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On γ - locally closed sets in fuzzy bitopological space

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Abstract

The main objective of this paper is to introduce the notion of (i, j)-fuzzy γ-locally closed set in fuzzy bitopological space and to obtain various basic properties of the new notion. Also, we define the dual form of γ-locally closed set which is termed as (i, j)-fuzzy γ-locally open set and show that it is a stronger form of $\tau_i\tau_j$-fuzzy b-locally open set. Finally, we study the notion of (i, j)-fuzzy γ-LC-continuous function and (i, j)-fuzzy γ-LC-irresolute function as an application of the newly defined concept and establish the relationships with some already existing functions.

Keywords: fuzzy bitopological space, (i, j)-fuzzy γ-open set, (i, j)-fuzzy γ-locally closed set, (i, j)-fuzzy γ-LC-continuous function

1. Introduction

The idea of fuzzy sets was introduced by Zadeh (1965). After that Chang studied the notion of fuzzy topological space in 1968 as an application of fuzzy set. The idea of bitopological spaces has been investigated from different aspects by Tripathy, Sarma and Acharjee (2011, 2012, 2014) and others. Moreover Kandil (1989) introduced a generalized idea of fuzzy topological space namely fuzzy bitopological space. Later on several authors were attracted by the notion of fuzzy bitopological spaces. Nasef (2001) introduced the notion of b-locally closed set in topological space. Further, Tripathy and Debnath (2015, 2013) introduced the notion of b-locally open set and γ-open set in fuzzy bitopological spaces respectively. Recently Paul *et al*. (2016) have studied some applications of γ-open sets in fuzzy bitopological spaces. The main objective of this paper is to present the notion of γ-locally closed set in this context. At the end of this paper, we study the notion of mappings as an application of γ-locally closed set and their inter-relationship with some existing functions.

Definition 1.1 A fuzzy subset β of a fuzzy bitopological space (X, τ_i, τ_j) is said to be:

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(i) (Kumar, 1994) (i, j)-fuzzy pre-closed set if τ_j-cl(τ_i-int(β))$\leq \beta$.

(ii) (Tripathy & Debnath, 2013) (i, j)-fuzzy γ-open if $\mu \wedge \beta$ is (i, j)-fuzzy pre-open for every (i, j)-fuzzy pre-open set μ in X, where $i \neq j$ and $i, j = 1, 2$,

(iii) (Paul *et al*., 2016) (i, j)-fuzzy locally closed set if $\beta = \delta \wedge \alpha$, where δ is τ_i-fuzzy open set and α is a τ_j-fuzzy closed set in X.

(iv) (iv) (Tripathy & Debnath, 2015) $\tau_i\tau_j$-fuzzy b-locally open if $\beta = \delta \vee \alpha$, where δ is τ_i-fuzzy b-open set and α is a τ_j-fuzzy b-closed set in X.

(v) (Paul *et al*., 2016) (i, j)-fuzzy dense set if β is either τ_i-fuzzy dense set or τ_j-fuzzy dense set,

Definition 1.2

(i) (Kandil, 1989) A mapping from a fuzzy bitopological space (X, τ_i, τ_j) to a another fuzzy bitopological space (Y, σ_i, σ_j) is said to be fuzzy pairwise closed if $\eta \in \tau_i$ $f(\eta) \in \sigma_i\sigma_j$.

(ii) (Tripathy & Debnath, 2013) For any fuzzy sub set, (i, j)- γ-cl(δ) is the smallest (i, j)-fuzzy γ-closed set containing δ.

(iii) (Tripathy & Debnath, 2013) A mapping $f: (X, \tau_i, \tau_j) \rightarrow (Y, \sigma_i, \sigma_j)$ is called fuzzy pairwise γ-continuous if the inverse image of each σ_i-open set in Y is (i, j)-fuzzy γ-open set in X.

Throughout this work, by (X, τ_i, τ_j) we mean a fuzzy bitopological space (for short, fbts).

2. (i, j)-Fuzzy γ-Locally Closed Set

In this section, we introduce the notion of (i, j)-fuzzy γ-closed set and study some basic properties of it. Also, we study a relationship between $\tau_i\tau_j$-fuzzy b-locally open set and (i, j)-fuzzy γ-locally open set. In particular, we show that the notion (i, j)-fuzzy γ-locally open set is a stronger form of $\tau_i\tau_j$-fuzzy b-locally open set.

Definition 2.1 A subset β of a fbts X is called (i, j)-fuzzy γ-locally closed set if $\beta = \alpha \wedge \delta$, where α is a (i, j)-fuzzy γ-open set and δ is (i, j)-fuzzy γ-closed set. The complement of (i, j)-fuzzy γ-locally closed set is called (i, j)-fuzzy γ-locally open set.

The collection of all (i, j)-fuzzy γ-locally closed sets of X is denoted by (i, j)FγLC(X).

Example 2.2 Let $X = \{x, y\}$ and $Y = \{a, b\}$. Consider the $\tau_i\tau_j$-fuzzy open sets on X are $\{\mu, \eta, 0_X, 1_X\}$, where μ = $\{(x, 0.4), (y, 0.3)\}$ and $\eta = \{(x, 0.2), (y, 0.3)\}$. Consider the $\sigma_i\sigma_j$-fuzzy open sets in Y are $\{\lambda, \rho, 0_Y, 1_Y\}$, where $\lambda = \{(a, 0.2), (b, 0.3)\}$ and $\rho = \{(a, 0.1), (b, 0.3)\}$. Now let $\tau_i = \{0_X, 1_X, \mu\}$, $\tau_j = \{0_X, 1_X, \eta\}$, $\sigma_i = \{0_Y, 1_Y, \lambda\}$ and $\sigma_j = \{0_Y, 1_Y, \rho\}$.

We get (i, j) Fγ O(X) = $\begin{cases} \{(x,\alpha),(y,\beta)\}, 0 \leq \alpha \leq 0.4, 0 \leq \beta \leq 0.3 \\ \{(x,\alpha),(y,\beta)\}, \alpha > 0.8 \quad and\, \beta > 0.7 \end{cases}$

One can easily verify that the fuzzy set $\{(x, 0.80), (y, 0.70)\}$ is a (i, j)-fuzzy γ-locally closed set, since $\{(x, 0.80), (y, 0.70)\} = \{(x, 0.81), (y, 0.71)\} \wedge \{(x, 0.80), (y, 0.70)\}$.

Remark 2.3 From the above example (2.2), we conclude that in a fbts (X, τ_i, τ_j)

(i) every (i, j)-fuzzy γ-locally closed set is a $\tau_i\tau_j$-fuzzy b-locally closed set but the converse is not true and

(ii) every (i, j)-fuzzy γ-open set and (i, j)-fuzzy γ-closed set is a (i, j)-fuzzy γ-locally closed set but the converse is not true.

Theorem 2.4 Let β be a subset of fbts (X, τ_i, τ_j), then the following conditions are equivalent:

(i) $\beta \in$(i, j)Fγ LC(X).

(ii) $\beta = \alpha \wedge$ (i, j)-γ-cl(β), for some (i, j)-fuzzy γ-open set α.

(iii) (i, j)-γ-cl(β) $-$ β is (i, j)-fuzzy γ-closed set.

(iv) $\beta \vee (1_X -$ (i, j)-γ-cl(β)) is (i, j)-fuzzy γ-open set.

(v) $\beta \leq$(i, j)- γ-int ($\beta \vee (1_X -$ (i, j) γ cl (β)))).

Proof: (i)$\Rightarrow$ (ii) Since $\beta \in$(i, j)Fγ LC(X), thus for any (i, j)-fuzzy γ-open set α and (i, j)-fuzzy γ-closed set μ of X, $\beta = \alpha \wedge \mu$. Now (i, j)-$\gamma$-cl($\beta$) $\leq \mu$ and it implies that $\alpha \wedge$ (i, j)-γ-cl(β) $\leq \mu \wedge \alpha = \beta$.

Again we have $\beta \leq \alpha \wedge$ (i, j)-γ-cl(β) . Thus from these relations we get $\beta = \alpha \wedge$ (i, j)-γ-cl(β).

(ii)$\Rightarrow$ (iii) Here, (i, j)- γ-cl(β)$-\beta$ = (i, j)- γ-cl(β) $\wedge$ $(1_X - \beta)$, which is a (i, j)-fuzzy γ-closed set.

(iii)$\Rightarrow$ (iv) We have, $\beta \vee (1_X -$ (i, j)-γ-cl(β)) = 1_X $-$((i, j)-γ-cl(β)).

Hence by (iii) $\beta \vee (1_X -$ (i, j)-γ-cl(β)) is (i, j)-fuzzy γ-open set.

(iv)$\Rightarrow$ (v) Since $\beta \vee (1_X -$ (i, j)-γ-cl(β)) is (i, j)-fuzzy γ-open set and this implies that $\beta \leq$(i, j)- γ-int $\beta \vee (1_X -$ (i, j)-γ-cl(β)).

(v)$\Rightarrow$ (i) From (v) , we have β = (i, j)-γ-int($\beta \vee (1_X -$ (i, j)-γ-cl(β)))$\wedge$ (i, j)-γ cl (β).

Proposition 2.5 Let β be a (i, j)-fuzzy γ-locally closed set in a fbts (X, τ_i, τ_j). Then

(i) (i, j)-γ-cl (β) is contained in a (i, j)-fuzzy γ-closed set.

(ii) β is (i, j)-fuzzy γ-open if (i, j)-γ cl (β) is (i, j)-fuzzy γ-open.

Proof: (i) We have (i, j)-γ-cl(β) = (i, j)-γ-cl ($\alpha \wedge$ (i, j)-γ-cl(β)) < (i, j)-γ-cl (α) $\wedge$ (i, j)-γ-cl (β) which is a (i, j)-fuzzy γ-closed set.

(ii) Also, (i, j)- γ-int (β) = (i, j)-γ-int($\alpha \wedge$ (i, j)-γ-cl(β))

= (i, j)-γ-int (α) $\wedge$ (i, j)-γ-int ((i, j)-γ-cl(β))

= α $\wedge$ ((i, j)-γ-cl(β)) = β. Thus β is (i, j)-fuzzy γ-open.

Proposition 2.6 The union of any two (i, j)-fuzzy γ-locally closed sets in a fbts is again a (i, j)-fuzzy γ-locally closed set.

Proof: Let $\alpha, \beta \in$ (i, j)-Fγ LC(X). Then by the above theorem (2.5), (i, j)-γ cl(α) $< \delta$ and (i, j)-γ cl(β) $< \lambda$, where δ and λ be two (i, j)-fuzzy γ-closed sets. Thus, (i, j)-γ cl(α) $\vee$ (i, j)-γ cl(β) $< \delta \vee \lambda$ $\Rightarrow$ (i, j)-γ cl($\alpha \vee \beta$) $< \delta \vee \lambda$, which implies that union of any two (i, j)-fuzzy γ-locally closed sets is a (i, j)-fuzzy γ-locally closed set.

Proposition 2.7 The intersection of any two (i, j)-fuzzy γ-locally closed sets in a fbts is again a (i, j)-fuzzy γ-locally closed set.

Proof: Let $\alpha, \beta \in$ (i, j)Fγ LC(X). Thus there exist (i, j)-fuzzy γ-open set α_1, α_2 and (i, j)-fuzzy γ-closed set β_1, β_2 such that $\alpha = \alpha_1 \wedge \beta_1$ and $\beta = \alpha_2 \wedge \beta_2$.

Now, $\alpha \wedge \beta = (\alpha_1 \wedge \beta_1) \wedge (\alpha_2 \wedge \beta_2)$ =$(\alpha_1 \wedge \alpha_2) \wedge (\beta_1 \wedge \beta_2)$, where $(\alpha_1 \wedge \alpha_2)$ is a (i, j)-fuzzy γ-open set and $(\beta_1 \wedge \beta_2)$ is a (i, j)-fuzzy γ-closed set. Hence $\alpha \wedge \beta \in$(i, j)F γ LC(X) .

Remark 2.8 The notions of (i, j)-fuzzy γ -locally closed set and (i, j)-fuzzy pre-closed set are independent of each other as verified in the following examples.

Example 2.9 We consider, example (2.2)

(i) It is easy to show that $\{(x, 0.4), (y, 0.85)\}$ is (i, j)-fuzzy γ -locally closed set, but not a (i, j)-fuzzy pre-closed set.

(ii) It can be verified that the fuzzy set $\{(x, 0.1),$ $(y, 0.8)\}$ is a (i, j)-fuzzy pre-closed set, but not a (i, j)-fuzzy γ -locally closed set.

Definition 2.10 A fuzzy subset β of a fbts (X, τ_i, τ_j) is called (i, j)-fuzzy γ -locally open if $\beta = \mu \vee \delta$, where μ is a (i, j)-fuzzy γ -open and δ is a (i, j)-fuzzy γ -closed in (X, τ_i, τ_j).

Theorem 2.11 A subset β of fbts (X, τ_i, τ_j) is called (i, j)-fuzzy γ -locally closed if its complement $(1_X - \beta)$ is a (i, j)-fuzzy γ -locally open.

Proof: The proof follows directly from the definition.

Remark 2.12 Every (i, j)-fuzzy γ -locally open set of a fbts is $\tau_i\tau_j$-fuzzy b-locally open set since every (i, j)-fuzzy γ -open set is a is $\tau_i\tau_j$-fuzzy b-open set, but the converse is not true as seen in the following example.

Example 2.13 Again we consider example (2.2).

The fuzzy set $\{(x, 0.9), (y, 0.2)\}$ is a $\tau_i\tau_j$-fuzzy b-locally open set but not a (i, j)-fuzzy γ -locally open set as it is not a maximum of (i, j)-fuzzy γ -closed set and (i, j)-fuzzy γ -open set.

Definition 2.14 A fuzzy subset δ of a fbts (X, τ_i, τ_j) is said to be (i, j)-fuzzy γ -dense set if (i, j)- γ -cl(δ) $=1_X$.

Theorem 2.15 A (i, j)-fuzzy γ -dense set of a fbts (X, τ_i, τ_j) is (i, j)-fuzzy γ -open set iff it is (i, j)-fuzzy γ -locally closed set.

Proof: Let β be a (i, j)-fuzzy γ -dense set in *X*.

Now, by the given hypothesis we have $\beta = \alpha \wedge$ (i, j)- γ -cl(β), where α is a (i, j)-fuzzy γ -open set in X.

Therefore, $\beta = \alpha \wedge 1_X = \alpha$, which implies that β is a (i, j)-fuzzy γ -open set.

Converse part: Since every (i, j)-fuzzy γ -open set is a (i, j)-fuzzy γ -locally closed set, thus β is a (i, j)-fuzzy γ -locally closed set.

Proposition 2.16 Let $\alpha < \beta$ and $\beta \in$(i, j)F γ LC(X), then there exists a (i, j)-fuzzy γ -locally closed set η such that $\alpha < \eta < \beta$.

Proof: From the given assumption we have, $\beta = \theta \wedge$ (i, j)- γ -cl(β), where θ is a (i, j)-fuzzy γ -open. Again, since $\alpha < \beta$ it implies that $\alpha < \theta$. Also, we have $\alpha <$ (i, j)- γ -cl(α). Thus $\alpha < \theta \wedge$(i, j)- γ -cl(α) $= \eta$. Hence η is (i, j)-fuzzy γ -locally closed set and $\alpha < \eta < \beta$.

3. (i, j)-Fuzzy γ -LC Continuous Function

In this section, we study the notion of (i, j)-fuzzy γ -LC continuous and (i, j)-fuzzy γ -LC irresolute functions as an application of (i, j)-fuzzy γ -locally closed set and establish some basic properties of these newly defined functions.

Definition 3.1 A function $f:(X,\tau_i,\tau_j)\to(Y,\sigma_i,\sigma_j)$ from a fbts (X,τ_i,τ_j) to another fbts (Y,σ_i,σ_j) is called (i, j)-fuzzy LC continuous if the inverse image of every σ_i -closed set in *Y* is (i, j)-fuzzy locally closed set in *X*.

Definition 3.2 A function $f:(X,\tau_i,\tau_j)\to(Y,\sigma_i,\sigma_j)$ from a fbts (X,τ_i,τ_j) to another fbts (Y,σ_i,σ_j) is called (i, j)-fuzzy γ-LC continuous if the inverse image of every σ_i -closed set in *Y* is (i, j)-fuzzy γ-locally closed set in *X*.

Remark 3.3 The notions of (i, j)-fuzzy LC-continuous and (i, j)-fuzzy γ-LC continuous function are independent of each other.

Definition 3.4 A function $f:(X,\tau_i,\tau_j)\to(Y,\sigma_i,\sigma_j)$ from a fbts (X,τ_i,τ_j) to another fbts (Y,σ_i,σ_j) is called $\sigma_i\sigma_j$-fuzzy continuous if the inverse image of every σ_i-fuzzy open set in *Y* is $\sigma_i\sigma_j$-open set in *X*.

We state the following result without proof.

Proposition 3.5 If $f:(X,\tau_i,\tau_j)\to(Y,\sigma_i,\sigma_j)$ is a (i, j)-fuzzy γ-LC continuous and $g:(Y,\sigma_i,\sigma_j)\to(Z,\delta_i,\delta_j)$ is a $\sigma_i\sigma_j$ -fuzzy continuous then (gof) is a (i, j)-fuzzy γ-LC continuous.

Theorem 3.6 A function $f:(X,\tau_i,\tau_j)\to(Y,\sigma_i,\sigma_j)$ from a fbts (X,τ_i,τ_j) to another fbts (Y,σ_i,σ_j) is (i, j)-fuzzy γ-continuous if it is (i, j)-fuzzy γ-LC continuous and the pre-image of every σ_i- closed set is (i, j)-fuzzy γ-dense set in *X*.

Proof: Let β be any σ_i-fuzzy closed set in *Y*. Since f is a (i, j)-fuzzy γ -LC continuous, it implies that $f^{-1}(\beta)$ is (i, j)-fuzzy γ-locally closed set in X. Again by the given hypothesis, we have (i, j)- γ -cl$(f^{-1}(\beta))=1_X$. Thus $f^{-1}(\beta)$ is a (i, j)-fuzzy γ -open set and consequently the proof is completed.

For any fuzzy sub setδ, (i, j)- γ Lcl(δ) is the smallest (i, j)-fuzzy γ-locally closed set containing δ.

Theorem 3.7 Let $f:(X,\tau_i,\tau_j)\to(Y,\sigma_i,\sigma_j)$ be a mapping between two fbts. Then the following are equivalent:

(i) f is (i, j)-fuzzy γ -LC continuous .

(ii) (i, j)- γ -L cl$(\delta) < f^{-1}(\sigma_i$-cl $(\delta))$, for every fuzzy subsets δ of X.

Proof: (i)$\Rightarrow$ (ii) Let f be a (i, j)-fuzzy γ -LC continuous.

Now for any fuzzy subset δ of X , we have

$f(\delta) < \sigma_i$- cl ($f(\delta)) \Rightarrow \delta < f^{-1}(\sigma_i$-cl $f(\delta)) \Rightarrow$ (i, j)-γ -L cl$(\delta) < f^{-1}(\sigma_i$-cl $(\delta))$.

(ii)$\Rightarrow$ (i) Let β be any σ_i-closed set in *Y*.

Thus from (ii) , we have

(i, j)- γ -L cl$f^{-1}(\beta) < f^{-1}(\beta)$. Thus f is (i, j)-fuzzy γ -LC continuous.

Theorem 3.8 Let $f:(X,\tau_i,\tau_j)\to(Y,\sigma_i,\sigma_j)$ and $g:(Y,\sigma_i,\sigma_j)\to(Z,\delta_i,\delta_j)$ be two functions such that $gof:X\to Z$ is (i, j)-fuzzy γ -LC continuous function. If g is $\sigma_i\sigma_j$ closed surjection, then f is (i, j)-fuzzy γ -LC continuous function.

Proof: Suppose that, β be a σ_i-fuzzy closed set in Y. Since g is $\sigma_i\sigma_j$ -closed surjection, therefore $g(\beta)$ is $\delta_i\delta_j$- fuzzy closed set in *Z*.

Again, since gof is (i, j)-fuzzy γ-LC continuous and g is surjective, we have $(gof)^{-1}(g(\beta)) = f^{-1}(\beta)$ is (i, j)-fuzzy γ-locally closed set in X.

Definition 3.9 A function $f: (X, \tau_i, \tau_j) \to (Y, \sigma_i, \sigma_j)$ is called (i, j)-fuzzy γ-LC-irresolute if the inverse image of every (i, j)-fuzzy γ-locally closed set in Y is (i, j)-fuzzy γ-locally closed set in X.

Theorem 3.10 Let $f: (X, \tau_i, \tau_j) \to (Y, \sigma_i, \sigma_j)$ and $g: (Y, \sigma_i, \sigma_j) \to (Z, \delta_i, \delta_j)$ be any two functions, then

(i) (gof) is (i, j)-fuzzy γ-LC-irresolute if f and g are both (i, j)-fuzzy γ-LC irresolute.

(ii) (gof) is (i, j)-fuzzy γ-LC continuous , if g is (i, j)-fuzzy γ-LC continuous and f is (i, j)-fuzzy γ-LC irresolute.

Proof:

(i) Let β be a (i, j)-fuzzy γ-locally closed set in (Z, δ_i, δ_j). Since g is (i, j)-fuzzy γ-LC irresolute, thus $f^{-1}(\beta)$ is (i, j)-fuzzy γ-locally closed set in (Y, σ_i, σ_j). Again, f is a (i, j)-fuzzy γ-LC irresolute, so $f^{-1}(g^{-1}(\beta))$ is a (i, j)-fuzzy γ-locally closed set in (X, τ_i, τ_j) . Hence (gof) is a (i, j)-fuzzy γ-LC irresolute.

(ii) Let α be a δ_i-fuzzy closed set in (Z, δ_i, δ_j) . Since g is (i, j)-fuzzy γ-LC continuous, thus $f^{-1}(\alpha)$ is (i, j)-fuzzy γ-locally closed set in (Y, σ_i, σ_j). Also, since f is a (i, j)-fuzzy γ-LC irresolute, so $f^{-1}(g^{-1}(\alpha))$ is (i, j)-fuzzy γ-locally closed set in (X, τ_i, τ_j) . Hence (gof) is (i, j)-fuzzy γ-LC continuous.

4. Conclusions

In the present work we studied the relationship between newly defined concepts and some existing notins in fuzzy bitopological space such as $\tau_i\tau_j$-fuzzy b-locally open set, (i, j)-fuzzy γ-dense set which may be helpful for the further work on (i, j)-fuzzy γ-locally closed set. The notions (i, j)-fuzzy γ-open set and (i, j)-fuzzy γ-dense set independent, nevertheless we establish an equivalent relationship between these concepts. Finally, we found one condition under which a (i, j)-fuzzy γ-LC continuous function is a (i, j)-fuzzy γ-continuous.

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