

**GENERALIZED CONTINUITY IN INTUITIONISTIC FUZZY  
TOPOLOGICAL SPACES**

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**Abstract:** In this paper we introduce and study the concept of intuitionistic fuzzy g-continuous mappings in intuitionistic fuzzy topological spaces.

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**AMS Subject classification :** 54A.

### **1. Introduction**

After the introduction of fuzzy sets by Zadeh [16] in 1965 and fuzzy topology by Chang [5] in 1967. Several researches were conducted on the generalizations of the notions of fuzzy sets and fuzzy topology. The concept of intuitionistic fuzzy sets was introduced by Atanassov [1] as a generalization of fuzzy sets. In the last 20 years various concepts of fuzzy mathematics have been extended for intuitionistic fuzzy sets. In 1997 Coker [6] introduced the concept of intuitionistic fuzzy topological spaces. Recently many fuzzy topological concepts such as fuzzy compactness [8], fuzzy connectedness [15], fuzzy separation axioms [4], fuzzy metric spaces [14], fuzzy continuity [9] fuzzy multifunctions [11] have been generalized for intuitionistic fuzzy topological spaces. In [13] the authors of this paper extend the concepts of fuzzy g-closed sets due to Thakur and Malviya [12] in intuitionistic fuzzy topological space. In the present paper we introduce and study the concepts of intuitionistic fuzzy g-continuous mappings in intuitionistic fuzzy topological space.

### **2. Preliminaries**

**Definition 2.1:** [1] Let  $X$  be a nonempty fixed set. An intuitionistic fuzzy set  $A$  in  $X$  is an object having the form

$$A = \{ \langle x, \mu_A(x), \gamma_A(x) \rangle : x \in X \}$$

where the functions  $\mu_A: X \rightarrow I$  and  $\gamma_A: X \rightarrow I$  denote the degree of membership (namely  $\mu_A(x)$ ) and the degree of nonmembership (namely  $\gamma_A(x)$ ) of each element  $x \in X$  to the set  $A$ , respectively, and  $0 \leq \mu_A(x) + \gamma_A(x) \leq 1$  for each  $x \in X$ .

**Definition 2.2:** [1] Let  $X$  be a nonempty set and the intuitionistic fuzzy sets  $A$  and  $B$  be in the form  $A = \{ \langle x, \mu_A(x), \gamma_A(x) \rangle : x \in X \}$ ,  $B = \{ \langle x, \mu_B(x), \gamma_B(x) \rangle : x \in X \}$  and let  $\{A_i : i \in J\}$  be an arbitrary family of intuitionistic fuzzy sets in  $X$ . Then

- (a)  $A \subseteq B$  if  $\forall x \in X [\mu_A(x) \leq \mu_B(x) \text{ and } \gamma_A(x) \geq \gamma_B(x)]$ ;
- (b)  $A = B$  if  $A \subseteq B$  and  $B \subseteq A$ ;
- (c)  $A^c = \{ \langle x, \gamma_A(x), \mu_A(x) \rangle : x \in X \}$ ;
- (d)  $\cap A_i = \{ \langle x, \wedge \mu_{A_i}(x), \vee \gamma_{A_i}(x) \rangle : x \in X \}$ ;
- (e)  $\cup A_i = \{ \langle x, \vee \mu_{A_i}(x), \wedge \gamma_{A_i}(x) \rangle : x \in X \}$ ;
- (f)  $0 = \{ \langle x, 0, 1 \rangle : x \in X \}$  and  $1 = \{ \langle x, 1, 0 \rangle : x \in X \}$ ;

**Definition 2.3** [6]: Two intuitionistic fuzzy sets  $A$  and  $B$  of  $X$  said to be  $q$ -coincident ( $AqB$  for short) if and only if there exists an element  $x \in X$  such that  $\mu_A(x) > \gamma_B(x)$  or  $\gamma_A(x) < \mu_B(x)$ .

**Definition 2.4**[6]: Let  $(X, \mathfrak{F})$  be an intuitionistic fuzzy topological space and  $A = \langle x, \mu_A(x), \gamma_A(x) \rangle$  be an intuitionistic fuzzy set in  $X$ . Then the fuzzy interior and fuzzy closure of  $A$  are defined by

$$\text{cl}(A) = \cap \{K : K \text{ is an intuitionistic fuzzy closed set in } X \text{ and } A \subseteq K\},$$

$$\text{int}(A) = \cup \{G : G \text{ is an intuitionistic fuzzy open set in } X \text{ and } G \subseteq A\}.$$

**Definition 2.5** [7] : Let  $X$  be a nonempty set and  $c \in X$  a fixed element in  $X$ . If  $\alpha \in (0,1]$  and  $\beta \in [0,1)$  are two real numbers such that  $\alpha + \beta \leq 1$  then  $c(\alpha, \beta) = \langle c, \alpha, \beta \rangle$  is called an intuitionistic fuzzy point in  $X$ , where  $\alpha$  denotes the degree of membership of  $c(\alpha, \beta)$ , and  $\beta$  denotes the degree of nonmembership of  $c(\alpha, \beta)$ .

**Definition 2.6** [6]: An intuitionistic fuzzy topology on a nonempty set  $X$  is a family  $\mathfrak{F}$  of intuitionistic fuzzy sets in  $X$  satisfy the following axioms:

- (T<sub>1</sub>)  $0, 1 \in \mathfrak{F}$ ,
- (T<sub>2</sub>)  $G_1 \cap G_2 \in \mathfrak{F}$  for any  $G_1, G_2 \in \mathfrak{F}$ ,
- (T<sub>3</sub>)  $\cup G_i \in \mathfrak{F}$  for any arbitrary family  $\{G_i : i \in J\} \subseteq \mathfrak{F}$ .

In this case the pair  $(X, \mathfrak{F})$  is called an intuitionistic fuzzy topological space and each intuitionistic fuzzy set in  $\mathfrak{F}$  is known as an intuitionistic fuzzy open set in  $X$ .

**Definition 2.7** [6]: The complement  $A^c$  of an intuitionistic fuzzy open set  $A$  in an intuitionistic fuzzy topological space  $(X, \mathfrak{F})$  is called an intuitionistic fuzzy closed set in  $X$ .

**Definition 2.8**[6]: Let  $X$  and  $Y$  be two nonempty sets and  $f: X \rightarrow Y$  be a function. Then

(a) If  $B = \{ \langle y, \mu_B(y), \gamma_B(y) \rangle : y \in Y \}$  is an intuitionistic fuzzy set in  $Y$ , then the preimage of  $B$  under  $f$  denoted by  $f^{-1}(B)$ , is the IFS in  $X$  defined by

$$f^{-1}(B) = \{ \langle x, f^{-1}(\mu_B)(x), f^{-1}(\gamma_B)(x) \rangle : x \in X \}$$

(b) If  $A = \{ \langle x, \lambda_A(x), \nu_A(x) \rangle : x \in X \}$  is an intuitionistic fuzzy set in  $X$ , then the image of  $A$  under  $f$  denoted by  $f(A)$  is the intuitionistic fuzzy set in  $Y$  defined by

$$f(A) = \{ \langle y, f(\lambda_A)(y), f(\nu_A)(y) \rangle : y \in Y \}$$

$$\text{where } f(\nu_A) = 1 - f(1 - \nu_A).$$

**Definition 2.9**[9] : Let  $(X, \mathfrak{I})$  and  $(Y, \Phi)$  be two intuitionistic fuzzy topological spaces and let  $f: X \rightarrow Y$  be a function. Then  $f$  is said to be intuitionistic fuzzy continuous if and only if the preimage of each intuitionistic fuzzy open set in  $Y$  is an intuitionistic fuzzy open set in  $X$ .

**Definition 2.10** [8] : A family  $\{ G_i : i \in \Lambda \}$  of intuitionistic fuzzy sets in  $X$  is said to be an intuitionistic fuzzy open cover of  $X$  if  $\bigcup \{ G_i : i \in \Lambda \} = 1$  and a finite subfamily

of an intuitionistic fuzzy open cover of  $X$  which also an intuitionistic fuzzy open cover of  $X$  is called a finite subcover  $\{ G_i : i \in \Lambda \}$ .

**Definition 2.11** [8] : An intuitionistic fuzzy topological space  $(X, \mathfrak{I})$  is called fuzzy compact if each intuitionistic fuzzy open cover has a finite subcover.

**Definition 2.12**[13]: An intuitionistic fuzzy set  $A$  of a intuitionistic fuzzy topological space  $(X, \mathfrak{I})$  is called an intuitionistic fuzzy generalized closed (intuitionistic fuzzy g-closed) if  $\text{cl}(A) \subseteq O$  whenever  $A \subseteq O$  and  $O$  is intuitionistic fuzzy open.

**Definition 2.13**[13]: Complement of an intuitionistic fuzzy g-closed set is called intuitionistic fuzzy g-open set.

**Remark 2.1** [13]: Every intuitionistic fuzzy closed set (intuitionistic fuzzy open set) is intuitionistic fuzzy g-closed(intuitionistic fuzzy open set) but its converse may not be true.

Throughout this paper  $f: (X, \mathfrak{I}) \rightarrow (Y, \sigma)$  denotes a mapping from an intuitionistic fuzzy topological space  $(X, \mathfrak{I})$  to another intuitionistic topological space  $(Y, \sigma)$ .

### 3. Intuitionistic Fuzzy g-Continuous Mapping

**Definition 3.1:** A mapping  $f: (X, \mathfrak{I}) \rightarrow (Y, \sigma)$  is said to be intuitionistic fuzzy g-continuous if the inverse image of every intuitionistic fuzzy closed set of  $Y$  is intuitionistic fuzzy g-closed in  $X$ .

**Remark 3.1:** Every intuitionistic fuzzy continuous mapping is intuitionistic fuzzy g-continuous, but the converse may not be true. For,

**Example 3.1:** Let  $X = \{a, b\}$ ,  $Y = \{x, y\}$  and the intuitionistic fuzzy set  $U$  and  $V$  are defined as follows:

$$U = \langle x, (0.5/a, 0.6/b), (0.4/a, 0.4/b) \rangle$$

$$V = \langle x, (0.3/a, 0.4/b), (0.6/a, 0.6/b) \rangle$$

Let  $\mathfrak{T} = \{0, U, 1\}$  and  $\sigma = \{0, V, 1\}$  be intuitionistic fuzzy topologies on  $X$

and  $Y$  respectively. Then the mapping  $f : (X, \mathfrak{T}) \rightarrow (Y, \sigma)$  defined by  $f(a) = x$  and  $f(b) = y$  is intuitionistic fuzzy  $g$ -continuous but not intuitionistic fuzzy continuous.

**Theorem 3.1:** A mapping  $f : (X, \mathfrak{T}) \rightarrow (Y, \sigma)$  is intuitionistic fuzzy  $g$ -continuous if and only if the inverse image of every intuitionistic fuzzy open set of  $Y$  is intuitionistic fuzzy  $g$ -open in  $X$ .

**Proof:** It is obvious because  $f^{-1}(U^c) = (f^{-1}(U))^c$  for every intuitionistic fuzzy set  $U$  of  $Y$ .

**Theorem 3.2:** If  $f : (X, \mathfrak{T}) \rightarrow (Y, \sigma)$  is intuitionistic fuzzy  $g$ -continuous then for each intuitionistic fuzzy point  $c(\alpha, \beta)$  of  $X$  and each fuzzy open set  $V$ ,  $f(c(\alpha, \beta)) \subseteq V$  there exist a intuitionistic fuzzy  $g$ -open set  $U$  such that  $c(\alpha, \beta) \subseteq U$  and  $f(U) \subseteq V$ .

**Proof:** Let  $c(\alpha, \beta)$  be a intuitionistic fuzzy point of  $X$  and  $V$  be a intuitionistic fuzzy open set such that  $c(\alpha, \beta) \subseteq V$ , put  $U = f^{-1}(V)$  then by hypothesis  $U$  is intuitionistic fuzzy  $g$ -open set of  $X$  such that  $c(\alpha, \beta) \subseteq U$  and  $f(U) = f(f^{-1}(V)) \subseteq V$ .

**Theorem 3.3:** If  $f : (X, \mathfrak{T}) \rightarrow (Y, \sigma)$  is fuzzy  $g$ -continuous, then for each intuitionistic fuzzy point  $c(\alpha, \beta)$  in  $X$  and each intuitionistic fuzzy open set  $V$  of  $Y$  such that  $c(\alpha, \beta)_q V$ , there exists  $c(\alpha, \beta)$  in an intuitionistic  $g$ -open set  $U$  of  $X$  such that  $c(\alpha, \beta)_q U$  and  $f(U) \subseteq V$ .

**Proof:** Let  $c(\alpha, \beta)$  be an intuitionistic fuzzy point of  $X$  and  $V$  be an intuitionistic fuzzy open set of  $Y$  such that  $f(c(\alpha, \beta))_q V$ . Put  $U = f^{-1}(V)$ . Then by hypothesis  $U$  is an intuitionistic fuzzy  $g$ -open set of  $X$  such that  $c(\alpha, \beta)_q U$  and  $f(U) = f(f^{-1}(V)) \subseteq V$ .

**Definition 3.2:** Let  $(X, \mathfrak{T})$  be an intuitionistic fuzzy topological space. The generalized closure of a intuitionistic fuzzy set  $A$  of  $X$  denoted by  $gcl(A)$  is the intersection of all intuitionistic fuzzy  $g$ -closed sets of  $X$  which contains  $A$ .

**Remark 3. 2:** It is clear that,  $A \subseteq gcl(A) \subseteq cl(A)$  for any intuitionistic fuzzy set  $A$  of  $X$ .

**Theorem 3. 4:** If  $f : (X, \mathfrak{T}) \rightarrow (Y, \sigma)$  is intuitionistic fuzzy  $g$ -continuous, then  $f(gcl(A)) \subseteq cl(f(A))$  for every intuitionistic fuzzy set  $A$  of  $X$ .

**Proof:** Let  $A$  be an intuitionistic fuzzy set of  $X$ . Then  $cl(f(A))$  is an intuitionistic fuzzy closed set of  $Y$ . Since  $f$  is fuzzy  $g$ -continuous  $f^{-1}(cl(f(A)))$  is intuitionistic fuzzy  $g$ -closed in  $X$ . Clearly  $A \subseteq f^{-1}(cl(f(A)))$ . Therefore  $gcl(A) \subseteq gcl(f^{-1}(cl(f(A)))) = f^{-1}(cl(f(A)))$ . Hence  $f(gcl(A)) \subseteq cl(f(A))$ .

**Remark 3. 3:** The converse of Theorem 3. 4 may not be true. For,

**Example 3.2:** Let  $X = \{a, b, c\}$ ,  $Y = \{x, y, z\}$  and the intuitionistic fuzzy set  $U$  and  $V$  are defined as:

$$U = \langle x, (1/a, 0/b, 0/c), (0/a, 1/b, 1/c) \rangle$$

$$V = \langle x, (1/x, 0/y, 1/z), (0/x, 1/y, 0/z) \rangle$$

Let  $\mathfrak{T} = \{0, U, 1\}$  and  $\sigma = \{0, V, 1\}$  be intuitionistic fuzzy topologies on  $X$

and  $Y$  respectively and  $f : (X, \mathfrak{T}) \rightarrow (Y, \sigma)$  be a mapping defined by  $f(a) = y$ ,  $f(b) = x$ ,  $f(c) = z$ . Then  $f(\text{gcl}(A)) \subseteq \text{cl}(f(A))$  holds for every intuitionistic fuzzy set  $A$  of  $X$ , but  $f$  is not fuzzy  $g$ -continuous.

**Definition 3.3:** An intuitionistic fuzzy topological space  $(X, \mathfrak{T})$  is said to be intuitionistic fuzzy  $T_{1/2}$  if every intuitionistic fuzzy  $g$ -closed set in  $X$  is intuitionistic fuzzy closed in  $X$ .

**Theorem 3.5:** A mapping  $f$  from an intuitionistic fuzzy  $T_{1/2}$ -space  $(X, \mathfrak{T})$  to an intuitionistic fuzzy topological space  $(Y, \sigma)$  is intuitionistic fuzzy continuous if and only if it is intuitionistic fuzzy  $g$ -continuous.

**Proof:** Obvious.

**Remark 3.4:** The composition of two intuitionistic fuzzy  $g$ -continuous mappings may not be intuitionistic fuzzy  $g$ -continuous. For,

**Example 3.3:** Let  $X = \{a, b\}$ ,  $Y = \{x, y\}$  and  $Z = \{p, q\}$  and the fuzzy sets  $U$ ,  $V$ , and  $W$  are defined as follows:

$$U = \langle x, (0.5/a, 0.7/b), (0.5/a, 0.3/b) \rangle$$

$$V = \langle x, (0.3/a, 0.2/b), (0.7/a, 0.8/b) \rangle$$

$$W = \langle x, (0.6/a, 0.4/b), (0.4/a, 0.6/b) \rangle$$

Let  $\tau = \{0, U, 1\}$ ,  $\sigma = \{0, V, 1\}$ , and  $\eta = \{0, W, 1\}$  be intuitionistic fuzzy

topologies on  $X$ ,  $Y$  and  $Z$  respectively. Let the mapping  $f : (X, \mathfrak{T}) \rightarrow (Y, \sigma)$  be defined by  $f(a) = x$ ,  $f(b) = y$  and the mapping  $g : (Y, \sigma) \rightarrow (Z, \eta)$  be defined by  $g(x) = p$  and  $g(y) = q$ . Then  $f$  and  $g$  are intuitionistic fuzzy  $g$ -continuous but  $g \circ f$  is not intuitionistic fuzzy  $g$ -continuous.

**Theorem 3.6:** If  $f : (X, \mathfrak{T}) \rightarrow (Y, \sigma)$  is intuitionistic fuzzy  $g$ -continuous and  $g : (Y, \sigma) \rightarrow (Z, \eta)$  is intuitionistic fuzzy continuous. Then  $g \circ f : (X, \mathfrak{T}) \rightarrow (Z, \eta)$  is intuitionistic fuzzy  $g$ -continuous.

**Proof:** If  $A$  is intuitionistic fuzzy closed in  $Z$ , then  $f^{-1}(A)$  is intuitionistic fuzzy closed in  $Y$

because  $g$  is intuitionistic fuzzy continuous. Therefore  $(g \circ f)^{-1}(A) = f^{-1}(g^{-1}(A))$  is intuitionistic fuzzy  $g$ -closed in  $X$ . Hence  $g \circ f$  is intuitionistic fuzzy  $g$ -continuous.

**Theorem 3.7:** If  $f : (X, \mathfrak{T}) \rightarrow (Y, \sigma)$  and  $g : (Y, \sigma) \rightarrow (Z, \eta)$  are two intuitionistic fuzzy  $g$ -continuous mappings and  $(Y, \sigma)$  is intuitionistic fuzzy  $T_{1/2}$  space then  $g \circ f : (X, \mathfrak{T}) \rightarrow (Z, \eta)$  is intuitionistic fuzzy  $g$ -continuous.

**Proof:** Obvious.

**Definition 3.4:** An intuitionistic fuzzy topological space  $(X, \mathfrak{T})$  is said to be intuitionistic fuzzy GO-compact if every intuitionistic fuzzy  $g$ -open cover of  $X$  has a finite subcover.

**Theorem 3.8 :** Intuitionistic fuzzy  $g$ -continuous image of an intuitionistic fuzzy GO-compact space is intuitionistic fuzzy compact.

**Proof :** Let  $f : (X, \mathfrak{T}) \rightarrow (Y, \sigma)$  be an intuitionistic fuzzy  $g$ -continuous map from an intuitionistic fuzzy GO-compact space  $(X, \mathfrak{T})$  onto an intuitionistic fuzzy topological space  $(Y, \sigma)$ . Let  $\{A_i : i \in \Lambda\}$  be an intuitionistic fuzzy  $g$ -open cover of  $Y$  then  $\{f^{-1}(A_i) : i \in \Lambda\}$  is an intuitionistic fuzzy  $g$ -open cover of  $X$ . Since  $X$  is intuitionistic fuzzy GO-compact it has finite intuitionistic fuzzy subcover say  $\{f^{-1}(A_1), \dots, f^{-1}(A_n)\}$ . Since  $f$  is onto  $\{A_1, \dots, A_n\}$  is an intuitionistic fuzzy open cover of  $Y$  and so  $(Y, \sigma)$  is intuitionistic fuzzy compact.

**Definition 3.5 :** An intuitionistic fuzzy topological space  $X$  is called intuitionistic fuzzy GO-connected if there is no proper intuitionistic fuzzy set of  $X$  which is both intuitionistic fuzzy  $g$ -open and intuitionistic fuzzy  $g$ -closed.

**Remark 3.5:** Every intuitionistic fuzzy GO-connected space is intuitionistic fuzzy  $C_5$ -connected [15], but the converse may not be true. For,

**Example 3. 4** Let  $X = \{a, b\}$ ,  $U = \langle x, (.5/a, .7/b), (.5/a, .3/b) \rangle$ ,

and  $\mathfrak{T} = \{0, U, 1\}$  be an intuitionistic topology on  $X$ , then  $(X, \mathfrak{T})$  is intuitionistic fuzzy connected but not fuzzy GO-connected.

**Theorem 3.9:** An intuitionistic fuzzy  $T_{1/2}$ -space is intuitionistic fuzzy  $C_5$ -connected if and only if it is intuitionistic fuzzy GO-connected.

**Proof:** Obvious.

**Theorem 3. 10 :** If  $f : (X, \mathfrak{T}) \rightarrow (Y, \sigma)$  is an intuitionistic fuzzy  $g$ -continuous surjection and  $X$  is intuitionistic fuzzy GO-connected then  $Y$  is intuitionistic fuzzy  $C_5$ -connected.

**Proof :** Suppose  $Y$  is not intuitionistic fuzzy connected. Then there exists a proper intuitionistic fuzzy set  $G$  of  $Y$  which is both intuitionistic fuzzy open and intuitionistic

fuzzy closed. Therefore  $f^{-1}(G)$  is a proper intuitionistic fuzzy closed and intuitionistic fuzzy open set of  $X$ , because  $f$  intuitionistic fuzzy  $g$ -continuous surjection. Hence  $X$  is not intuitionistic fuzzy  $GO$ -connected.

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