Intuitionistic fuzzy rare α-continuity

R. Dhavaseelan*
Department of Mathematics
Sona College of Technology
Salem-636005, Tamil Nadu
India
dhavaseelan.r@gmail.com

S. Jafari
College of Vestsjaelland South
Herrestraede 11, 4200 Slagelse
Denmark
jafaripersia@gmail.com

Abstract. In this paper, the concepts of intuitionistic fuzzy rare α-continuous function, intuitionistic fuzzy rarely continuous function, intuitionistic fuzzy rarely pre-continuous function, intuitionistic fuzzy rarely semi-continuous function are introduced and studied in light of the concept of rare set in intuitionistic fuzzy setting. We present some basic properties.

Keywords: intuitionistic fuzzy rare set, intuitionistic fuzzy rarely α-continuous function, intuitionistic fuzzy rarely pre- continuous function, intuitionistic fuzzy almost α-continuous function, intuitionistic fuzzy weekly α-continuous function, intuitionistic fuzzy rarely semi continuous function.

1. Introduction

The study of fuzzy sets was initiated by Zadeh [20] in 1965. Thereafter the paper of Chang [3] in 1968 paved the way for the subsequent tremendous growth of the numerous fuzzy topological concepts. In the course of time, Fuzzy Topology proved to be very beneficial in fixing many realistic problems.

Several mathematicians have tried almost all the pivotal concepts of General Topology for extension to the fuzzy settings. In 1981, Azad [1] gave fuzzy version of the concepts given by Levine ([12], [13]) and thus initiated the study of weak forms of several notions in fuzzy topological spaces.

Popa [17] introduced the notion of rare continuity as a generalization of weak continuity [12] which has been further investigated by Long and Herrington [14] and S. Jafari ([9], [10]). Noiri [15] introduced and investigated weakly α-continuity as a generalization of weak continuity. He also introduced and investigated almost α-continuity [16]. The concept of rare α-continuity was introduced by S. Jafari [11]. The concept of new weaker form of Popa's rare

∗. Corresponding author

continuity via α-open sets [6] and rare s-precontinuity for multifunctions [7] are introduced by E. Ekici and S. Jafari. The concept of fuzzy rare α-continuity was introduced by R. Dhavaseelan and S. Jafari [5].

The purpose of the present paper is to introduce the concepts of intuitionistic fuzzy rare α-continuous function, intuitionistic fuzzy rarely continuous function, intuitionistic fuzzy rarely pre-continuous function, intuitionistic fuzzy rarely semi-continuous function in the light of the concept of rare set in a intuitionistic fuzzy setting.

Definition 1.1 ([4])**.** An intuitionistic fuzzy topology (IFT) on a nonempty set X is a family τ of IFSs in X satisfying the following axioms:

(i) $0_\sim, 1_\sim \in \tau$;

(ii) $G_1 \cap G_2 \in \tau$ for any $G_1, G_2 \in \tau$;

(iii) $\cup G_i \in \tau$ for arbitrary family $\{G_i \mid i \in \Lambda\} \subseteq \tau$.

In this case the ordered pair (X, τ) or simply X is called an intuitionistic fuzzy topological space (IFTS) and each IFS in τ is called an intuitionistic fuzzy open set (IFOS). The complement $\overline{A}$ of an IFOS A in X is called an intuitionistic fuzzy closed set (IFCS) in X.

Definition 1.2 ([4])**.** Let A be an intuitionistic fuzzy set in an intuitionistic fuzzy topological space X. Then:

$int(A) = \bigcup\{G \mid G$ is an IFOS in X and $G \subseteq A\}$ is called the intuitionistic fuzzy interior of A;

$cl(A) = \bigcap\{G \mid G$ is an IFCS in X and $G \supseteq A\}$ is called the intuitionistic fuzzy closure of A.

Definition 1.3 ([18])**.** Let X be a nonempty set. If $r \in I_0$,$s \in I_1$ are fixed real numbers such that $r + s \leq 1$, then the intuitionistic fuzzy set $x_{r,s}$ is called an intuitionistic fuzzy point(briefly IFP)in X given by

$$x_{r,s}(x_p) = \begin{cases} (r, s), & \text{if } x = x_p \\ (0, 1), & \text{if } x \neq x_p, \end{cases}$$

for $x_p \in X$ is called the support of $x_{r,s}$, where r denotes the degree of membership value and s is the degree of non-membership value of $x_{r,s}$.

Definition 1.4 ([2, 8])**.** An intuitionistic fuzzy set A in an intuitionistic fuzzy topological space (X, T) is called

(1) an intuitionistic fuzzy semiopen set (briefly IFSOS) if $A \subseteq cl(int(A))$;

(2) an intuitionistic fuzzy α-open set(briefly IFαOS) if $A \subseteq int(cl(int(A)))$;

(3) an intuitionistic fuzzy preopen set (briefly IFPOS) if $A \subseteq int(cl(A))$;

(4) an intuitionistic fuzzy regular open set (briefly IFROS) if $A = int(cl(A))$.

An IFS A is called an intuitionistic fuzzy semiclosed set, intuitionistic fuzzy α-closed set, intuitionistic fuzzy preclosed set, and intuitionistic fuzzy regular closed set, respectively (briefly IFSCS, IFαCS, IFPCS, and IFRCS resp.), if the complement of A is an IFSOS, IFαOS, IFPOS, and IFROS, respectively.

Definition 1.5 ([19])**.** Let A be an IFS of an IFTS (X, T). The α-closure of A (briefly $\alpha cl(A)$) is defined as $\alpha cl(A) = \bigcap\{K|$ K is an $IF\alpha CS$ in X and $A \subseteq K\}$.

Definition 1.6 ([19])**.** Let A be an IFS of an IFTS (X, T). The α-interior of A (briefly $\alpha int(A)$) is defined as $\alpha int(A) = \bigcup\{K|$ K is an $IF\alpha OS$ in X and $K \subseteq A\}$.

2. Main results

Definition 2.1. An intuitionistic fuzzy set R is called intuitionistic fuzzy rare set if $IFint(R) = 0_\sim$.

Definition 2.2. An intuitionistic fuzzy set R is called intuitionistic fuzzy nowhere dense set if $IFint(IFcl(R)) = 0_\sim$.

Definition 2.3. Let (X, T) and (Y, S) be two intuitionistic fuzzy topological spaces. A function $f : (X, T) \to (Y, S)$ is called:

(i) intuitionistic fuzzy α-continuous function if for each intuitionistic fuzzy point $x_{r,s}$ in X and each intuitionistic fuzzy open set G in Y containing $f(x_{r,s})$, there exists an intuitionistic fuzzy α-open set U in X such that $f(U) \leq G$.

(ii) intuitionistic fuzzy almost α-continuous function if for each intuitionistic fuzzy point $x_{r,s}$ in X and each intuitionistic fuzzy open set G containing $f(x_{r,s})$, there exists an intuitionistic fuzzy α-open set U such that $f(U) \leq IFint(IFcl(G))$.

(iii) intuitionistic fuzzy weakly α-continuous function if for each intuitionistic fuzzy point $x_{r,s}$ in X and each intuitionistic fuzzy open set G containing $f(x_{r,s})$, there exists an intuitionistic fuzzy α-open set U such that $f(U) \leq IFcl(G)$.

Definition 2.4. Let (X, T) and (Y, S) be two intuitionistic fuzzy topological spaces. A function $f : (X, T) \to (Y, S)$ is called:

(i) intuitionistic fuzzy rarely α-continuous function if for each intuitionistic fuzzy point $x_{r,s}$ in X and each intuitionistic fuzzy open set G in (Y, S) containing $f(x_{r,s})$, there exist an intuitionistic fuzzy rare set R with $G \cap IFcl(R) = 0_\sim$ and intuitionistic fuzzy α open set U in (X, T) such that $f(U) \leq G \cup R$.

(ii) intuitionistic fuzzy rarely continuous function if for each intuitionistic fuzzy point $x_{r,s}$ in X and each intuitionistic fuzzy open set G in (Y,S) containing $f(x_{r,s})$, there exist an intuitionistic fuzzy rare set R with $G \cap IFcl(R) = 0_\sim$ and intuitionistic fuzzy open set U in (X,T) such that $f(U) \leq G \cup R$.

(iii) intuitionistic fuzzy rarely pre-continuous function if for each intuitionistic fuzzy point $x_{r,s}$ in X and each intuitionistic fuzzy open set G in (Y,S) containing $f(x_{r,s})$, there exist an intuitionistic fuzzy rare set R with $G \cap IFcl(R) = 0_\sim$ and intuitionistic fuzzy preopen set U in (X,T) such that $f(U) \leq G \cup R$.

(iv) intuitionistic fuzzy rarely semi-continuous function if for each intuitionistic fuzzy point $x_{r,s}$ in X and each intuitionistic fuzzy open set G in (Y,S) containing $f(x_{r,s})$, there exist an intuitionistic fuzzy rare set R with $G \cap IFcl(R) = 0_\sim$ and intuitionistic fuzzy semiopen set U in (X,T) such that $f(U) \leq G \cup R$.

Example 2.1. Let $X = \{a,b,c\}$. Define the intuitionistic fuzzy sets A, B and C as follows: $A = \langle x, (\frac{a}{0}, \frac{b}{0}, \frac{c}{1}), (\frac{a}{1}, \frac{b}{1}, \frac{c}{0})\rangle$, $B = \langle x, (\frac{a}{1}, \frac{b}{0}, \frac{c}{0}), (\frac{a}{0}, \frac{b}{1}, \frac{c}{1})\rangle$ and $C = \langle x, (\frac{a}{0}, \frac{b}{1}, \frac{c}{0}), (\frac{a}{1}, \frac{b}{0}, \frac{c}{1})\rangle$. Then $T = \{0_\sim, 1_\sim, A\}$ and $S = \{0_\sim, 1_\sim, A, B, A \cup B\}$ are intuitionistic fuzzy topologies on X. So (X,T) and (X,S) are intuitionistic fuzzy topological spaces. Define $f : (X,T) \to (X,S)$ as an identity function. Clearly f is intuitionistic fuzzy rarely α-continuous function.

Proposition 2.1. Let (X,T) and (Y,S) be any two intuitionistic fuzzy topological spaces. For a function $f : (X,T) \to (Y,S)$, the following statements are equivalent:

(i) The function f is intuitionistic fuzzy rarely α-continuous function at $x_{r,s}$ in (X,T).

(ii) For each intuitionistic fuzzy open set G containing $f(x_{r,s})$, there exists an intuitionistic fuzzy α-open set U in (X,T) such that $IFint(f(U) \cap \overline{G}) = 0_\sim$.

(iii) For each intuitionistic fuzzy open set G containing $f(x_{r,s})$, there exists an intuitionistic fuzzy α-open set U in (X,T) such that $IFint(f(U)) \leq IFcl(G)$.

(iv) For each intuitionistic fuzzy open set G in (Y,S) containing $f(x_{r,s})$, there exists an intuitionistic fuzzy rare set R with $G \cap IFcl(R) = 0_\sim$ such that $x_{r,s} \in IFint_\alpha(f^{-1}(G \cup R))$.

(v) For each intuitionistic fuzzy open set G in (Y,S) containing $f(x_{r,s})$, there exists an intuitionistic fuzzy rare set R with $IFcl(G) \cap R = 0_\sim$ such that $x_{r,s} \in IFint_\alpha(f^{-1}(IFcl(G) \cup R))$.

(vi) For each intuitionistic fuzzy regular open set G in (Y, S) containing $f(x_{r,s})$, there exists an intuitionistic fuzzy rare set R with $IFcl(G) \cap R = 0_\sim$ such that $x_{r,s} \in IFint_\alpha(f^{-1}(G \cup R))$.

Proof. (i)⇒ (ii). Let G be an intuitionistic fuzzy open set in (Y, S) containing $f(x_{r,s})$. By $f(x_{r,s}) \in G \leq IFint(IFcl(G))$ and $IFint(IFcl(G))$ containing $f(x_{r,s})$, there exist an intuitionistic fuzzy rare set R with $IFint(IFcl(G)) \cap IFcl(R) = 0_\sim$ and an intuitionistic fuzzy α-open set U in (X, T) containing $x_{r,s}$ such that $f(U) \leq IFint(IFcl(G)) \cup R$. We have $IFint(f(U) \cap \overline{G}) = IFint(f(U)) \cap IFint(\overline{G}) \leq IFint(IFcl(G) \cup R) \cap \overline{(IFcl(G))} \leq IFcl(G) \cup IFint(R) \cap \overline{(IFcl(G))} = 0_\sim$.

(ii)⇒(iii). It is straightforward.

(iii)⇒ (i). Let G be an intuitionistic fuzzy open set in (Y, S) containing $f(x_{r,s})$. Then by (iii), there exists an intuitionistic fuzzy α-open set U containing $x_{r,s}$ such that $IFint(f(U) \leq IFcl(G)$. We have $f(U) = (f(U) \cap \overline{(IFint(f(U)))}) \cup IFint(f(U)) < (f(U) \cap \overline{(IFint(f(U)))}) \cup IFcl(G) = (f(U) \cap \overline{(IFint(f(U)))}) \cup G \cup (IFcl(G) \cap \overline{G}) = (f(U) \cap \overline{(IFint(f(U)))} \cap \overline{G}) \cup G \cup (IFcl(G) \cap \overline{G})$. Set $R_1 = f(U) \cap \overline{(IFint(f(U)))} \cap \overline{G}$ and $R_2 = IFcl(G) \cap \overline{G}$. Then R_1 and R_2 are intuitionistic fuzzy rare sets. More $R = R_1 \cup R_2$ is an intuitionistic fuzzy set such that $IFcl(R) \cap G = 0_\sim$ and $f(U) \leq G \cup R$. This show that f is intuitionistic fuzzy rarely α-continuous function.

(i)⇒ (iv). Suppose that G is an intuitionistic fuzzy open set in (Y, S) containing $f(x_{r,s})$. Then there exist an intuitionistic fuzzy rare set R with $G \cap IFcl(R) = 0_\sim$ and U which is an intuitionistic fuzzy α open set in (X, T) containing $x_{r,s}$ such that $f(U) \leq G \cup R$. It follows that $x_{r,s} \in U \leq f^{-1}(G \cup R)$. This implies that $x_{r,s} \in IFint_\alpha(f^{-1}(G \cup R))$.

(iv)⇒ (v). Suppose that G is an intuitionistic fuzzy open set in (Y, S) containing $f(x_{r,s})$. Then there exists an intuitionistic fuzzy rare set R with $G \cap IFcl(R) = 0_\sim$ such that $x_{r,s} \in IFint_\alpha(f^{-1}(G \cup R))$. Since $G \cap IFcl(R) = 0_\sim, R \leq \overline{G}$, where $\overline{G} = \overline{(IFcl(G))} \cup (IFcl(G) \cap \overline{G})$. Put we have $R \leq R \cup \overline{(IFcl(G))} \cup (IFcl(G) \cap \overline{G})$. Now, $R_1 = R \cap \overline{(IFcl(G))}$. It follows that R_1 is an intuitionistic fuzzy rare set with $IFcl(G) \cap R_1 = 0_\sim$. Therefore $x_{r,s} \in IFint_\alpha(f^{-1}(G \cup R)) \leq IFint_\alpha(f^{-1}(G \cup R_1))$.

(v)⇒ (vi). Assume that G is an intuitionistic fuzzy regular open set in (Y, S) containing $f(x_{r,s})$. Then there exists an intuitionistic fuzzy rare set R with $IFcl(G) \cap R = 0_\sim$, such that $x_{r,s} \in IFint_\alpha(f^{-1}(IFcl(G) \cup R))$. Now $R_1 = R \cup (IFcl(G) \cup \overline{G})$. It follows that R_1 is an intuitionistic fuzzy rare set and $(G \cap IFcl(R_1)) = 0_\sim$. Hence $x_{r,s} \in IFint_\alpha(f^{-1}(IFcl(G) \cup R)) = IFint_\alpha(f^{-1}(G \cup (IFcl(G) \cap \overline{G})) \cup R) = IFint_\alpha(f^{-1}(G \cup R_1))$. Therefore $x_{r,s} \in IFint_\alpha(f^{-1}(G \cup R_1))$.

(vi)⇒ (ii). Let G be an intuitionistic fuzzy open set in (Y, S) containing $f(x_{r,s})$. By $f(x_{r,s}) \in G \leq IFint(IFcl(G))$ and the fact that $IFint(IFcl(G))$ is an intuitionistic fuzzy regular open in (Y, S), there exists an intuitionis-

tic fuzzy rare set R and $IFint(IFcl(G)) \cap IFcl(R) = 0_\sim$ such that $x_{r,s} \in IFint_\alpha(f^{-1}(IFint(IFcl(G)) \cup R)$.

Let $U = IFint_\alpha(f^{-1}(IFint(IFcl(G)) \cup R)$. Hence U is an intuitionistic fuzzy α-open set in (X,T) containing $x_{r,s}$ and therefore $f(U) \leq IFint(IFcl(G)) \cup R$. Hence, we have $IFint(f(U) \cap \overline{G}) = 0_\sim$. □

Proposition 2.2. Let (X,T) and (Y,S) be any two intuitionistic fuzzy topological space. Then a function $f : (X,T) \to (Y,S)$ is an intuitionistic fuzzy rarely α-continuous function if and only if $f^{-1}(G) \leq IFint_\alpha(f^{-1}(G \cup R))$ for every intuitionistic fuzzy open set G in (Y,S), where R is an intuitionistic fuzzy rare set with $IFcl(R) \cap G = 0_\sim$.

Proof. Suppose that G is an intuitionistic fuzzy rarely α-open set in (Y,S) containing $f(x_{r,s})$. Then $G \cap IFcl(R) = 0_\sim$ and U be an intuitionistic fuzzy α-open set in (X,T) containing $x_{r,s}$ such that $f(U) \leq G \cup R$. It follows that $x_{r,s} \in U \leq f^{-1}(G \cup R)$. This implies that $f^{-1}(G) \leq IFint_\alpha(f^{-1}(G \cup R))$. □

Definition 2.5. A function $f : (X,T) \to (Y,S)$ is intuitionistic fuzzy $I\alpha$-continuous function at $x_{r,s}$ in (X,T) if for each intuitionistic fuzzy open set G in (Y,S) containing $f(x_{r,s})$, there exists an intuitionistic fuzzy α-open set U containing $x_{r,s}$ such that $IFint(f(U)) \leq G$.

If f has this property at each intuitionistic fuzzy point $x_{r,s}$ in (X,T), then we say that f is intuitionistic fuzzy $I\alpha$-continuous function on (X,T).

Example 2.2. Let $X = \{a,b,c\}$. Define the intuitionistic fuzzy sets A and B as follows: $A = \langle x, (\frac{a}{0}, \frac{b}{1}, \frac{c}{0}), (\frac{a}{1}, \frac{b}{0}, \frac{c}{1})\rangle$ and $B = \langle x, (\frac{a}{1}, \frac{b}{0}, \frac{c}{0}), (\frac{a}{0}, \frac{b}{1}, \frac{c}{1})\rangle$. Then $T = \{0_\sim, 1_\sim, A\}$ and $S = \{0_\sim, 1_\sim, B\}$ be intuitionistic fuzzy topologies on X. Suppose (X,T) and (X,S) are intuitionistic fuzzy topological spaces. Let $f : (X,T) \to (X,S)$ be defined by $f(a) = f(b) = b$ and $f(c) = c$. It is obvious that f is an intuitionistic fuzzy $I\alpha$-continuous function.

Proposition 2.3. Let (Y,S) be an intuitionistic fuzzy regular space [2]. Then the function $f : (X,T) \to (Y,S)$ is an intuitionistic fuzzy $I\alpha$-continuous function on X if and only if f is an intuitionistic fuzzy rarely α-continuous function on X.

Proof. $\Rightarrow$ It is obvious.
$\Leftarrow$ Let f be an intuitionistic fuzzy rarely α-continuous function on (X,T). Suppose that $f(x_{r,s}) \in G$, where G is an intuitionistic fuzzy open set in (Y,S) and $x_{r,s}$ an intuitionistic fuzzy point in X. By the intuitionistic fuzzy regularity of (Y,S), there exists an intuitionistic fuzzy open set G_1 in (Y,S) containing $f(x_{r,s})$ and $IFcl(G_1) \leq G$. Since f is intuitionistic fuzzy rarely α-continuous function, then there exists an intuitionistic fuzzy α-open set U such that $IFint(f(U)) \leq IFcl(G_1)$. This implies that $IFint(f(U)) \leq G$, which means that f is intuitionistic fuzzy $I\alpha$ continuous function on X. □

Definition 2.6. A function $f : (X, T) \to (Y, S)$ is called intuitionistic fuzzy pre-α-open if for every intuitionistic fuzzy α-open set U in X such that $f(U)$ is an intuitionistic fuzzy α-open in Y.

Proposition 2.4. If a function $f : (X, T) \to (Y, S)$ is an intuitionistic fuzzy pre-α-open and an intuitionistic fuzzy rarely α-continuous function then f is intuitionistic fuzzy almost α-continuous function.

Proof. Suppose that $x_{r,s}$ is an intuitionistic fuzzy point in X and G an intuitionistic fuzzy open set in Y containing $f(x_{r,s})$. Since f is intuitionistic fuzzy rarely α-continuous function at $x_{r,s}$, then there exists an intuitionistic fuzzy α-open set U in X, such that $IFint(f(U)) \subset IFcl(G)$. Since f is intuitionistic fuzzy pre-α-open, we have $f(U) \subset IFint(IFcl(IFint(f(U)))) \subset IFint(IFcl(G))$. Hence f is intuitionistic fuzzy almost α-continuous function. □

For a mapping $f : X \to Y$, the graph $g : X \to X \times Y$ of f is defined by $g(x) = (x, f(x))$, for each $x \in X$.

Proposition 2.5. Let $f : (X, T) \to (Y, S)$ be any function. If the $g : X \to X \times Y$ of f is intuitionistic fuzzy rarely α-continuous function then f is also intuitionistic fuzzy rarely α-continuous function.

Proof. Suppose that $x_{r,s}$ is an intuitionistic fuzzy point in X and an intuitionistic fuzzy open set W in Y containing $g(x_{r,s})$. It follows that there exists intuitionistic fuzzy open sets 1_X and V in X and Y respectively such that $(x_{r,s}, f(x_{r,s})) \in 1_X \times V \subset W$. Since f is intuitionistic fuzzy rarely α-continuous function, there exists an intuitionistic fuzzy α-open set G such that $IFint(f(G)) \subset IFcl(V)$. Let $E = 1_X \cap G$. It follows that E is an intuitionistic fuzzy α-open set in X, and we have $IFint(g(E)) \subset IFint(1_X \times f(G)) \subset 1_X \times IFcl(V) \subset IFcl(W)$. Therefore g is an intuitionistic fuzzy rarely α-continuous function. □

3. Conclusion

In this paper, the notion of intuitionistic fuzzy rare α-continuity is introduced and studied.

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