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RESEARCH ARTICLE

ON THE CONCEPT OF HAUSDORFFNESS IN FUZZY BICLOSURE SPACE

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ABSTRACT

The purpose of this paper is to introduce the concept of Hausdorffness in fuzzy biclosure space. We obtain some important results relating to fuzzy pairwise T_2 space (in short FP-T_2). In particular, we find that T_2 satisfy basic desirable properties viz. hereditary, productive and projective properties. T_2 Fuzzy biclosure spaces are "good extensions" of the corresponding concepts in a biclosure spaces.

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INTRODUCTION

1.The notions of closure spaces were introduced by Birkhoff, (1967) and Cech, (1966) independently. Later on Boonpok, (2010) introduced the notion of biclosure spaces. Such spaces are equipped with two arbitrary closure operator .Further the concept of fuzzy closure spaces has been introduced by Mahhour and Ghanim, (1985) and Srivastava *et al.* (1994). Mahhour and Ghanim generalize the concept of Cech closure spaces while Srivastava *et al* generalizes the concept of Birkhoff closure spaces. Later on Tapi and Navalakhe, (2011) introduced and studied the concept of fuzzy biclosure spaces. In this paper we have introduced the concept of fuzzy biclosure space as in (Srivastava *et al.*, 2016). In this paper we have introduced Hausdorffness in fuzzy biclosure spaces. We have studied T_2 separation axioms in fuzzy biclosure spaces, in detail. Several important results have been obtain e.g. it has been observed that T_2 axioms in a fuzzy biclosure space satisfy the hereditary, productive and projective properties and also "good extensions" of the corresponding concepts in a closure spaces.

2.Preliminaries- Here I and I_0 will denote the intervals (0, 1) and (0, 1) respectively. For a set X, I^x denotes the set of all functions from X to I.

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A constant fuzzy set taking value $\alpha \in (0, 1)$ will be denoted by $\underline{\alpha}$ .If $A \subseteq X$, $\mathbf{1}_A$denotes the characteristic function of A, by A itself. Any fuzzy set u in $A \subseteq X$ will be identified with the fuzzy set in X, which takes the same value as u for $x \in A$ and 0 for $x \in X\text{-}A$. Now, we recall the definition of closure operations on a set X. A fuzzy point 'x_r' in a non empty set X is a fuzzy set in X, taking value $r \in (0,1)$ at x and 0 elsewhere . Here x and r respectively called the support and value of x_r. A fuzzy point x_r is said to belong to a fuzzy set A (notation: $x_r \in A$) if $r < A(x)$ .It can be seen easily that (i) $x_r \in A \nRightarrow x_r \notin coA$, (ii) $x_r \in \bigcup_{i\in A} A_i \Leftrightarrow x_r \in A_i$ for some $i \in A$ and (iii) any fuzzy set is a union of all fuzzy points belonging to it. A fuzzy singleton x_r in a non empty set X is a fuzzy set in X, taking value $r \in (0, 1)$ at x and 0 elsewhere. In particular, x_1 denotes the fuzzy singleton with support x and value 1. Two fuzzy points / fuzzy singletons are said to be distinct if their supports are distinct. A fuzzy singleton x_r in a non empty set X is said to be quasi-coincident with a fuzzy set A in X (Notation: x_r q A) if $r + A(x) > 1$. If x_r is not quasi-coincident with a fuzzy set A in X (Notation: $x_r \, \bar{q}$ A). Two fuzzy sets A and B in X are said to be quasi-coincident if $\exists\, x \in X$ such that $A(x) + B(x) > 1$. If fuzzy sets A and B in X are not quasi-coincident, we write A $\bar{q}$ B. It can be easily seen that A $\bar{q}$ B$\Leftrightarrow A \subseteq coB$. A fuzzy set A in X is called a constant fuzzy set if there exists some $\alpha \in I$ such that $A(x) = \alpha$ for all x in X. We shall denote this constant fuzzy set taking value α, by.

In particular $\underline{0}$ and $\underline{1}$ shall be frequently denoted as ϕ and X respectively. For $A \subseteq X$, the characteristic function of A shall be denoted by A itself or χ_A. All undefined concepts are taken from Lowen (1976) and Ming and Ming (1980).

Definition 2.1 (Cech, 1966)

A map C: P(X)→ P(X) defined on the power set P(X) of a set X is called a closure operator on X and the pair (X, C) is called a closure space if the following axioms are satisfied:

(C1)´ $C(\varphi) = \varphi$
(C2)´ $A \subseteq C(A) \quad \forall A \subseteq X$
(C3)´ $A \subseteq B \Rightarrow C(A) \subseteq C(B) \quad \forall A, B \subseteq X$

Now we define fuzzy biclosure space which is parrallel line as in (Srivastava, 2000)

Definition 2.2 (Srivastava *et al.*, 2016)

A function c_i: $I^x \rightarrow I^x$, i=1, 2 is called a fuzzy biclosure operation on X if the following axioms are satisfied:

(c1)´´ $c_i(\underline{\alpha}) = \underline{\alpha}$, $\alpha \in (0, 1)$, i= 0, 1

(c2)´´ $A \subseteq c_i(A)$, $\forall A \in I^x$

(c3)´´ $A \subseteq B \Rightarrow c_i(A) \subseteq c_i(B)$, $\forall A, B \in I^x$

(c4)´´ $c_i(c_i(A)) = c_i(A)$, $\forall A, B \in I^x$

Definition 2.3- A subset A of a fuzzy biclosure space (X, c_1, c_2) is said to be fuzzy closed if:

$$c_1(c_2(A)) = A$$

The complement of fuzzy closed set is known as fuzzy open set.

Definition 2.4- We say that the property "FP" in a fuzzy biclosure space is a good extension of the corresponding property 'P' in a biclosure space if (X, C_1, C_2) satisfies 'P' iff (X, ωC_1, ωC_2) satisfies "FP".

Proposition 2.1 (Srivastava *et al.*, 1994)- Let (X, C_1, C_2) be a fuzzy biclosure space.Then for all $A \subseteq X$. A is C_i- closed iff 1_A is ωC-closed.

Definition 2.5 (Viriyapong *et al.*, 2012)- Let (X,c_1,c_2) and (Y, c_1^*, c_2^*) be two fuzzy biclosure spaces and f: (X,c_1,c_2) → (Y, c_1^*, c_2^*) be a map. Then f is said to be fuzzy continuous (in short, F-continuous) if the inverse image of each c_i^*- fuzzy open set (closed set) is c_i -fuzzy open set (closed set) for $i = 1,2$.

Definition 2.6 (Viriyapong *et al.*, 2012) - Let (X,c_1,c_2) and (Y, c_1^*, c_2^*) be two fuzzy biclosure spaces and f: (X,c_1,c_2) → (Y, c_1^*, c_2^*) be a map. Then f is said to be fuzzy pairwise continuous (in short, fuzzy P-continuous) if the maps f_i(X, c_i) → (Y, c_i^*) are fuzzy continuous for $i = 1,2$.

Definition 2.7- A biclosure space (X,c_1,c_2) is called pairwise T_2(in short, P- T_2) if $\forall x, y \in X, x \neq y$, ∃ U∈ c_1 , V∈ c_2 such that $x \in U, y \in V$ and $U \cap V = \phi$.

Definition 2.8 (Viriyapong *et al.*, 2012)- Let (X,c) be a closure space. A subset A⊆ X is called a generalized closed set, briefly a g-closed set, if $cA \subseteq G$ whenever G is an open subset of (X,c) with $A \subseteq G$. A subset $A \subseteq X$ is called a generalized open set, briefly a g-open set, if its complement is g-closed.

Definition 2.9 (Viriyapong *et al.*, 2012)- Let (X,c) be a closure space. A subset A⊆ X is called a ∂-closed set, if $cA \subseteq G$ whenever G is a g-open subset of (X,c) with $A \subseteq G$. A subset $A \subseteq X$ is called a ∂-open set if its complement is ∂ –closed.

Note that- For a subset A of a closure space (X,c), the following implications hold:-

A is closed ⇒ A is ∂ –closed⇒ A is g –closed.

Definition 2.10- Let (X,c_1,c_2) be a biclosure space . A biclosure space (Y, c_1^*, c_2^*) is called a subspace of (X,c_1,c_2) if Y ⊆ X and $c_i^*A = c_iA \cap Y$ for each i ∈ {1, 2} and each subset A ⊆ Y.

Definition 2.11- Let (X,c_1,c_2) and (Y, c_1^*, c_2^*) be a fuzzy biclosure space . A map f : (X, c_1, c_2) → (Y, c_1^*, c_2^*) is said to be fuzzy continuous if $f(c_i\mu) \leq c_1^* f(\mu)$ for every subset μ in X. In other words, a map f : (X, c_i) → (Y, c_i^*) is fuzzy continuous iff $c_i f^{-1}(\upsilon) \leq f^{-1}(c_1^*\upsilon)$ for i= 1, 2 and for every fuzzy subset υ in Y.

Clearly, if map f: (X, c_1, c_2) → (Y, c_1^*, c_2^*) is fuzzy continuous then $f^{-1}(\upsilon)$ is a fuzzy closed set υ in (Y, c_1^*, c_2^*).

Definition 2.12- Let (X,c_1,c_2) be a fuzzy biclosure space . A fuzzy set μ in (X,c_1,c_2) is called generalized fuzzy closed briefly g-fuzzy closed, if $(c_i\mu) \leq \upsilon$ whenever υ is a fuzzy open set in (X,c_1,c_2) with $\mu \leq \upsilon$. A fuzzy set μ in (X,c_1,c_2) is called generalized fuzzy open, briefly g- fuzzy open, if its complement is g-fuzzy closed.

Definition 2.13- Let (X,c_1,c_2) be a fuzzy biclosure space . A fuzzy set μ in (X,c_1,c_2) is called ∂ -fuzzy closed, if $(c_i\mu) \leq \upsilon$ whenever υ is a fuzzy g-open set in (X,c_1,c_2) with $\mu \leq \upsilon$. A fuzzy (X,c_1,c_2) is called ∂ -fuzzy open if its complement is ∂ - fuzzy closed.

Note that- For a fuzzy set μ in a fuzzy biclosure (X,c_1,c_2) the following implication hold:-

μ is fuzzy closed ⇒ μ is g- fuzzy closed ⇒ μ is ∂- fuzzy closed

Relative, sum and product fuzzy closure operations

Here we define relative fuzzy closure operation on a subset *A* of an fbcs *X*, sum fuzzy closure operation on $X = \cup X_t$ for a family {(X_t ,c_{1t},c_{2t}): $t \in j$} of pairwise disjoint fuzzy biclosure space and product fuzzy biclosure operation for a family of fuzzy biclosure space. The definition of relative fuzzy biclosure operation and the sum fuzzy biclosure operation are defined as.

Definition 3.1- Let (X,c_1,c_2) be a fuzzy biclosure space and $A \subseteq X$ .Then the fuzzy closure operation c_{iA} defined above is called the relative fuzzy closure operation on *A* and the fuzzy biclosure space (A,c_{1A},c_{2A}) is called a fuzzy closure subspace of (X,c_1,c_2) .

Definition 3.2 –Let $\mathfrak{F} = \{(X_t, c_{1t}, c_{2t}): t \in \mathfrak{F}\}$ be a family of pair wise disjoint fuzzy biclosure spaces.Then the fuzzy closure operation $\bigoplus c_{it}$ defined above is called the sum fuzzy biclosure operation on $\cup X_t$ and the corresponding pair (X, $\bigoplus c_{1t}$,$\bigoplus c_{2t}$) is called the sum fuzzy biclosure space of the family $\mathfrak{F}$.

Now, we define the product fuzzy closure operation for a family of fuzzy biclosure operation. Let $\{(X_j, c_{1j}, c_{2j}) : j \in J\}$be a family of fuzzy biclosure spaces and let $X=\prod_{j\in J} Xj$ and p_j:X→X_j be the mapping. Let $c_i : I^x \to I^x$ be the mapping given by

c(u)=inf {v∈I^x: v≥u, and v=$\wedge_j p_j^{-1}(u_j)$ where each u_j is c_j –closed}.

Then c is a fuzzy closure operation on X.

Definition 3.3- Let $\{(X_j, c_{1j}, c_{2j}) : j \in J\}$ be a family of fuzzy biclosure spaces then the fuzzy biclosure operation defined above is called the product fuzzy biclosure operation on X=$\prod x_j$ and the fuzzy biclosure space (X,c_1,c_2) is called the product fuzzy biclosure space of the family $\{(X_j, c_{1j}, c_{2j}) : j \in J\}$.

Definition 3.4- (Birkhoff, 1967**)** Let c_1 and c_2 be two fuzzy closure operations on X.The fuzzy biclosure space (X,c_1,c_2) is said to be coarser than (X, c_1^*, c_2^*) (or that (X, c_1^*, c_2^*) is finer than (X,c_1,c_2)) if $c_i(A) \subseteq c_i^*(A)$ for all A∈I^x Now we define Hausdorffness in fuzzy biclosure space.

Hausdorff Fuzzy biclosure spaces

Definition 4.1– A fuzzy biclosure space (X, c_1, c_2) is called Hausdorff if ∀ pair of distinct fuzzy points x_r, y_s in X, ∃ $U, V \in c_1, c_2$ such that $x_r \in U, y_s \in V$ and $U \cap V = \phi$.

Definition 4.2 (Viriyapong *et al*., 2012**)-** A fuzzy biclosure space (X,c_1,c_2) is said to be a generalized Hausdorff fuzzy biclosure space, briefly g-Hausdorff fuzzy biclosure space, if for any two distinct fuzzy points x_r, y_s in X with x ≠ y, ∃ a g-fuzzy open set μ in (X,c_1) and g-fuzzy open set υ in (X,c_2) such that $x_r \in \mu, y_s \in \upsilon$ and $\mu \wedge \upsilon = 0_x$.

Definition 4.3 (Viriyapong *et al*., 2012**)-** A fuzzy biclosure space (X,c_1,c_2) is said to be a $\partial -$ Hausdorff fuzzy biclosure space, if for any two distinct fuzzy points x_r, y_s in X with x ≠ y, ∃ a ∂ -fuzzy open set μ in (X,c_1) and ∂ -fuzzy open set υ in (X,c_2) such that $x_r \in \mu, y_s \in \upsilon$ and $\mu \wedge \upsilon = 0_x$.

Proposition 4.1- Let (X,c_1,c_2) and (Y, c_1^*, c_2^*) be a fuzzy biclosure space. Let f : (X, c_1, c_2) → (Y, c_1^*, c_2^*) be injective and continuous. If (Y, c_1^*, c_2^*) is a Hausdorff fuzzy biclosure space, then (X,c_1,c_2) is a Hausdorff fuzzy biclosure space.

Proof- Let (X,c_1,c_2) and (Y, c_1^*, c_2^*) be a fuzzy biclosure space. Let f : (X, c_1, c_2) → (Y, c_1^*, c_2^*) be injective and continuous. Let $x_r, y_s \in X$, $x \neq y$, if f be injective and continuous, then $(f(x))_r$, $(f(y))_s$ are distinct points of Y such that $f(x) \neq f(y)$.

To show that-(X,c_1,c_2) is a Hausdorff fuzzy biclosure space. Since (Y, c_1^*, c_2^*) is a Hausdorff fuzzy biclosure space, ∃ open sets G and H such that $(f(x))_r$∈ G, $(f(y))_s$∈ H and $G \cap H = \phi$.

Then $x_r \in f^{1}(G)$ $y_s \in f^{1}(H)$,

$f^{1}(G) \cap f^{1}(H) = f^{1}(G \cap H)$
$= f^{1}(\phi)$
$= \phi$, it showing that(X,c_1,c_2) is a Hausdorff biclosure space.

Theorem-4.1- Let (X, c_1, c_2) be a biclosure space .Then (X, c_1, c_2) is P-T_2 iff (X, ωC_1, ωC_2) is FP-$T_2(i)$.

Proof- Let (X, c_1, c_2) is P-T_2, to show that (X, ωC_1, ωC_2) is FP-T_2. Let any pair of distinct fuzzy points x_r, y_s in X. Then x≠y. Since (X, c_1, c_2) is P-T_2 ∃U ∈ c_1, V∈ c_2 such that $x \in U, y \in V$ and$U \cap V = \phi$. Now consider χ_u, χ_v. Then χ_u∈ ωC_1, χ_v∈ ωC_2, $x_r \subseteq \chi_u, y_s \subseteq \chi_v$ and $\chi_u \cap \chi_v = \phi$, it showing that (X, ω$C_1$, ω$C_2$) is FP-$T_2(i)$.

Conversely, let (X, ωC_1, ωC_2) is FP-$T_2(i)$. To show that (X, c_1, c_2) is P-T_2, let x, y∈ X, x≠y. Let$r \in (0,1)$. Then x_r, y_r are two distinct fuzzy points in X so ∃U ∈ ωC_1, V∈ ωC_2 such that $x_r \in U, y_r \in V$ and $U \cap V = \phi$. Now consider $U^{-1}(r, 1)$, $V^{-1}(r, 1)$. Then $U^{-1}(r, 1) \in C_1$, $V^{-1}(r, 1) \in C_2$ and $x \in U^{-1}(r, 1)$, $y \in V^{-1}(r, 1)$ and $U^{-1}(r, 1) \cap V^{-1}(r, 1) = \phi$, it showing that (X, c_1, c_2) is P-T_2.

Theorem-4.2- $\{(X_i, c_{1i}\ c_{2i})): i \in \mathcal{A}\}$ be a family of fuzzy biclosure spaces. Then the product space ($\prod X_i$, $\prod c_{1i}$, $\prod c_{2i}$) is FP-T_2 iff each coordinate fuzzy biclosure spaces is FP-T_2.

Proof- Let each coordinate space be FP-T_2. Then to show that the product space is FP-T_2, take any two distinct fuzzy points x_r, y_s in X=$\prod X_i$. Then x≠y. Let$x = \prod x_i, y = \prod y_i$, then $x_j \neq y_j$ for some $j \in \mathcal{A}$. Now consider the distinct fuzzy points$(x_j)_r$ and $(y_j)_s$ in X_j. Since $(X_i, c_{1i}\ c_{2i})$ is FP-T_2, ∃ disjoint fuzzy open sets $U_j \in c_{1i}$, $V_j \in c_{2i}$ such that $(x_j)_r \in U_j$, $(y_j)_s \in V_j$, $U_j \cap V_j = \phi$. Now consider the fuzzy open sets $U = \prod U_i^{'}, V = \prod V_i^{'}$ in X, where $U_i^{'} = V_j^{'} = X$ for$i \neq j$, and $U_j^{'} = U_j = V_j$ for$i = j$. Then $x_r \in U$, $y_s \in V$,$U \cap V = \phi$. Hence the product fuzzy biclosure space is FP-$T_2(i)$.

Conversely, Let the product space be FP-T_2. Take the coordinate space say $(X_i, c_{1i}\ c_{2i})$, let consider the two distinct fuzzy points$(x_j)_r$ and $(y_j)_s$ in X_j. Construct two fuzzy points x_r, y_s in X such that $x = \prod x_i^{'}, y = \prod y_i^{'}$, where $x_j^{'} = \prod y_i^{'}$, for $i \neq j$ and $x_j^{'} = x_j, y_j^{'} = y_j$, then x_r, y_s are distinct fuzzy points in X and now using that ($\prod X_i$, $\prod c_{1i}$, $\prod c_{2i}$) is FP-T_2 , ∃ fuzzy open sets $U \in \prod c_{1j}$, $V \in \prod c_{2j}$, such that $x_r \in U$, $y_s \in V$ and $U \cap V = \phi$. Now since U is fuzzy open in $\prod c_{1j}$ and $x_r \in U$ ∃ fuzzy open sets $\prod U_i^{'}$ in $\prod c_{1i}$ such that.

$$x_r \in \prod U_i^{'} \subseteq U, \tag{1}$$

and similarly ∃ a basic fuzzy open say $\prod V_i^{'}$ in $\prod c_{2i}$ such that

$$x_s \in \prod V_i^{'} \subseteq V, \tag{2}$$

From (1)

$$r < \inf_i U_i^{'}(x_i^{'}) \Rightarrow r < U_i^{'}(x_i^{'}) \quad \forall\ i \in \mathcal{A} \tag{3}$$

And From (2)

$$s < \inf_i V_i^{'}(y_i^{'}) \Rightarrow s < V_i^{'}(y_i^{'}) \qquad \forall \quad i \in \mathcal{A} \tag{4}$$

Now consider $U_j^{'}$ and $V_j^{'}$, further, we claim that $U_j^{'} \cap V_j^{'} = \phi$ for if not, then $\exists\ z_j \in X_j$ such that.

$$U_j^{'}(z_j) > 0 \text{ And } V_j^{'}(z_j) > 0 \tag{5}$$

Now let $z = \prod z_i^{'}$ where $z_i^{'} = x$ for $i \neq j$ and $z_j^{'} = z_j$ them $\prod U_i^{'}(z) > 0$ in view of (3), (4) and (5) which is a contradiction since $\prod U_i^{'} \subseteq$ U, $\prod V_i^{'} \subseteq$ V and $U \cap V = \phi$. Hence $(X_i, c_{1i}\ c_{2i})$ is FP-$T_2(i)$.

Theorem-4.3- Every closed subspace of a Hausdorff fuzzy biclosure space is Hausdorff.

Proof- Let (X, c_1, c_2) be Hausdorff space and let (Y, c_{1A}, c_{2A}) be a closed subspace of (X, c_1, c_2) i.e. $Y \subseteq$ X.

To show that- (Y, c_{1A}, c_{2A}) isHausdorff i.e.T_2.

Let x_r, y_s be two distinct points of Y. Since Y⊆X. x_r, y_s are also two distinct points of X. Since (X, c_1, c_2) is a T_2 space, ∃ G ∈ c_1, H ∈ c_2 such that $G \cap H = \phi$. Let G be c_1- closed and H be c_2- closed.

Let G∩Y∈ c_{1A} and H∩Y∈ c_{2A}.Then for $x_r, y_s \in$ Y, ∃ G_y = G∩Y ∈ c_1 and H_y = H∩Y ∈ c_2 (Finite intersection of closed sets is closed).

$G_y \cap H_y$= (G∩Y) ∩ (H∩Y)
= (G∩H) ∩Y
= ϕ∩Y
= ϕ

Showing that (Y, c_{1A}, c_{2A}) is also T_2.

Conclusion

In this paper we have introduced and studied Hausdorffness in fuzzy biclosure space. We observed that our definition of Hausdorffness satisfies fundamental properties viz. hereditary, productive and projective properties. It is also good extension of the corresponding concept in closure space.Some more results relating to Hausdorffness is also obtained.

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