseteq F, F \text{ is IF } sg^*\text{-closed in } X\}$.

If A is IF sg^*-closed set then $\text{scl}^*(A) = A$.

Theorem 4.2. In an IF topological space (X, τ), if $\{x_{(\alpha, \beta)}\} \neq \{y_{(\chi, \delta)}\}$ then $\text{scl}^* \{x_{(\alpha, \beta)}\} \neq \text{scl}^* \{y_{(\chi, \delta)}\}$.

Proof : By theorem 4.1 in the IF topological space (X, τ) IF point $\{x_{(\alpha, \beta)}\}$ is either IF semi g-closed or its complement $\{x_{(\alpha, \beta)}\}^c$ is IF sg^*-closed. Hence the proof will be complete if we consider the following two cases.

If IF point $\{x_{(\alpha, \beta)}\}$ is IF semi g-closed then $\{x_{(\alpha, \beta)}\}$ is also IF sg^*-closed, since an IF semi g-closed set is an IF sg^*-closed set. Hence $\text{scl}^* \{x_{(\alpha, \beta)}\} = \{x_{(\alpha, \beta)}\}$. Now $\{y_{(\chi, \delta)}\} \notin \{x_{(\alpha, \beta)}\}$, therefore $\text{scl}^* \{x_{(\alpha, \beta)}\} \neq \text{scl}^* \{y_{(\chi, \delta)}\}$.

Now let $\{x_{(\alpha, \beta)}\}^c$ be IF semi g^*-closed. Since $\{y_{(\chi, \delta)}\} \subset \{x_{(\alpha, \beta)}\}^c$, $\{y_{(\chi, \delta)}\} \in \text{scl}^* \{y_{(\chi, \delta)}\} \subset \{x_{(\alpha, \beta)}\}^c$ and hence $\text{scl}^* \{x_{(\alpha, \beta)}\} \neq \text{scl}^* \{y_{(\chi, \delta)}\}$.

By IFSO (τ) we mean the collection of all IF semi open sets in the space (X, τ) and similarly, we define $\text{IFSO}^*(\tau) = \{A : \text{scl}^*(A^c) = A^c\}$.

Theorem 4.3. In an IF topological space (X, τ), $\text{IFSO}(\tau) \subset \text{IFSO}^*(\tau)$.

Proof : Let $A \in \text{IFSO}(\tau)$. Then A^c is IF semi closed and $A^c = \text{scl}(A^c)$. Since A^c is IF semi closed, therefore A^c is is also IF sg^*-closed, so $\text{scl}^*(A^c) = A^c$. Hence $A \in \text{IFSO}^*(\tau)$.

Theorem 4.4. An IF topological space (X, τ) is IF semi T_a-space iff $\text{IFSO}(\tau) = \text{IFSO}^*(\tau)$.

Proof : Let (X, τ) be an IF semi T_a-space. Then $\text{scl}(A) = \text{scl}^*(A)$ holds for every IF subset A, since IF semi closed sets and IF sg^*-closed sets coincide in IF semi T_a- space. Therefore we have $\text{IFSO}(\tau) = \text{IFSO}^*(\tau)$.

Conversely, let A be IF sg^*-closed set of (X, τ). Then $A = \text{scl}^*(A)$ and hence $A^c \in \text{IFSO}(\tau)$. Thus A is IF semi closed. Therefore (X, τ) is IF semi T_a-space.

Theorem 4.5. An IF topological space (X, τ) is IF semi T_a- space iff for each $x_{(\alpha, \beta)} \in X$, $\{x_{(\alpha, \beta)}\}$ is IF semi open or IF semi g-closed.

Proof : Let $x_{(\alpha, \beta)} \in X$ and $\{x_{(\alpha, \beta)}\}$ is not IF semi g-closed. Then $\{x_{(\alpha, \beta)}\}^c$ is not IF semi g-open. This implies that $1_\sim$ is the only IF semi g-open set containing $\{x_{(\alpha, \beta)}\}^c$. scl $\{x_{(\alpha, \beta)}\}^c \subseteq 1_\sim$. So $\{x_{(\alpha, \beta)}\}^c$ is IF sg^*-closed set of (X, τ). Since (X, τ) is IF semi T_a-space, $\{x_{(\alpha, \beta)}\}^c$ is IF semi closed. Therefore $\{x_{(\alpha, \beta)}\}$ is IF semi open.

For the converse part it is enough to prove that $\text{IFSO}^*(\tau) \subset \text{IFSO}(\tau)$. Let $A^c \in \text{IFSO}^*(\tau)$ and $A \notin \text{IFSO}(\tau)$. Then $\text{scl}^*(A^c) = A^c$ and $\text{scl}(A^c) \neq A^c$. Then there exist a point $x_{(\alpha, \beta)}$ of X such that $x_{(\alpha, \beta)} \in \text{scl}(A^c)$ and $x_{(\alpha, \beta)} \notin \text{scl}^*(A^c) = A^c$. Since $x_{(\alpha, \beta)} \notin \text{scl}^*(A^c)$ there exists an IF semi g^*-closed set F such that $x_{(\alpha, \beta)} \notin F$ and $A^c \subset F$. By the hypothesis, $\{x_{(\alpha, \beta)}\}$ is IF semi open or IF semi g-closed.

Case I. Let $\{x_{(\alpha,\beta)}\}$ is IF semi open. Since $\{x_{(\alpha,\beta)}\}^c$ is IF semi closed and $A^c \subset \{x_{(\alpha,\beta)}\}^c$, we have scl $(A^c) \subset \{x_{(\alpha,\beta)}\}^c$, *i.e.* $x_{(\alpha,\beta)} \notin$ scl (A^c). This contradicts the fact that $x_{(\alpha,\beta)} \in$ scl (A^c). Therefore $A \in$ IFSO (τ).

Case II. Let $\{x_{(\alpha,\beta)}\}$ is IF semi g-closed. Since $\{x_{(\alpha,\beta)}\}^c$ is IF semi g-open set containing the IF sg^*-closed set $F \supset A^c$, we have $\{x_{(\alpha,\beta)}\}^c \supset$ scl $(F) \supset$ scl (A^c). Therefore $\{x_{(\alpha,\beta)}\} \notin$ scl (A^c). This is a contradiction. Hence $A \in$ IFSO (τ). Hence in both the cases $A \in$ IFSO (τ). Hence IFSO* $(\tau) \subset$ IFSO (τ).

Definition 4.3. An IF topological space (X, τ) is said to be an IF semi T_0- space iff for any pair of distinct points $x_{(\alpha,\beta)}$ and $y_{(\chi,\delta)}$ in X, either $x_{(\alpha,\beta)} \notin$ scl $\{y_{(\chi,\delta)}\}$ or $y_{(\chi,\delta)} \notin$ scl $\{x_{(\alpha,\beta)}\}$, *i.e.* scl $\{x_{(\alpha,\beta)}\} \neq$ scl $\{y_{(\chi,\delta)}\}$.

Theorem 4.6. Every IF semi T_a- space is IF semi T_0- space.

Proof : Let (X, τ) be an IF semi T_a- space but not IF semi T_0-space. Then there exists two distinct points $x_{(\alpha,\beta)}$ and $y_{(\chi,\delta)}$ in X, such that scl $\{x_{(\alpha,\beta)}\} =$ scl $\{y_{(\chi,\delta)}\}$. Let $A = \{x_{(\alpha,\beta)}\}^c$. Clearly $\{x_{(\alpha,\beta)}\}$ is not IF semi closed, otherwise scl $\{x_{(\alpha,\beta)}\} = \{x_{(\alpha,\beta)}\} \neq$ scl $\{y_{(\chi,\delta)}\}$. By the theorem 4.1, A is IF sg^*-closed. But A is not IF semi closed, otherwise $y_{(\chi,\delta)} \in \{x_{(\alpha,\beta)}\}^c = A$ implies scl $\{y_{(\chi,\delta)}\} \subseteq \{x_{(\alpha,\beta)}\}^c$ and scl $\{x_{(\alpha,\beta)}\} \neq$ scl $\{y_{(\chi,\delta)}\}$, contradicting our hypothesis. Hence (X, τ) is IF semi T_0- space.

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