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Results on Fuzzy Weakly (r, s)-Continuous Mappings on the Intuitionistic Fuzzy Topological Spaces in Šostak's Sense

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Abstract

In this paper, we investigate some characterizations for fuzzy weakly (r, s)-continuous mapping on an intuitionistic fuzzy topological space in Šostak's sense.

Key words : fuzzy weakly (r, s)-continuous, fuzzy (r, s)-continuous, fuzzy (r, s)-semiopen, fuzzy (r, s)-preopen, fuzzy (r, s)-β-open, fuzzy (r, s)-regular open

1. Introduction

The concept of fuzzy set was introduced by Zadeh [13]. As a generalization of fuzzy sets, the concept of intuitionistic fuzzy sets was introduced by Atanassov [1]. Chang [2] defined fuzzy topological spaces using fuzzy sets. In [3], Chattopadhyay, Hazra and Samanta introduced the concept of smooth fuzzy topological spaces which are a generalization of fuzzy topological spaces. Çoker and his colleagues [4,5,6,7] introduced intuitionistic fuzzy topological spaces using intuitionistic fuzzy sets. In [5], Çoker and Demirci introduced intuitionistic fuzzy topological spaces in Šostak's sense as a generalization of smooth fuzzy topological spaces and intuitionistic fuzzy topological spaces.

The concepts of fuzzy (r, s)-open sets, fuzzy (r, s)-semiopen sets and fuzzy (r, s)-preopen sets are introduced in [8,9]. Lee and Kim [10] introduced and studied the concept of fuzzy weakly (r, s)-continuous mappings. In this paper, we investigate some characterizations for fuzzy weakly (r, s)-continuous mappings on the intuitionistic fuzzy topological space in Šostak's sense.

2. Preliminaries

Let I be the unit interval $[0, 1]$ of the real line. A member μ of I^X is called a fuzzy set of X. For any $\mu \in I^X$, μ^c denotes the complement $1 - \mu$. By $\tilde{0}$ and $\tilde{1}$ we denote constant maps on X with value 0 and 1, respectively. All other notations are standard notations of fuzzy set theory.

Let X be a nonempty set. An *intuitionistic fuzzy set* A is an ordered pair

$$A = \{< x, \mu_A(x), \gamma_A(x) >: x \in X\}(\text{ simply, } A = (\mu_A, \gamma_A))$$

where the functions $\mu_A : X \to I$ and $\gamma_A : X \to I$ denote the degree of membership and the degree of nonmembership, respectively, and $0 \le \mu_A(x) + \gamma_A(x) \le 1$ for $x \in X$.

An *intuitionistic fuzzy point* $x_{(\alpha,\beta)}$ in X is an intuitionistic fuzzy set

$$x_{(\alpha,\beta)} = (\mu_A, \gamma_A)$$

where the functions $\mu_A : X \to I$ and $\gamma_A : X \to I$ are defined as follows.

$$(\mu_A(y), \gamma_A(y)) = \begin{cases} (\alpha, \beta), & \text{if } y = x, \\ (0, 1), & \text{if } y \ne x, \end{cases}$$

and $0 \le \alpha + \beta \le 1$.

An intuitionistic fuzzy point $x_{(\alpha,\beta)}$ is said to belong to an intuitionistic fuzzy set $A = (\mu_A, \gamma_A)$ in X, denoted by $x_{(\alpha,\beta)} \in A$, if $\mu_A(x) \ge \alpha$ and $\gamma_A(x) \le \beta$ for $x \in X$.

An intuitionistic fuzzy set A in X is the union of all intuitionistic fuzzy points which belong to A.

Definition 2.1. ([1]) Let $A = (\mu_A, \gamma_A)$ and $B = (\mu_B, \gamma_B)$ be intuitionistic fuzzy sets on X. Then

(1) $A \subseteq B$ iff $\mu_A \le \mu_B$ and $\gamma_A \ge \gamma_B$.
(2) $A = B$ iff $A \subseteq B$ and $B \subseteq A$.
(3) $A^c = (\gamma_A, \mu_A)$.
(4) $A \cap B = (\mu_A \wedge \mu_B, \gamma_A \vee \gamma_B)$.
(5) $A \cup B = (\mu_A \vee \mu_B, \gamma_A \wedge \gamma_B)$.
(6) $0_\sim = (\tilde{0}, \tilde{1})$ and $1_\sim = (\tilde{1}, \tilde{0})$.

Let f be a map from a set X to a set Y. Let $A = (\mu_A, \gamma_A)$ be an intuitionistic fuzzy set of X and $B = (\mu_B, \gamma_B)$ an intuitionistic fuzzy set of Y.

The image of A under f, denoted by $f(A)$, is an intuitionistic fuzzy set in Y defined by

$$f(A) = (f(\mu_A), \tilde{1} - f(\tilde{1} - \gamma_A)).$$

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The inverse image of B under f, denoted by $f^{-1}(B)$, is an intuitionistic fuzzy set in X defined by

$$f^{-1}(B) = (f^{-1}(\mu_B), f^{-1}(\gamma_B)).$$

A *smooth fuzzy topology* [11] on X is a map $T : I^X \to I$ which satisfies the following properties:

(1) $T(\tilde{0}) = T(\tilde{1}) = 1$.

(2) $T(\mu_1 \wedge \mu_2) \geq T(\mu_1) \wedge T(\mu_2)$ for $\mu_1, \mu_2 \in I^X$.

(3) $T(\bigvee \mu_i) \geq \bigwedge T(\mu_i)$ for $\mu_i \in I^X$.

The pair (X, T) is called a *smooth fuzzy topological space.*

An *intuitionistic fuzzy topology* on X is a family T of intuitionistic fuzzy sets in X which satisfies the following properties:

(1) $0_\sim, 1_\sim \in T$.

(2) If $A_1, A_2 \in T$, then $A_1 \cap A_2 \in T$.

(3) If $A_i \in T$ for all i, then $\bigcup A_i \in T$.

The pair (X, T) is called an *intuitionistic fuzzy topological space.*

Let $I(X)$ be a family of all intuitionistic fuzzy sets of X and let $I \otimes I$ be the set of the pair (r, s) such that $r, s \in I$ and $0 \leq r + s \leq 1$.

Definition 2.2. ([6]) Let X be a nonempty set. An *intuitionistic fuzzy topology in Šostak's sense* (SoIFT for short) $\mathcal{T} = (\mathcal{T}_1, \mathcal{T}_2)$ on X is a map $\mathcal{T} : I(X) \to I \otimes I$ which satisfies the following properties:

(1) $\mathcal{T}_1(0_\sim) = \mathcal{T}_1(1_\sim) = 1$ and $\mathcal{T}_2(0_\sim) = \mathcal{T}_2(1_\sim) = 0$.

(2) $\mathcal{T}_1(A \cap B) \geq \mathcal{T}_1(A) \wedge \mathcal{T}_1(B)$ and $\mathcal{T}_2(A \cap B) \leq \mathcal{T}_2(A) \vee \mathcal{T}_2(B)$.

(3) $\mathcal{T}_1(\bigcup A_i) \geq \bigwedge \mathcal{T}_1(A_i)$ and $\mathcal{T}_2(\bigcup A_i) \leq \bigvee \mathcal{T}_2(A_i)$.

The $(X, \mathcal{T}) = (X, \mathcal{T}_1, \mathcal{T}_2)$ is said to be an *intuitionistic fuzzy topological space in Šostak's sense* (SoIFTS for short). Also, we call $\mathcal{T}_1(A)$ a *gradation of openness* of A and $\mathcal{T}_2(A)$ a *gradation of nonopenness* of A.

Definition 2.3. ([10]) Let $x_{(\alpha,\beta)}$ be an intuitionistic fuzzy point in an SoIFTS $(X, \mathcal{T}_1, \mathcal{T}_2)$ and $(r, s) \in I \otimes I$. Then an intuitionistic fuzzy set A is said to be a *fuzzy (r, s)-neighborhood* of $x_{(\alpha,\beta)}$ if there is a fuzzy (r, s)-open set B in X such that $x_{(\alpha,\beta)} \in B \subseteq A$.

3. Main Results

Definition 3.1. ([10]) Let $f : (X, \mathcal{T}_1, \mathcal{T}_2) \to (Y, \mathcal{U}_1, \mathcal{U}_2)$ be a mapping from an SoIFTS X to another SoIFTS Y and $(r, s) \in I \otimes I$. Then f is said to be *fuzzy weakly (r, s)-continuous* if for each fuzzy (r, s)-open set B of Y, $f^{-1}(B) \subseteq int(f^{-1}(cl(B, r, s)), r, s)$.

Theorem 3.2. Let $f : (X, \mathcal{T}_1, \mathcal{T}_2) \to (Y, \mathcal{U}_1, \mathcal{U}_2)$ be a mapping from an SoIFTS X to another SoIFTS Y and $(\alpha, \beta), (r, s) \in I \otimes I$. Then f is a fuzzy weakly (r, s)-continuous mapping if and only if for every intuitionistic fuzzy point $x_{(\alpha,\beta)}$ and each fuzzy (r, s)-neighborhood V of $f(x_{(\alpha,\beta)})$, there exists a fuzzy (r, s)-neighborhood U of $x_{(\alpha,\beta)}$ such that $f(U) \subseteq cl(V, r, s)$.

Proof. Let $x_{(\alpha,\beta)}$ be an intuitionistic fuzzy point in X and V a fuzzy (r, s)-neighborhood of $f(x_{(\alpha,\beta)})$; then there exists a fuzzy (r, s)-open set B such that $f(x_{(\alpha,\beta)}) \subseteq B \subseteq V$. Since f is a fuzzy weakly (r, s)-continuous mapping,

$$\begin{aligned} f^{-1}(B) &\subseteq int(f^{-1}(cl(B, r, s)), r, s) \\ &\subseteq int(f^{-1}(cl(V, r, s)), r, s). \end{aligned}$$

Set $U = f^{-1}(cl(V, r, s))$; then

$$x_{(\alpha,\beta)} \in f^{-1}(B) \subseteq int(U, r, s) \subseteq U.$$

Hence U is a fuzzy (r, s)-neighborhood of $x_{(\alpha,\beta)}$ and $f(U) \subseteq cl(V, r, s)$.

For the converse, let V be a fuzzy (r, s)-open set in Y. By hypothesis, for each $x_{(\alpha,\beta)} \in f^{-1}(V)$, there exists a fuzzy (r, s)-neighborhood $U_{x_{(\alpha,\beta)}}$ of $x_{(\alpha,\beta)}$ such that $f(U_{x_{(\alpha,\beta)}}) \subseteq cl(V, r, s)$. Now we can say there exists a fuzzy (r, s)-open set $G_{x_{(\alpha,\beta)}}$ such that

$$x_{(\alpha,\beta)} \in G_{x_{(\alpha,\beta)}} \subseteq U_{x_{(\alpha,\beta)}} \subseteq f^{-1}(cl(V, r, s))$$

for each $x_{(\alpha,\beta)} \in f^{-1}(V)$.

Thus we have

$$\begin{aligned} f^{-1}(V) &\subseteq \cup\{G_{x_{(\alpha,\beta)}} : x_{(\alpha,\beta)} \in f^{-1}(V)\} \\ &\subseteq f^{-1}(cl(V, r, s)). \end{aligned}$$

Since $\cup\{G_{x_{(\alpha,\beta)}} : x_{(\alpha,\beta)} \in f^{-1}(V)\}$ is a fuzzy (r, s)-open set, we have $f^{-1}(V) \subseteq int(f^{-1}(cl(V, r, s)), r, s)$. □

Theorem 3.3. Let $f : (X, \mathcal{T}_1, \mathcal{T}_2) \to (Y, \mathcal{U}_1, \mathcal{U}_2)$ be a mapping from an SoIFTS X to another SoIFTS Y and $(\alpha, \beta), (r, s) \in I \otimes I$. Then the following statements are equivalent:

(1) f is a fuzzy weakly (r, s)-continuous mapping.

(2) For each intuitionistic fuzzy point $x_{(\alpha,\beta)}$ and each fuzzy (r, s)-open set V containing $f(x_{(\alpha,\beta)})$, there exists a fuzzy (r, s)-open set U containing $x_{(\alpha,\beta)}$ such that $f(U) \subseteq cl(V, r, s)$.

(3) $cl(f^{-1}(int(F, r, s)), r, s) \subseteq f^{-1}(F)$ for each fuzzy (r, s)-closed set F in Y.

(4) $cl(f^{-1}(int(cl(B, r, s), r, s)), r, s) \subseteq f^{-1}(cl(B, r, s))$ for each fuzzy intuitionistic fuzzy set B in Y.

(5) $f^{-1}(int(B, r, s)) \subseteq int(f^{-1}(cl(int(B, r, s), r, s)), r, s)$ for each fuzzy intuitionistic fuzzy set B in Y.

(6) $cl(f^{-1}(V), r, s) \subseteq f^{-1}(cl(V, r, s))$ for a fuzzy (r, s)-open set V in Y.

Proof. (1) $\Leftrightarrow$ (2) From Theorem 3.2, it is obvious.

(1) $\Rightarrow$ (3) Let F be any fuzzy (r,s)-closed set of Y. Then $1_\sim - F$ is a fuzzy (r,s)-open set in Y and by (1),

$$\begin{aligned} f^{-1}(1_\sim - F) &\subseteq int(f^{-1}(cl(1_\sim - F, r, s)), r, s) \\ &= int(f^{-1}(1_\sim - int(F, r, s)), r, s) \\ &= int(1_\sim - f^{-1}(int(F, r, s), r, s)) \\ &= 1_\sim - cl(f^{-1}(int(F, r, s)), r, s). \end{aligned}$$

Hence we have $cl(f^{-1}(int(F,r,s)),r,s) \subseteq f^{-1}(F)$.

(3) $\Rightarrow$ (4) Let B be any intuitionistic fuzzy set in Y. Since $cl(B,r,s)$ is a fuzzy (r,s)-closed set in Y, by (3),

$$cl(f^{-1}(int(cl(B,r,s),r,s))) \subseteq f^{-1}(cl(B,r,s)).$$

(4) $\Rightarrow$ (5) Let B be any intuitionistic fuzzy set of Y. Then,

$$\begin{aligned} & f^{-1}(int(B,r,s)) \\ = \;& 1_\sim - (f^{-1}(cl(1_\sim - B, r, s))) \\ \subseteq \;& 1_\sim - cl(f^{-1}(int(cl(1_\sim - B, r, s), r, s)), r, s) \\ = \;& int(f^{-1}(cl(int(B, r, s), r, s)), r, s). \end{aligned}$$

Hence,

$$f^{-1}(int(B,r,s)) \subseteq int(f^{-1}(cl(int(B,r,s),r,s)),r,s).$$

(5) $\Rightarrow$ (6) Let V be any fuzzy (r,s)-open set of Y. Then by (5),

$$\begin{aligned} & 1_\sim - f^{-1}(cl(V,r,s)) \\ = \;& f^{-1}(int(1_\sim - V, r, s)) \\ \subseteq \;& int(f^{-1}(cl(int(\tilde{1} - V, r, s), r, s)), r, s) \\ = \;& int(1_\sim - (f^{-1}(int(cl(V, r, s), r, s)), r, s)) \\ = \;& 1_\sim - cl(f^{-1}(int(cl(V, r, s), r, s)), r, s) \\ \subseteq \;& 1_\sim - cl(f^{-1}(V), r, s). \end{aligned}$$

Hence we have

$$cl(f^{-1}(V),r,s) \subseteq f^{-1}(cl(V,r,s)).$$

(6) $\Rightarrow$ (2) Let V be a fuzzy (r,s)-open set containing $f(x_{(\alpha,\beta)})$. By (6),

$$\begin{aligned} x_{(\alpha,\beta)} &\in f^{-1}(V) \\ &\subseteq f^{-1}(int(cl(V,r,s),r,s)) \\ &= 1_\sim - f^{-1}(cl(1_\sim - cl(V,r,s),r,s)) \\ &\subseteq 1_\sim - cl(f^{-1}(1_\sim - cl(V,r,s)),r,s) \\ &= int(f^{-1}(cl(V,r,s)),r,s). \end{aligned}$$

Set $U = int(f^{-1}(cl(V,r,s)),r,s)$. Then U is a fuzzy (r,s)-open set satisfying $f(U) \subseteq cl(V,r,s)$. □

Definition 3.4. Let A be an intuitionistic fuzzy set in an SoIFTS $(X, \mathcal{T}_1, \mathcal{T}_2)$ and $(r,s) \in I \otimes I$. Then A is said to be

(1) *fuzzy (r,s)-semiopen* [8] if there is a fuzzy (r,s)-open set B in X such that $B \subseteq A \subseteq cl(B,r,s)$,

(2) *fuzzy (r,s)-preopen* [9] if $A \subseteq int(cl(A,r,s),r,s)$,

(3) *fuzzy (r,s)-regular open* [10] if $A = int(cl(A,r,s),r,s)$,

(4) *fuzzy (r,s)-β-open* if $A \subseteq cl(int(cl(A,r,s),r,s),r,s)$.

fuzzy (r,s)-semiopen
↗ ↘
fuzzy (r,s)-open fuzzy (r,s)-β-open
↘ ↗
fuzzy (r,s)-preopen

The following examples show that the converses of the above diagram may not be true.

Example 3.5. Let $X = \{x,y\}$ and A_1, A_2 and A_3 be intuitionistic fuzzy sets of X defined as

$$A_1(x) = (0, 0.8), \quad A_1(y) = (0.3, 0.5);$$

$$A_2(x) = (0.8, 0), \quad A_2(y) = (0.3, 0.5);$$

and

$$A_3(x) = (0.8, 0), \quad A_3(y) = (0.6, 0.3);$$

Define $\mathcal{T} : I(X) \to I \otimes I$ by

$$\mathcal{T}(A) = (\mathcal{T}_1(A), \mathcal{T}_2(A)) = \begin{cases} (1,0) & \text{if } A = 0_\sim, 1_\sim, \\ (\frac{1}{2}, \frac{1}{3}) & \text{if } A = A_1, \\ (0,1) & \text{otherwise.} \end{cases}$$

Then $(\mathcal{T}_1, \mathcal{T}_2)$ is an SoIFT on X. Since $cl(A_3, \frac{1}{2}, \frac{1}{3}) = 1_\sim$, clearly A_3 is a fuzzy $(\frac{1}{2}, \frac{1}{3})$-$\beta$-open set but it is not fuzzy $(\frac{1}{2}, \frac{1}{3})$-semiopen.

Example 3.6. Let $X = \{x,y,z\}$ and A_1, A_2 and A_3 be intuitionistic fuzzy sets of X defined as

$A_1(x) = (0, 0.8)$, $A_1(y) = (0.3, 0.6)$, $A_1(z) = (0.3, 0.6)$;

$A_2(x) = (0.8, 0)$, $A_2(y) = (0.6, 0.3)$, $A_2(z) = (0.6, 0.3)$;

and

$A_3(x) = (0.8, 0)$, $A_3(y) = (0.5, 0.3)$, $A_3(z) = (0.5, 0.3)$.

Consider an SoIFT $\mathcal{T} : I(X) \to I \otimes I$ on X defined as follows.

$$\mathcal{T}(A) = (\mathcal{T}_1(A), \mathcal{T}_2(A)) = \begin{cases} (1,0) & \text{if } A = 0_\sim, 1_\sim, \\ (\frac{1}{2}, \frac{1}{3}) & \text{if } A = A_1, \\ (0,1) & \text{otherwise.} \end{cases}$$

Since $A_3 \subseteq cl(int(cl(A_3, \frac{1}{2}, \frac{1}{3}), \frac{1}{2}, \frac{1}{3}), \frac{1}{2}, \frac{1}{3})$ and $int(cl(A_3, \frac{1}{2}, \frac{1}{3}), \frac{1}{2}, \frac{1}{3}) \subseteq A_3$, A_3 is a fuzzy $(\frac{1}{2}, \frac{1}{3})$-$\beta$-open set but not a fuzzy $(\frac{1}{2}, \frac{1}{3})$-preopen set.

Theorem 3.7. Let $f : (X, \mathcal{T}_1, \mathcal{T}_2) \to (Y, \mathcal{U}_1, \mathcal{U}_2)$ be a mapping from an SoIFTS X to another SoIFTS Y and $(r, s) \in I \otimes I$. Then the following statements are equivalent:

(1) f is a fuzzy weakly (r, s)-continuous mapping.

(2) $cl(f^{-1}(int(cl(G,r,s),r,s)),r,s) \subseteq f^{-1}(cl(G,r,s))$ for each fuzzy (r, s)-open set G in Y.

(3) $cl(f^{-1}(int(cl(V,r,s),r,s)),r,s) \subseteq f^{-1}(cl(V,r,s))$ for each fuzzy (r, s)-preopen set V in Y.

(4) $cl(f^{-1}(int(K,r,s)),r,s) \subseteq f^{-1}(K)$ for each fuzzy (r, s)-regular closed set K in Y.

(5) $cl(f^{-1}(int(cl(G,r,s),r,s)),r,s) \subseteq f^{-1}(cl(G,r,s))$ for each fuzzy (r, s)-β-open set G in Y.

(6) $cl(f^{-1}(int(cl(G,r,s),r,s)),r,s) \subseteq f^{-1}(cl(G,r,s))$ for each fuzzy (r, s)-semiopen set G in Y.

Proof. (1) $\Rightarrow$ (2) Let G be a fuzzy (r,s)-open set of Y; then by Theorem 3.3 (3), we have $cl(f^{-1}(int(cl(G,r,s),r,s)),r,s) \subseteq f^{-1}(cl(G,r,s))$.

(2) $\Rightarrow$ (3) Let V be a fuzzy (r, s)-preopen set in Y. Then $V \subseteq int(cl(V,r,s),r,s)$. Set $A = int(cl(V,r,s),r,s)$. Since A is a fuzzy fuzzy (r, s)-open set, from (2), it follows

$$cl(f^{-1}(int(cl(A,r,s),r,s)),r,s) \subseteq f^{-1}(cl(A,r,s)).$$

Since $cl(A,r,s) = cl(V,r,s)$, we have

$$cl(f^{-1}(int(cl(V,r,s),r,s)),r,s) \subseteq f^{-1}(cl(V,r,s)).$$

(3) $\Rightarrow$ (4) Let K be a fuzzy (r, s)-regular closed set of Y. Since $int(K,r,s)$ is a fuzzy (r, s)-preopen set, by (3),

$$cl(f^{-1}(int(cl(int(K,r,s),r,s),r,s)),r,s)$$
$$\subseteq f^{-1}(cl(int(K,r,s),r,s)).$$

Since $int(K,r,s) = int(cl(int(K,r,s),r,s),r,s)$ and $K = cl(int(K,r,s),r,s)$, we have

$$cl(f^{-1}(int(K,r,s)),r,s) \subseteq f^{-1}(K).$$

(4) $\Rightarrow$ (5) Let G be a fuzzy (r,s)-β-open set. Then $G \subseteq (cl(int(cl(G,r,s),r,s),r,s)$ and $cl(G,r,s)$ is a fuzzy (r, s)-regular closed set. Hence by (4), we have

$$cl(f^{-1}(int(cl(G,r,s),r,s)),r,s) \subseteq f^{-1}(cl(G,r,s)).$$

(5) $\Rightarrow$ (6) It is obvious.

(6) $\Rightarrow$ (1) Let V be a fuzzy (r, s)-open set; then since V is a fuzzy (r, s)-semiopen set, by (6) and $V \subseteq int(cl(V,r,s),r,s)$, we have

$$cl(f^{-1}(V),r,s) \subseteq cl(f^{-1}(int(cl(V,r,s),r,s)),r,s)$$
$$\subseteq f^{-1}(cl(V,r,s)).$$

Hence, f is a fuzzy weakly (r, s)-continuous mapping. □

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