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Fuzzy (r, s)-semicontinuous mappings on the intuitionistic fuzzy topological spaces in Šostak's sense

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Abstract

In this paper, we investigate some characterizing theorems for fuzzy (r, s)-semicontinuous, (r, s)-semiopen and (r, s)-semiclosed mappings on the intuitionistic fuzzy topological space in Šostak's sense.

Key words : fuzzy (r, s)-semicontinuous, intuitionistic fuzzy topology

1. Introduction

The concept of fuzzy set was introduced by Zadeh [11]. Chang [2] defined fuzzy topological spaces. These spaces and its generalizations are later studied by several authors, one of which, developed by Šostak [10], used the idea of degree of openness. This type of generalization of fuzzy topological spaces was later rephrased by Chattopadhyay, Hazra, and Samanta [3], and by Ramadan [9].

As a generalization of fuzzy sets, the concept of intuitionistic fuzzy sets was introduced by Atanassov [1]. Recently, Çoker and his colleagues [4,5,7] introduced intuitionistic fuzzy topological spaces using intuitionistic fuzzy sets. Using the idea of degree of openness and degree of nonopenness, R. Erturk and M. Demirci [6] defined intuitionistic fuzzy topological spaces in Šostak's sense as a generalization of smooth fuzzy topological spaces and intuitionistic fuzzy topological spaces.

In this paper, we investigate some characterizing theorems for fuzzy (r, s)-semicontinuous, (r, s)-semiopen and (r, s)-semiclosed 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

$$A = (\mu_A, \gamma_A)$$

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 $\mu_A + \gamma_A \leq \tilde{1}$.

Obviously every fuzzy set μ on X is an intuitionistic fuzzy set of the form $(\mu, \tilde{1} - \mu)$.

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 $\mu_A \leq \mu_B$ and $\gamma_A \geq \gamma_B$.
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. Then:

1. 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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2. 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* on X is a map $T : I^X \to I$ which satisfies the following properties:

1. $T(\tilde{0}) = T(\tilde{1}) = 1$.
2. $T(\mu_1 \wedge \mu_2) \geq T(\mu_1) \wedge T(\mu_2)$.
3. $T(\bigvee \mu_i) \geq \bigwedge T(\mu_i)$.

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 $r + s \leq 1$.

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.

Let $(X, \mathcal{T})$ be an intuitionistic fuzzy topological space in Šostak's sense. Then it is easy to see that for each $(r, s) \in I \otimes I$, the family $\mathcal{T}_{(r,s)}$ defined by

$$\mathcal{T}_{(r,s)} = \{A \in I(X) \mid \mathcal{T}_1(A) \geq r \text{ and } \mathcal{T}_2(A) \leq s\}$$

is an intuitionistic fuzzy topology on X.

Let (X, T) be an intuitionistic fuzzy topological space and $(r, s) \in I \otimes I$. Then the map $T^{(r,s)} : I(X) \to I \otimes I$ defined by

$$T^{(r,s)}(A) = \begin{cases} (1,0) & \text{if } A = 0_\sim, 1_\sim \\ (r,s) & \text{if } A \in T - \{0_\sim, 1_\sim\} \\ (0,1) & \text{otherwise} \end{cases}$$

becomes an intuitionistic fuzzy topology in Šostak's sense on X.

Definition 2.3 ([8]) Let A be an intuitionistic fuzzy set in a 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* if there is a fuzzy (r, s)-open set B in X such that $B \subseteq A \subseteq \mathrm{cl}(B, r, s)$,
2. *fuzzy (r, s)-semiclosed* if there is a fuzzy (r, s)-closed set B in X such that $\mathrm{int}(B, r, s) \subseteq A \subseteq B$.

Definition 2.4 ([8]) Let $(X, \mathcal{T}_1, \mathcal{T}_2)$ be a SoIFTS. For each $(r, s) \in I \otimes I$ and for each $A \in I(X)$, the *fuzzy (r, s)-semiclosure* is defined by

$$\mathrm{scl}(A, r, s)$$

$$= \bigcap \{B \in I(X) \mid A \subseteq B, B \text{is fuzzy } (r, s)\text{-semiclosed}\}$$

and the *fuzzy (r, s)-semiinterior* is defined by

$$\mathrm{sint}(A, r, s)$$

$$= \bigcup \{B \in I(X) \mid A \supseteq B, B \text{is fuzzy } (r, s)\text{-semiopen}\}.$$

Lemma 2.5([8]) For an intuitionistic fuzzy set A in a SoIFTS $(X, \mathcal{T}_1, \mathcal{T}_2)$ and $(r, s) \in I \otimes I$,

1. $\mathrm{sint}(A, r, s)^c = \mathrm{scl}(A^c, r, s)$.
2. $\mathrm{scl}(A, r, s)^c = \mathrm{sint}(A^c, r, s)$.

3. Fuzzy (r, s)-semicontinuous mappings

Definition 3.1 ([8]) Let $f : (X, \mathcal{T}_1, \mathcal{T}_2) \to (Y, \mathcal{U}_1, \mathcal{U}_2)$ be a mapping from a SoIFTS X to another SoIFTS Y and $(r, s) \in I \otimes I$. Then f is said to be

1. a fuzzy (r, s)-continuous mapping if $f^{-1}(B)$ is a fuzzy (r, s)-open set of X for each fuzzy (r, s)-open set B of Y,
2. a fuzzy (r, s)-open mapping if $f(A)$ is a fuzzy (r, s)-open set of Y for each fuzzy (r, s)-open set A of X,
3. a fuzzy (r, s)-closed mapping if $f(A)$ is a fuzzy (r, s)-closed set of Y for each fuzzy (r, s)-closed set A of X.

Definition 3.2 ([8]) Let $f : (X, \mathcal{T}_1, \mathcal{T}_2) \to (Y, \mathcal{U}_1, \mathcal{U}_2)$ be a mapping from a SoIFTS X to another SoIFTS Y and $(r, s) \in I \otimes I$. Then f is said to be

1. fuzzy (r, s)-semicontinuous if $f^{-1}(B)$ is a fuzzy (r, s)-semiopen set of X for each fuzzy (r, s)-open set B of Y,
2. fuzzy (r, s)-semiopen if $f(A)$ is a fuzzy (r, s)-semiopen set of Y for each fuzzy (r, s)-open set A of X,
3. fuzzy (r, s)-semiclosed if $f(A)$ is a fuzzy (r, s)-semiclosed set of Y for each fuzzy (r, s)-closed set A of X.

It is clear that every fuzzy (r, s)-continuous ((r, s)-open, (r, s)-closed, respectively) mapping is a fuzzy (r, s)-semicontinuous ((r, s)-semiopen, (r, s)-semiclosed, respectively) mapping for each $(r, s) \in I \otimes I$. However the converse need not be true, which is shown by the following example.

Example 3.3 Let $X = \{x, y\}$ and A_1 and A_2 be intuitionistic fuzzy sets of X defined as

$$A_1(x) = (0.6, 0.3), \quad A_1(y) = (0.3, 0.5);$$

and

$$A_2(x) = (0.8, 0.1), \quad A_2(y) = (0.5, 0.4).$$

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

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

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

$$\mathcal{U}(A) = (\mathcal{U}_1(A), \mathcal{U}_2(A)) = \begin{cases} (1, 0) & \text{if } A = 0_\sim, 1_\sim, \\ (\frac{1}{2}, \frac{1}{3}) & \text{if } A = A_2, \\ (0, 1) & \text{otherwise.} \end{cases}$$

Then clearly $(\mathcal{T}_1, \mathcal{T}_2)$ and $(\mathcal{U}_1, \mathcal{U}_2)$ are SoIFTs on X. Consider the identity mapping $1_X : (X, \mathcal{T}_1, \mathcal{T}_2) \to (X, \mathcal{U}_1, \mathcal{U}_2)$. Then it is a fuzzy $(\frac{1}{2}, \frac{1}{3})$-semicontinuous mapping which is not a fuzzy $(\frac{1}{2}, \frac{1}{3})$-continuous mapping.

Theorem 3.4 Let $f : (X, \mathcal{T}_1, \mathcal{T}_2) \to (Y, \mathcal{U}_1, \mathcal{U}_2)$ be a mapping and $(r, s) \in I \otimes I$. Then the following statements are equivalent:

1. f is a fuzzy (r, s)-semicontinuous mapping.
2. $f^{-1}(B)$ is a fuzzy (r, s)-semiclosed set of X for each fuzzy (r, s)-closed set B of Y.
3. $f(\text{scl}(A, r, s)) \subseteq \text{cl}(f(A), r, s)$ for each intuitionistic fuzzy set A of X.
4. $\text{scl}(f^{-1}(B), r, s) \subseteq f^{-1}(\text{cl}(B, r, s))$ for each intuitionistic fuzzy set B of Y.
5. $f^{-1}(\text{int}(B, r, s)) \subseteq \text{sint}(f^{-1}(B), r, s)$ for each intuitionistic fuzzy set B of Y.

Proof. (1) $\Leftrightarrow$ (2) It is obvious.

(2) $\Rightarrow$ (3) Let A be any intuitionistic fuzzy set of X. Since $\text{cl}(f(A), r, s)$ is fuzzy (r, s)-closed set of Y, $f^{-1}(\text{cl}(f(A), r, s))$ is a fuzzy (r, s)-semiclosed set of X. Thus

$$\begin{aligned} \text{scl}(A, r, s) &\subseteq \text{scl}(f^{-1}f(A), r, s) \\ &\subseteq \text{scl}(f^{-1}(\text{cl}(f(A), r, s)), r, s) \\ &= f^{-1}(\text{cl}(f(A), r, s)). \end{aligned}$$

Hence

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

(3) $\Rightarrow$ (4) Let B be any intuitionistic fuzzy set of Y. By (3),

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

Thus

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

(4) $\Rightarrow$ (5) Let B be any intuitionistic fuzzy set of Y. Then B^c is a intuitionistic fuzzy set of Y. By (4),

$$\begin{aligned} \text{scl}(f^{-1}(B)^c, r, s) &= \text{scl}(f^{-1}(B^c), r, s) \\ &\subseteq f^{-1}(\text{cl}(B^c, r, s)). \end{aligned}$$

By Lemma 2.5,

$$f^{-1}(\text{int}(B,r,s)) = f^{-1}(\text{cl}(B^c,r,s))^c$$
$$\subseteq \text{scl}(f^{-1}(B^c),r,s)^c = \text{sint}(f^{-1}(B),r,s).$$

(5) ⇒ (1) Let B be any fuzzy (r,s)-open set of Y. Then $\text{int}(B,r,s) = B$. By (5),

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

So $f^{-1}(B) = \text{sint}(f^{-1}(B),r,s)$ and hence $f^{-1}(B)$ is a fuzzy (r,s)-semiopen set of X. Thus f is a fuzzy (r,s)-semicontinuous mapping.

Theorem 3.5 Let $f : (X,\mathcal{T}_1,\mathcal{T}_2) \to (Y,\mathcal{U}_1,\mathcal{U}_2)$ be a bijection and $(r,s) \in I \otimes I$. Then f is a fuzzy (r,s)-semicontinuous mapping if and only if $\text{int}(f(A),r,s) \subseteq f(\text{sint}(A,r,s))$ for each intuitionistic fuzzy set A of X.

Proof. Let f be a fuzzy (r,s)-semicontinuous mapping and A any intuitionistic fuzzy set of X. Since $\text{int}(f(A),r,s)$ is fuzzy (r,s)-open in Y, $f^{-1}(\text{int}(f(A),r,s))$ is fuzzy (r,s)-semiopen in X. Since f is one-to-one, we have

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

Since f is onto,

$$\text{int}(f(A),r,s) = ff^{-1}(\text{int}(f(A),r,s)) \subseteq f(\text{sint}(A,r,s)).$$

Conversely, let B be fuzzy (r,s)-open in Y. Then $\text{int}(B,r,s) = B$. Since f is onto,

$$f(\text{sint}(f^{-1}(B),r,s)) \supseteq \text{int}(ff^{-1}(B),r,s)$$
$$= \text{int}(B,r,s) = B.$$

Since f is one-to-one, we have

$$f^{-1}(B) \subseteq f^{-1}f(\text{sint}(f^{-1}(B),r,s))$$
$$= \text{sint}(f^{-1}(B),r,s) \subseteq f^{-1}(B).$$

Thus $f^{-1}(B) = \text{sint}(f^{-1}(B),r,s)$ and hence f is fuzzy (r,s)-semiopen in X. Therefore f is fuzzy (r,s)-semicontinuous.

Theorem 3.6 Let $f : (X,\mathcal{T}_1,\mathcal{T}_2) \to (Y,\mathcal{U}_1,\mathcal{U}_2)$ be a mapping and $(r,s) \in I \otimes I$. Then the following statements are equivalent:

1. f is a fuzzy (r,s)-semiopen mapping.
2. $f(\text{int}(A,r,s)) \subseteq \text{sint}(f(A),r,s)$ for each intuitionistic fuzzy set A of X.
3. $\text{int}(f^{-1}(B),r,s) \subseteq f^{-1}(\text{sint}(B,r,s))$ for each intuitionistic fuzzy set B of Y.

Proof. (1) ⇒ (2) Let A be any intuitionistic fuzzy set of X. Clearly $\text{int}(A,r,s)$ is a fuzzy (r,s)-open set of X. Since f is a fuzzy (r,s)-open mapping, $f(\text{int}(A,r,s))$ is a fuzzy (r,s)-semiopen set of Y. Thus

$$f(\text{int}(A,r,s)) = \text{sint}(f(\text{int}(A,r,s)),r,s)$$
$$\subseteq \text{sint}(f(A),r,s).$$

(2) ⇒ (3) Let B be any intuitionistic fuzzy set of Y. Then $f^{-1}(B)$ is an intuitionistic fuzzy set of X. By (2),

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

Thus we have

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

(3) ⇒ (1) Let A be any fuzzy (r,s)-open set of X. Then $\text{int}(A,r,s) = A$ and $f(A)$ is an intuitionistic fuzzy set of Y. By (3),

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

Hence we have

$$f(A) \subseteq ff^{-1}(\text{sint}(f(A),r,s))$$
$$\subseteq \text{sint}(f(A),r,s) \subseteq f(A).$$

Thus $f(A) = \text{sint}(f(A),r,s)$ and hence $f(A)$ is a fuzzy (r,s)-semiopen set of Y. Therefore f is a fuzzy (r,s)-semiopen mapping.

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

1. f is a fuzzy (r,s)-semiclosed mapping.
2. $\text{scl}(f(A),r,s) \subseteq f(\text{cl}(A,r,s))$ for each intuitionistic fuzzy set A of X.

Proof. (1) $\Rightarrow$ (2) Let A be any intuitionistic fuzzy set of X. Clearly $\mathrm{cl}(A, r, s)$ is a fuzzy (r, s)-closed set of X. Since f is a fuzzy (r, s)-semiclosed mapping, $f(\mathrm{cl}(A, r, s))$ is a fuzzy (r, s)-semiclosed set of Y. Thus we have

$$\begin{aligned} \mathrm{scl}(f(A), r, s) &\subseteq \mathrm{scl}(f(\mathrm{cl}(A, r, s)), r, s) \\ &= f(\mathrm{cl}(A, r, s)). \end{aligned}$$

(2) $\Rightarrow$ (1) Let A be any fuzzy (r, s)-closed set of X. Then $\mathrm{cl}(A, r, s) = A$. By (2),

$$\begin{aligned} \mathrm{scl}(f(A), r, s) &\subseteq f(\mathrm{cl}(A, r, s)) \\ &= f(A) \subseteq \mathrm{scl}(f(A), r, s). \end{aligned}$$

Thus $f(A) = \mathrm{scl}(f(A), r, s)$ and hence $f(A)$ is a fuzzy (r, s)-semiclosed set of Y. Therefore f is a fuzzy (r, s)-semiclosed mapping.

Theorem 3.8 Let $f : (X, \mathcal{T}_1, \mathcal{T}_2) \to (Y, \mathcal{U}_1, \mathcal{U}_2)$ be a bijection and $(r, s) \in I \otimes I$. Then f is a fuzzy (r, s)-semiclosed mapping if and only if $f^{-1}(\mathrm{scl}(B, r, s)) \subseteq \mathrm{cl}(f^{-1}(B), r, s)$ for each intuitionistic fuzzy set B of Y.

Proof. Let f be a fuzzy (r, s)-semiclosed mapping and B *any intuitionistic fuzzy set of* Y. *Then* $f^{-1}(B)$ *is an* intuitionistic fuzzy set of X. Since f is onto, we have

$$\begin{aligned} \mathrm{scl}(B, r, s) &= \mathrm{scl}(ff^{-1}(B), r, s) \\ &\subseteq f(\mathrm{cl}(f^{-1}(B), r, s)). \end{aligned}$$

Since f is one-to-one, we have

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

Conversely, let A be any fuzzy (r, s)-closed set of X. Then $\mathrm{cl}(A, r, s) = A$. Since f is one-to-one,

$$\begin{aligned} f^{-1}(\mathrm{scl}(f(A), r, s)) &\subseteq \mathrm{cl}(f^{-1}f(A), r, s) \\ &= \mathrm{cl}(A, r, s) = A. \end{aligned}$$

Since f is onto, we have

$$\begin{aligned} \mathrm{scl}(f(A), r, s) &= ff^{-1}(\mathrm{scl}(f(A), r, s)) \subseteq f(A) \\ &\subseteq \mathrm{scl}(f(A), r, s). \end{aligned}$$

Thus $f(A) = \mathrm{scl}(f(A), r, s)$ and hence $f(A)$ is a fuzzy (r, s)-semiclosed set of Y. Therefore f is a fuzzy (r, s)-semiclosed mapping.

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