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On Fuzzy Irresolute Functions

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Abstract

As a generalization of the notions of fuzzy α-irresolute, fuzzy preirresolute, fuzzy irresolute and fuzzy β-irresolute functions, we introduce the notion of fuzzy $\beta\alpha$-continuous functions and investigate the relationships between fuzzy $\beta\alpha$-continuous functions and fuzzy separation axioms.

Key words : fuzzy β-open set, fuzzy α-open set, fuzzy $\beta\alpha$-continuity

1. Introduction and Preliminaries

The notions of fuzzy irresolute, fuzzy α-irresolute and fuzzy preirresolute functions were introduced and studied by Mukherjee and Sinha [6], Thakur and Saraf [11] and Park and Park [8], respectively.

The aim of this paper is to introduce a new class of fuzzy functions which is called $\beta\alpha$-continuous functions including the classes of fuzzy irresolute, fuzzy α-irresolute, fuzzy preirresolute and fuzzy β-irresolute functions. Furthermore, we obtain basic properties of $\beta\alpha$-continuous functions and investigate relationships between fuzzy $\beta\alpha$-continuity and fuzzy covering properties and fuzzy $\beta\alpha$-continuity and fuzzy separations axioms, respectively.

The class of fuzzy sets on a universe X will be denoted by I^X and fuzzy sets on X will be denoted by Greek letters as μ, ρ, η, etc. A family τ of fuzzy sets in X is called a fuzzy topology [3] for X iff (1) $\emptyset, X \in \tau$ (2) $\mu \wedge \rho \in \tau$ whenever $\mu, \rho \in \tau$ and (3) $\vee\{\mu_\alpha : \alpha \in I\} \in \tau$ whenever each $\mu_\alpha \in \tau (\alpha \in I)$. In this case, the pair (X, τ) (or simply X) is called a fuzzy topological space (for short, fuzzy space). Every member of τ is called a fuzzy open set [7]. For a fuzzy set μ in X, $\operatorname{int}\mu$ and $\operatorname{cl}\mu$ will denote the interior and closure of μ, respectively. A fuzzy set in X is called a fuzzy point iff it takes the value 0 for all $y \in X$ except one, say, $x \in X$. If its value at x is $\alpha (0 < \alpha \leq 1)$, we denote this fuzzy point by x_α, where the point x is called its support [7]. For any fuzzy point x_ε and any fuzzy set μ, we write $x_\varepsilon \in \mu$ iff $\varepsilon \leq \mu(x)$.

Definition 1.1. A fuzzy set μ in X is called:

(1) fuzzy α-open [10] if $\mu \leq \operatorname{int}\operatorname{cl}\operatorname{int}(\mu)$;
(2) fuzzy semiopen [1] if $\mu \leq \operatorname{cl}\operatorname{int}(\mu)$;
(3) fuzzy preopen [10] $\mu \leq \operatorname{int}\operatorname{cl}(\mu)$;
(4) fuzzy β-open [5, 12] if $\mu \leq \operatorname{cl}\operatorname{int}\operatorname{cl}(\mu)$.

The complement of a fuzzy α-open (resp. fuzzy semiopen, fuzzy preopen, fuzzy β-open) set is called fuzzy α-closed (resp. fuzzy semiclosed, fuzzy preclosed, fuzzy β-closed).

Definition 1.2. A fuzzy function $f: X \to Y$ is said to be:

(1) fuzzy open [3] (resp. always fuzzy β-open) if $f(\rho)$ is fuzzy open (resp. fuzzy β-open) in Y for every fuzzy open (resp. fuzzy β-open) set ρ in X;

(2) fuzzy irresolute [6] if $f^{-1}(\rho)$ is fuzzy semiopen in X for each fuzzy semiopen set ρ in Y;

(3) fuzzy α-irresolute [11] if $f^{-1}(\rho)$ is fuzzy α-open in X for each fuzzy α-open set ρ in Y;

(4) fuzzy preirresolute [8] if $f^{-1}(\rho)$ is fuzzy preopen in X for each fuzzy preopen set ρ in Y;

(5) fuzzy β-irresolute if $f^{-1}(\rho)$ is fuzzy β-open in X for each fuzzy β-open set ρ in Y.

2. Fuzzy $\beta\alpha$-continuous functions

Definition 2.1. A fuzzy function $f: X \to Y$ is said to be fuzzy $\beta\alpha$-continuous if for each fuzzy point $x_\varepsilon \in X$ and each fuzzy α-open set ρ in Y containing $f(x_\varepsilon)$, there exists a fuzzy β-open set μ in X containing x_ε such that $f(\mu) \leq \rho$.

Theorem 2.2. For a fuzzy function $f: X \to Y$, the following statements are equivalent:

(1) f is fuzzy $\beta\alpha$-continuous;
(2) for every fuzzy α-open set ρ in Y, $f^{-1}(\rho)$ is fuzzy

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β-open;

(3) for every fuzzy α-closed set ρ in Y, $f^{-1}(\rho)$ is fuzzy β-closed.

Proof. (1) ⇒(2): Let ρ be a fuzzy α-open set in Y and let $x_\varepsilon \in f^{-1}(\rho)$. Since $f(x_\varepsilon) \in \rho$, by (1), there exists a fuzzy β-open set μ_{x_ε} in X containing x_ε such that $\mu_{x_\varepsilon} \leq f^{-1}(\rho)$. We obtain that $f^{-1}(\rho) = \bigvee_{x_\varepsilon \in f^{-1}(\rho)} \mu_{x_\varepsilon}$. Thus, $f^{-1}(\rho)$ is fuzzy β-open.

(2) ⇒(1): Let ρ be a fuzzy α-open set in Y and let $f(x_\varepsilon) \in \rho$. We have $x_\varepsilon \in f^{-1}(\rho)$. By (2), $f^{-1}(\rho)$ is a fuzzy β-open set. Take $\eta = f^{-1}(\rho)$. Then $f(\eta) \leq \rho$. Thus, f is fuzzy $\beta\alpha$-continuous.

(2) ⇒(3): Let ρ be a fuzzy α-closed set in Y. Then $Y \setminus \rho$ is fuzzy α-open. By (2), $f^{-1}(Y \setminus \rho) = X \setminus f^{-1}(\rho)$ is fuzzy β-open. Thus, $f^{-1}(\rho)$ is fuzzy β-closed.

(3) ⇒(2): Similar to (2) ⇒(3).

Definition 2.3. A fuzzy filter base Λ is said to be fuzzy β-convergent (resp. fuzzy α-convergent) to a fuzzy point $x_\varepsilon \in X$ if for any fuzzy β-open (resp. fuzzy α-open) set ρ in X containing x_ε, there exists a fuzzy set $\mu \in \Lambda$ such that $\mu \leq \rho$.

Theorem 2.4. If a fuzzy function $f: X \to Y$ is fuzzy $\beta\alpha$-continuous, then for each fuzzy point $x_\varepsilon \in X$ and each fuzzy filter base Λ in X which is β-convergent to x_ε, the fuzzy filter base $f(\Lambda)$ is fuzzy α-convergent to $f(x_\varepsilon)$.

Proof. Let $x_\varepsilon \in X$ and Λ be any fuzzy filter base in X which is β-convergent to x_ε. Since f is fuzzy $\beta\alpha$-continuous, then for any fuzzy α-open set λ in Y containing $f(x_\varepsilon)$, there exists a fuzzy β-open set μ in X containing x_ε such that $f(\mu) \leq \lambda$. Since Λ is fuzzy β-convergent to x_ε, there exists a $\rho \in \Lambda$ such that $\rho \leq \mu$. This means that $f(\rho) \leq \lambda$ and therefore the fuzzy filter base $f(\Lambda)$ is fuzzy α-convergent to $f(x_\varepsilon)$.

Remark 2.5. For $f: X \to Y$, the following diagram holds:

	fuzzy α-irresolute	
	⇓	
fuzzy β-irr. ⇒	fuzzy $\beta\alpha$-conti.	⇐ fuzzy preirr.
	⇑	
	fuzzy irresolute	

The following examples show that these implications are not reversible.

Example 2.6. Let $X = \{a, b\}$, $Y = \{x, y\}$ and λ, μ are fuzzy sets defined as follows:

$$\lambda(a) = 0.3,\ \lambda(b) = 0.6,$$

$$\mu(x) = 0.7,\ \mu(y) = 0.5.$$

Let $\tau_1 = \{X, \emptyset, \lambda\}$ and $\tau_2 = \{Y, \emptyset, \mu\}$. Then the fuzzy function $f: (X, \tau_1) \to (Y, \tau_2)$ defined by $f(a) = x$ and $f(b) = y$ is fuzzy $\beta\alpha$-continuous but neither fuzzy α-irresolute nor irresolute.

Example 2.7. In the above example, we take

$$\mu(x) = 0.7,\ \mu(y) = 0.6.$$

Then the fuzzy function $f: (X, \tau_1) \to (Y, \tau_2)$ defined by $f(a) = x$ and $f(b) = y$ is fuzzy $\beta\alpha$- continuous but neither fuzzy preirresolute nor β- irresolute.

Theorem 2.8. Let $f: X \to Y$ be a fuzzy function and let $g: X \to X \times Y$ be the fuzzy graph function of f [1], defined by $g(x_\varepsilon) = (x_\varepsilon, f(x_\varepsilon))$ for each $x_\varepsilon \in X$. If g is fuzzy $\beta\alpha$-continuous, then f is fuzzy $\beta\alpha$-continuous.

Proof. Let ρ be fuzzy α-open set in Y. Then $X \times \rho$ is fuzzy α-open set in $X \times Y$. Since g is fuzzy $\beta\alpha$-continuous, then $f^{-1}(\rho) = g^{-1}(X \times \rho)$ is fuzzy β-open in X. Thus, f is fuzzy $\beta\alpha$-continuous.

Definition 2.9. A fuzzy space X said to be:

(1) fuzzy β-compact [4] (resp. fuzzy α-compact [4, 11]) if every fuzzy β-open (resp. fuzzy α-open) cover of X has a finite subcover;

(2) fuzzy countably β-compact (resp. fuzzy countably α-compact) if every fuzzy β-open (resp. fuzzy α-open) countably cover of X has a finite subcover;

(3) fuzzy β-Lindelof (resp. fuzzy α-Lindelof) if every cover of X by fuzzy β-open (resp. fuzzy α-open) sets has a countable subcover.

Theorem 2.10. Let $f: X \to Y$ be a fuzzy $\beta\alpha$-continuous surjection. Then the following statements hold:

(1) If X is fuzzy β-compact, then Y is fuzzy α-compact.

(2) If X is fuzzy β-Lindelof, then Y is fuzzy α-Lindelof.

(3) If X is fuzzy countably β-compact, then Y is fuzzy countably α-compact.

Proof. We prove only (1). Let $\{\mu_\alpha: \alpha \in I\}$ be any fuzzy α-open cover of Y. Since f is fuzzy $\beta\alpha$- continuous, then $\{f^{-1}(\mu_\alpha): \alpha \in I\}$ is a fuzzy β- open cover of X. Since X is fuzzy β-compact, there exists a finite subset I_0 of I such that $X = \bigvee \{f^{-1}(\mu_\alpha): \alpha \in I_0\}$. Then we have $Y = \bigvee \{\mu_\alpha: \alpha \in I_0\}$ and thus Y is fuzzy α-compact.

Definition 2.11. A fuzzy space X is said to be fuzzy β-

connected (resp. fuzzy connected [9]) if it cannot be expressed as the union of two nonempty, disjoint fuzzy β-open (resp. fuzzy open) sets.

Theorem 2.12. If $f: X \to Y$ is fuzzy $\beta\alpha$-continuous surjective function and X is fuzzy β- connected space, then Y is fuzzy connected space.

Proof. Suppose that Y is not fuzzy connected space. Then there exists nonempty disjoint fuzzy open sets β and μ such that $Y = \beta \vee \mu$. Hence, β and μ are fuzzy α-open sets in Y. Since f is fuzzy $\beta\alpha$-continuous, $f^{-1}(\beta)$ and $f^{-1}(\mu)$ are fuzzy β-closed and β-open. Moreover, $f^{-1}(\beta)$ and $f^{-1}(\mu)$ are nonempty disjoint and $X = f^{-1}(\beta) \vee f^{-1}(\mu)$. This shows that X is not fuzzy β-connected. This is a contradiction. Therefore, Y is fuzzy connected.

Definition 2.13. A fuzzy space X is called hyper-connected [2] if every fuzzy open set is dense.

Remark 2.14. The following example shows that fuzzy $\beta\alpha$-continuous surjection do not necessarily preserve fuzzy hyperconnectedness.

Example 2.15. Let $X = \{a, b\}$, $Y = \{x, y\}$ and λ, μ are fuzzy sets defined as follows:

$$\lambda(a) = 0.3,\ \lambda(b) = 0.6,$$

$$\mu(x) = 0.5,\ \mu(y) = 0.5.$$

Let $\tau_1 = \{X, \emptyset, \lambda\}$ and $\tau_2 = \{Y, \emptyset, \mu\}$. Then the fuzzy function $f: (X, \tau_1) \to (Y, \tau_2)$ defined by $f(a) = x$ and $f(b) = y$ is fuzzy $\beta\alpha$-continuous surjective and (X, τ_1) is hyperconnected. But (Y, τ_2) is not hyperconnected.

3. Several properties

In this section, we investigate the relationships between fuzzy $\beta\alpha$-continuous functions and separation axioms and those graphs.

Definition 3.1. A fuzzy space X is said to be fuzzy β-T_1 (resp. fuzzy α-T_1) if for each pair of distinct fuzzy points x_ε and y_ν of X, there exist fuzzy β-open (resp. α-open) sets β and μ containing x_ε and y_ν, respectively, such that $y_\nu \not\in \beta$ and $x_\varepsilon \not\in \mu$.

Theorem 3.2. If $f: X \to Y$ is a fuzzy $\beta\alpha$-continuous injection and Y is fuzzy α-T_1, then X is fuzzy β-T_1.

Proof. Suppose that Y is fuzzy α-T_1. For any distinct fuzzy points x_ε and y_ν in X, there exist fuzzy α-open sets μ and ρ in Y such that $f(x_\varepsilon) \in \mu$, $f(y_\nu) \notin \mu$, $f(x_\varepsilon) \notin \rho$ and $f(y_\nu) \in \rho$. Since f is fuzzy $\beta\alpha$-continuous, $f^{-1}(\mu)$ and $f^{-1}(\rho)$ are β-open sets in X such that $x_\varepsilon \in f^{-1}(\mu)$, $y_\nu \not\in f^{-1}(\mu)$, $x_\varepsilon \not\in f^{-1}(\rho)$ and $y_\nu \in f^{-1}(\rho)$. This shows that X is fuzzy β-T_1.

Definition 3.3. A fuzzy space X is said to be fuzzy β-T_2 (resp. fuzzy α-T_2) if for each pair of distinct fuzzy points x_ε and y_ν of X, there exist disjoint fuzzy β-open (resp. fuzzy α-open) sets β and μ in X such that $x_\varepsilon \in \beta$ and $y_\nu \in \mu$.

Theorem 3.4. If $f: X \to Y$ is a fuzzy $\beta\alpha$-continuous injection and Y is fuzzy α-T_2, then X is fuzzy β-T_2.

Proof. For any pair of distinct fuzzy points x_ε and y_ν in X, there exist disjoint fuzzy α-open sets β and μ in Y such that $f(x_\varepsilon) \in \beta$ and $f(y_\nu) \in \mu$. Since f is fuzzy $\beta\alpha$-continuous, $f^{-1}(\beta)$ and $f^{-1}(\mu)$ is fuzzy β-open in X containing x_ε and y_ν, respectively. Then we obtain $f^{-1}(\beta) \wedge f^{-1}(\mu) = \emptyset$. This shows that X is fuzzy β-T_2.

Definition 3.5. A fuzzy space X is said to be fuzzy strongly α-regular (resp. fuzzy strongly β- regular) if for each fuzzy α-closed (resp. fuzzy β-closed) set η and each fuzzy point $x_\varepsilon \not\in \eta$, there exist disjoint fuzzy open sets β and μ such that $\eta \leq \beta$ and $x_\varepsilon \in \mu$.

Definition 3.6. A fuzzy space X is said to be fuzzy strongly α-normal (resp. fuzzy strongly β-normal) if for every pair of disjoint fuzzy α-closed (resp. fuzzy β-closed) sets η_1 and η_2 in X, there exist disjoint fuzzy open sets β and μ such that $\eta_1 \leq \beta$ and $\eta_2 \leq \mu$.

Theorem 3.7. If $f: X \to Y$ is fuzzy $\beta\alpha$-continuous, fuzzy open bijection and X is a fuzzy strongly β-regular space, then Y is fuzzy strongly α-regular.

Proof. Let η be fuzzy α-closed set in Y and $y_\nu \not\in \eta$. Take $y_\varepsilon = f(x_\varepsilon)$. Since f is fuzzy $\beta\alpha$-continuous, $f^{-1}(\eta)$ is a fuzzy β-closed set. Take $\lambda = f^{-1}(\eta)$. We have $x_\varepsilon \not\in \lambda$. Since X is fuzzy strongly β-regular, there exist disjoint fuzzy open sets β and μ such that $\lambda \leq \beta$ and $x_\varepsilon \in \mu$. Thus, we obtain that $\eta = f(\lambda) \leq f(\beta)$ and $y_\varepsilon = f(x_\varepsilon) \in f(\mu)$ such that $f(\beta)$ and $f(\mu)$ are disjoint fuzzy open sets. This shows that Y is fuzzy strongly α-regular.

Theorem 3.8. If $f: X \to Y$ is fuzzy $\beta\alpha$-continuous, fuzzy open bijection and X is a fuzzy strongly β-normal space, then Y is fuzzy strongly α-normal.

Proof. Let η_1 and η_2 be disjoint fuzzy α-closed sets in

Y. Since f is fuzzy $\beta\alpha$-continuous, $f^{-1}(\eta_1)$ and $f^{-1}(\eta_2)$ are fuzzy β-closed sets. Take $\beta = f^{-1}(\eta_1)$ and $\mu = f^{-1}(\eta_2)$. We have $\beta \wedge \mu = \emptyset$. Since X is fuzzy strongly β-normal, there exist disjoint fuzzy open sets λ and ρ such that $\beta \leq \lambda$ and $\mu \leq \rho$. We obtain that $\eta_1 = f(\beta) \leq f(\lambda)$ and $\eta_2 = f(\mu) \leq f(\rho)$ such that $f(\lambda)$ and $f(\rho)$ are disjoint fuzzy open sets. Thus, Y is fuzzy strongly α-normal.

Recall that for a fuzzy function $f: X \to Y$, the subset $\{(x_\varepsilon, f(x_\varepsilon)) : x_\varepsilon \in X\} \leq X \times Y$ is called the graph of f and is denoted by $G(f)$.

Definition 3.9. A graph $G(f)$ of a fuzzy function $f: X \to Y$ is said to be fuzzy β-α-closed if for each $(x_\varepsilon, y_\nu) \in (X \times Y) \setminus G(f)$, there exist a fuzzy β-open set β in X containing x_ε and a fuzzy α-open set μ in Y containing y_ν such that $(\beta \times \mu) \wedge G(f) = \emptyset$.

Lemma 3.10. A graph $G(f)$ of $f: X \to Y$ is fuzzy β-α-closed in $X \times Y$ if and only if for each $(x_\varepsilon, y_\nu) \in (X \times Y) \setminus G(f)$, there exist a fuzzy β-open set β in X containing x_ε and a fuzzy α-open set μ in Y containing y_ν such that $f(\beta) \wedge \mu = \emptyset$.

Theorem 3.11. If $f: X \to Y$ is fuzzy $\beta\alpha$-continuous and Y is fuzzy α-Hausdorff, then $G(f)$ is fuzzy β-α-closed in $X \times Y$.

Proof. Let $(x_\varepsilon, y_\nu) \in (X \times Y) \setminus G(f)$. Then $f(x_\varepsilon) \neq y_\nu$. Since Y is fuzzy α-Hausdorff, there exist disjoint fuzzy α-open sets β and μ in Y such that $f(x_\varepsilon) \in \beta$ and $y_\nu \in \mu$. Since f is fuzzy $\beta\alpha$-continuous, there exists a β-open set ρ in X containing x_ε such that $f(\rho) \leq \beta$. Therefore, we obtain $y_\nu \in \mu$ and $f(\rho) \wedge \mu = \emptyset$. This shows that $G(f)$ is fuzzy β-α-closed.

Theorem 3.12. Let $f: X \to Y$ has a fuzzy β-α-closed graph $G(f)$. If f is injective, then X is fuzzy β-T_1.

Proof. Let x_ε and y_ν be any two distinct fuzzy points of X. Then, $(x_\varepsilon, f(y_\nu)) \in (X \times Y) \setminus G(f)$. By definition of fuzzy β-α-closed graph, there exist a fuzzy β-open set β in X and a fuzzy α-open set μ in Y such that $f(x_\varepsilon) \in \beta$, $y_\nu \in \mu$ and $f(\rho) \wedge \mu = \emptyset$ and hence $\beta \wedge f^{-1}(\mu) = \emptyset$. Therefore, we have $y_\nu \notin \beta$. This implies that X is fuzzy β-T_1.

Theorem 3.13. Let $f: X \to Y$ has a fuzzy β-α-closed graph $G(f)$. If f is surjective always fuzzy β-open function, then Y is fuzzy β-T_2.

Proof. Let y_ν and y_ξ be any distinct points of Y. Since f is surjective, $f(x_\nu) = y_\nu$ for some $x_\nu \in X$ and $(x_{\text{nu}}, y_\xi) \in (X \times Y) \setminus G(f)$. By the fuzzy β-α-closedness of graph $G(f)$, there exists a fuzzy β-open set β in X and a fuzzy α-open set μ in Y such that $x_\nu \in \beta$, $y_\xi \in \mu$ and $(\beta \times \mu) \wedge G(f) = \emptyset$. Then, we have $f(\beta) \wedge \mu = \emptyset$. Since f is always fuzzy β-open, then $f(\beta)$ is fuzzy β-open such that $f(x_\nu) = y_\nu \in f(\beta)$. This implies that Y is fuzzy β-T_2.

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