RESEARCH PAPER

ON THE CHARACTERIZATION OF (1,2)S_P-CONTINUOUS FUNCTION VIA (1,2)S_P-OPEN SETS IN BITOPOLOGICAL SPACES

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Abstract:
The purpose of this paper is to introduce the concept of (1,2)S_p-continuous function in bitopological spaces. The basic properties and some of its characterizations and relationships are investigated.

Key words:
(1,2)semi-open, (1,2)pre-open, (1,2)pre-closed, (1,2)S_p-open, (1,2)S_p-closed, (1,2)S_p-continuous function.

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1. INTRODUCTION

Continuity is a basic concept of the study in topological spaces. In 1963, Kelly [2] introduced Bitopology. In 2010, Shareef [5] introduced a class of continuous function called S_p-continuous function in terms of S_p-open sets in topological spaces. In 2017, Shareef et.al [6] introduced (1,2)S_p-open sets in bitopological spaces. In this paper, define new class of continuous function called (1,2)S_p-continuous function in bitopological spaces and study some of their characterizations using (1,2)S_p-open sets.

2. PRELIMINARIES

Definition 2.1. [3] A subset A of X is called

i. (1,2)α-open if $A \subseteq \tau_1$-Int($\tau_1\tau_2$-Cl(τ_1-Int(A))).
ii. (1,2)semi-open if $A \subseteq \tau_1\tau_2$-Cl(τ_1-Int(A)).
iii. (1,2)pre-open if $A \subseteq \tau_1$-Int($\tau_1\tau_2$-Cl(A)).
iv. (1,2)regular-open if $A = \tau_1$-Int($\tau_1\tau_2$-Cl(A)).

The collection of all (1,2)α-open, (1,2)semi-open, (1,2)pre-open and (1,2)regular-open sets are denoted by (1,2)αO(X), (1,2)SO(X), (1,2)PO(X) and (1,2)RO(X) respectively.

Definition 2.2. [4] A subset A of X is called

i. (1,2)α-closed if τ_1Cl($\tau_1\tau_2$-Int(τ_1-Cl(A))) $\subseteq A$.
ii. (1,2)semi-closed if $\tau_1\tau_2$-Int(τ_1-Cl(A)) $\subseteq A$.
iii. (1,2)pre-closed if τ_1-Cl($\tau_1\tau_2$-Int(A)) $\subseteq A$.
iv. (1,2)regular-closed if $A = \tau_1$-Cl($\tau_1\tau_2$-Int(A)).

The set of all (1,2)α-closed, (1,2)-semi-closed, (1,2)pre-closed and (1,2)regular-closed sets are denoted by (1,2)αCL(X), (1,2)SCL(X), (1,2)PCL(X) and (1,2)RCL(X) respectively. Also, for any subset A. of X, the (1,2)α-closure, (1,2)-semi closure, (1,2)pre-closure and (1,2)regular - closure of A is denoted as (1,2)αCl(X), (1,2)SCl(X), (1,2)PCl(X) and (1,2)RCl(X) respectively.

Definition 2.3. [6] A bitopological space (X, τ_1, τ_2) is said to be τ_1-locally indiscrete if every τ_1-open subset of X is τ_1-closed.

Definition 2.4. [4] A function f: (X, τ_1, τ_2) → (Y, σ_1, σ_2) is said to be (1,2)α-continuous (resp. (1,2)semi-continuous) if the inverse image of each (1,2)α-open set in Y is (1,2)α-open set in X (resp. (1,2)semi-open set in Y is (1,2)semi-open in X).

Lemma 2.5. [7] A function f: (X, τ_1, τ_2) → (Y, σ_1, σ_2) is bijective if and only if f(X \ A) = (Y \ $f(A)$) for each subset A of X.

Definition 2.6. [6] A (1,2)semi-open set A of X is called (1,2)S_p-open set if for each $x \in A$, there exists a (1,2)pre-closed set F such that $x \in$ F ⊆ A.

The complement of a (1,2)S_p-open set is a (1,2)S_p-closed set and the family of all (1,2)S_p-open (resp. (1,2)S_p-closed) subsets of X is denoted by (1,2)S_p-O(X) (resp. (1,2)S_p-CL(X)).

Definition 2.7. [6] A point $x \in$ X is said to be a (1,2)S_p-interior point of A, if there exists a (1,2)S_p-open set U containing x such that $x \in U \subseteq A$. The union of all (1,2)S_p-open sets contained in A is said to be (1,2)S_p-interior of A and it is denoted by (1,2)S_p-Int(A).

Definition 2.8. [6] Let A be a set in a bitopological space X. A point $x \in$ X is said to be a (1,2)S_p-closure of A if and only if $A \cap U = \Phi$, for every (1,2)S_p-open set U containing x. The intersection of all (1,2)S_p-closed sets F containing A is called the (1,2)S_p-closure of A and is denoted by (1,2)S_p-Cl(A).

Lemma 2.9. [1] Let Y be a subspace of the bitopological space X and Y is (1,2)regular-closed subset of X, if A is (1,2)S_p-open subset of Y, then A is (1,2)S_p-open set in X.

Proposition 2.10. [1] A (1,2)semi-closed subset A of a bitopological space X is (1,2)S_p-closed if and only if A is an intersection of (1,2)pre-open set.

Proposition 2.11. [6] A subset A of a bitopological space (X, τ_1, τ_2) is (1,2)S_p-open if and only if A is (1,2)semi-open and it is the union of (1,2)pre-closed sets.

Theorem 2.12. [6] Let $\{A_\alpha : \alpha \in \Delta\}$ be a family of (1,2)S_p-open sets in a bitopological space (X, τ_1, τ_2). Then $\cup_{\alpha \in \Delta} A_\alpha$ is also a (1,2)S_p-open set in X.

Remark 2.13. [1] Any intersection of (1,2)S_p-closed sets of a bitopological space X is (1,2)S_p-closed.

Definition 2.14. [1] A subset N of a space X is said to be (1,2)S_p-neighborhood ((1,2)S_p-nbhd) of a point $x \in$ X, if there exists a (1,2)S_p-open set U such that $x \in U \subseteq N$.

Proposition 2.15. [1] Let X be a bitopological space and let A and B be two subsets of X, then:

i. If $A \subseteq B$, where A is (1,2)S_p-neighborhood of $x \in$ X, then B is also (1,2)S_p-neighborhood of x.
ii. An arbitrary union of (1,2)S_p-neighborhood of a point $x \in$ X, is also (1,2)S_p- neighborhood of x.
iii. If A is (1,2)S_p-open set if and only if it is (1,2)S_p-neighborhood of each of it's point.
iv. If A is (1,2)S_p-neighborhood of a point $x \in$ X, then A is (1,2)semi-neighborhood of x.

Lemma 2.16. [1] Let A and B be subsets of a bitopological space X, then

i. (1,2)S_p-Cl(A) is the smallest (1,2)S_p-closed set containing A.
ii. A is (1,2)S_p-closed set if and only if A = (1,2)S_p-Cl(A).
iii. If $A \subseteq B$, then (1,2)S_p-Cl(A) ⊆ (1,2)S_p-Cl(B).
iv. (1,2)SCl(A) ⊆ (1,2)S_p-Cl(A).

Proposition 2.17. [1] Let X be a bitopological space and $A \subset$ X, then

i. (X \ (1,2)S_p-Int(A)) = (1,2)S_p-Cl(A).
ii. (1,2)S_p-Cl(A) = (1,2)S_p-Int(X \ A).
iii. (1,2)S_p-Int(A) = (X \ (1,2)S_p-Int(X \ A)).

3. (1,2)S_P-Continuous Function

Definition 3.1. A function f: (X, τ_1, τ_2) → (Y, σ_1, σ_2) is called (1,2)S_p-continuous at x ∈ X if for every σ_1-open set V in Y containing $f(x)$, there exists a (1,2)S_p-open set U in X containing x such that f (U) ⊆ V. Hence, f is (1,2)S_p-continuous if it is (1,2)S_p-Continuous at each point x ∈ X.

Example 3.2. Let X = {a, b, c} with two topologies τ_1 = {Φ, X, {a}, {c}, {a, c}} and τ_2 = {Φ, X}.Hence, (1,2)S-O(X) = {Φ, X, {a}, {c}, {a, b}, {a, c}, {b, c}}, (1,2)P-CL(X) = {X, Φ, {b}, {a, b}, {b, c}}, (1,2)S_p-O(X) = {Φ, X, {a, b}, {b, c}}.

Also, let Y = {a, b, c} with two topologies σ_1 = {Φ, Y, {a}, {b}, {a, b}} and σ_2 = {Φ, Y}. Hence, (1,2)S-O(Y) = {Φ, Y, {a}, {b}, {a, b}, {a, c}, {b, c}}}, (1,2)P-CL(Y) = {Y, Φ, {c}, {a, c}, {b, c}}, (1,2)S_p-O(Y) = { Φ, Y, {a, c}, {b, c}}. A function f: (X, τ_1, τ_2) → (Y, σ_1, σ_2) is defined as f(a) = f(b) = f(c) = a. Here, f is a (1,2)S_p-continuous function.

Proposition 3.3. Let X be a bitopological space and let A, B be two subsets of X, then:

i. if $A \subset B$, where A is (1,2)S_p-neighborhood of x ∈ X, then B is also (1,2)S_p-neighborhood of x.
ii. an arbitrary union of (1,2)S_p-neighborhood of a point x ∈ X is also (1,2)$S_p$neighborhood of x.
iii. if A is (1,2)S_p-open set if and only if it is (1,2)S_p-neighborhood of each of it's point.

Proof. (i) Let $A \subset B$, where A is (1,2)S_p-neighborhood of x ∈ X. Then there exists a (1,2)S_p-open set U containing x such that $x \in U \subset A \subset B$ which implies B is (1,2)S_p-neighborhood of x.

The proofs of **(ii)** and **(iii)** are obvious.

Proposition 3.4. A function f: (X, τ_1, τ_2) → (Y, σ_1, σ_2) is (1,2)S_p-continuous if and only if for every σ_1-open subset V of Y, $f^{-1}(V)$ is a (1,2)S_p-open set in X.

Proof. Let f: (X, τ_1, τ_2) → (Y, σ_1, σ_2) be (1,2)S_p-continuous and let V be any σ_1-open set in Y. Then show that $f^{-1}(V)$ is a (1,2)S_p-open set in X. If $f^{-1}(V)$ = Φ, then $f^{-1}(V)$ is (1,2)S_p-open set in X. Suppose, if $f^{-1}(V) \neq \Phi$, then there exists a $x \in f^{-1}(V)$. Also, since f is (1,2)S_p-continuous, there exists a (1,2)S_p-open set U_x in X such that $x \in U_x$ and $f(U_x) \subseteq V$ which implies that $x \in U_x \subseteq f^{-1}(V)$. Thus $f^{-1}(V)$ is (1,2)S_p-neighborhood of each of its points. Hence, by proposition 3.3, $f^{-1}(V)$ is a (1,2)S_p-open set in X.

Conversely, let for each σ_1-open subset V of Y, $f^{-1}(V)$ is a (1,2)S_p-open set in X. Then show that f is (1,2)S_p-continuous at x ∈ X. Let x ∈ X. Then $f(x) \in V$ which implies that $x \in f^{-1}(V)$. Hence, $f^{-1}(V)$ is (1,2)S_p-open set in X containing x and $f(f^{-1}(V)) \subseteq V$. Hence, f is (1,2)S_p-continuous.

Remark 3.5. Every (1,2)S_p-continuous is (1,2)semi-continuous but the converse is not true as shown in the following example.

Example 3.6. In Example 3.2, (1,2)S-O(X) = {Φ, X, {a}, {b}, {a, b}, {a, c}, {b, c}}, (1,2)P-CL(X) = {X, Φ, {c}, {a, c}, {b, c}}, (1,2)S_p-O(X) = {Φ, X, {a, c}, {b, c}}.

Also, let Y = {a, b, c} with two topologies σ_1 = {Φ, Y, {a}, {b}, {a, b}, {a, c}}, σ_2 = {Φ, Y}. Hence, (1,2)S-O(Y) = {Φ, Y, {a}, {b}, {a, b}, {a, c}}, (1,2)P-CL(Y) = {Y, Φ, {b}, {c}, {a, c}, {b, c}}, (1,2)S_p-O(Y) = {Φ, Y, {b}, {a, c}}. A function f: X→ Y is defined as f(a) = b, f(b) = a, f(c) = c. Here, f is (1,2)semi-continuous but not (1,2)S_p-continuous.

Theorem 3.7. The following statements are equivalents for the function f: (X, τ_1, τ_2) → (Y, σ_1, σ_2):

i. f: (X, τ_1, τ_2) → (Y, σ_1, σ_2) is (1,2)S_p-continuous.
ii. the inverse image of every σ_1-open set in Y is (1,2)S_p-open set in X.
iii. the inverse image of every σ_1-closed set in Y is (1,2)S_p-closed set in X.
iv. for each $A \subseteq$ X, f((1,2)S_p-Cl(A)) $\subseteq$ $\sigma_1\sigma_2$-Cl(f(A)).
v. for each $A \subseteq$ X, σ_1-Int(f(A)) $\subseteq$ f((1,2)S_p-Int (A)).
vi. for each $B \subseteq$ Y, (1,2)S_p-Cl(f^{-1}(B)) $\subseteq f^{-1}$($\sigma_1\sigma_2$-Cl(B)).
vii. for each $B \subseteq$ Y, f^{-1}(σ_1-Int(B)) $\subseteq$ (1,2)S_p-Int(f^{-1}(B)).

Proof. (i) ⇒ (ii) It is clear from Proposition 3.4.

(ii) ⇒ (iii) Let B be any σ_1-closed subset of Y, then (Y – B) is σ_1-open in Y, and then by (ii), f^{-1}(Y – B) = (X – f^{-1}(B)) is a (1,2)S_p-open set in X. Thus f^{-1}(B) is a (1,2)S_p-closed set in X.

(iii) ⇒ (iv) Let For each $A \subseteq$ X, then f(A) $\subseteq$ Y. since f(A) $\subseteq$ $\sigma_1\sigma_2$-Cl(f(A)) and by (iii), f^{-1}($\sigma_1\sigma_2$-Cl(f(A))) is a (1,2)S_p-closed set in X and $A \subseteq f^{-1}$($\sigma_1\sigma_2$-Cl(f(A))), then (1,2)S_p-Cl(A) $\subseteq f^{-1}$($\sigma_1\sigma_2$-Cl(f(A))) which implies that f((1,2)S_p-Cl(A)) $\subseteq$ $\sigma_1\sigma_2$-Cl(f(A)).

(iv) ⇒ (v) Let $A \subseteq$ X, then (X – A) $\subseteq$ Y and then by (iv), f((1,2)S_p-Cl(X – A)) $\subseteq$ $\sigma_1\sigma_2$-Cl(f(X – A)). Therefore by Lemma 2.5, f(X – (1,2)S_p-Int(A)) $\subseteq$ $\sigma_1\sigma_2$-Cl(Y – f(A)). This implies that (Y – f((1,2)S_p-Int(A)) $\subseteq$ (Y – (σ_1-Int(f(A))) implies σ_1-Int(f(A)) $\subseteq$ f((1,2)S_p-Int(A)).

(v) ⇒ (vi) Let $B \subseteq$ Y, then f^{-1}(B) $\subseteq$ X implies (X – f^{-1}(B)) $\subseteq$ X. Therefore by (v), σ_1-Int(f(X – f^{-1}(B))) $\subseteq$ f((1,2)S_p-Int(X – f^{-1}(B))), then σ_1-Int(Y – f(f^{-1}(B))) $\subseteq$ f(X – (1,2)S_p-Cl(f^{-1}(B))) which implies that σ_1-Int(Y – B) $\subseteq$ (Y – f((1,2)S_p-Cl(f^{-1}(B)))). Then (Y – $\sigma_1\sigma_2$-Cl(B)) $\subseteq$ (Y – f((1,2)S_p-Cl(f^{-1}(B)))) implies f((1,2)S_p-Cl(f^{-1}(B)))) $\subseteq$ $\sigma_1\sigma_2$-Cl(B). Hence, (1,2)S_p-Cl(f^{-1}(B)) $\subseteq$ f^{-1}($\sigma_1\sigma_2$-Cl(B)).

(vi) ⇒ (vii) Let $B \subseteq$ Y, then (Y – B) $\subseteq$ Y. Therefore by (vi), (1,2)S_p-Cl(f^{-1}(Y - B)) $\subseteq$ f^{-1}($\sigma_1\sigma_2$-Cl(Y – B)), then (1,2)S_p-Cl(X – f^{-1}(B)) $\subseteq$ f^{-1}(Y – σ_1-Int(B)) and by Proposition 2.17, (X – (1,2)S_p-Int(f^{-1}(B))) $\subseteq$ (X – f^{-1} (σ_1-Int(B)) which implies f^{-1}(σ_1-Int(B)) $\subseteq$ (1,2)S_p-Int(f^{-1}(B)).

(vii) ⇒ (i) Let $x \in$ X and B be any σ_1-open subset of Y containing f(x), then by (vii), f^{-1}(σ_1-Int(B)) $\subseteq$ (1,2)S_p-Int(f^{-1}(B)) which implies f^{-1}(B) $\subseteq$ (1,2)S_p-Int(f^{-1}(B)). Thus f^{-1}(B) is (1,2)S_p-open set in X containing x such that f(f^{-1}(B)) $\subseteq$ B. Hence, f is a (1,2)S_p-continuous function.

Corollary 3.8. If f: X → Y is (1,2)semi-continuous and X is τ_1-locally indiscrete, then f is (1,2)S_p-continuous.

Theorem 3.9. If the function f: (X, τ_1, τ_2) → (Y, σ_1, σ_2) be a surjective function, then the following statements are equivalent:

i. f is (1,2)S_p-continuous.

ii. for every $B \subseteq$ Y, τ_1-Int($\tau_1\tau_2$-Cl($f^{-1}(B)$)) $\subseteq f^{-1}$($\sigma_1\sigma_2$-Cl(B)) and f^{-1}($\sigma_1\sigma_2$-Cl(B)) = $\bigcap_{i \in \Delta} V_i$ where V_i ∈ (1,2)P-O(X).

iii. for every $B \subseteq$ Y, f^{-1}(σ_1-Int(B)) $\subseteq$ τ_1-Cl($\tau_1\tau_2$-Int($f^{-1}(B)$)) and f^{-1}(σ_1-Int(B)) = $\bigcup_{i \in \Delta} F_i$, where F_i ∈ (1,2)P-CL(X).

iv. for every $A \subseteq$ X, f(τ_1-Int($\tau_1\tau_2$-Cl(A))) $\subseteq$ $\sigma_1\sigma_2$-Cl($f(A)$) and f^{-1}($\sigma_1\sigma_2$-Cl($f(A)$)) = $\bigcap_{i \in \Delta} V_i$ where V_i ∈ (1,2)P-O(X).

Proof. (i) ⇒ (ii) Let $B \subseteq$ Y, then $\sigma_1\sigma_2$-Cl(B) is σ_1-closed in Y. Since f is (1,2)S_p-continuous, then by Theorem 3.7, f^{-1}($\sigma_1\sigma_2$-Cl(B)) is (1,2)S_p-closed in X which implies f^{-1}($\sigma_1\sigma_2$-Cl(B)) is (1,2)semi-closed and f^{-1}($\sigma_1\sigma_2$-Cl(B)) = $\bigcap_{i \in \Delta} V_i$ where V_i ∈ (1,2)P-O(X). Thus τ_1-Int($\tau_1\tau_2$-Cl(f^{-1}($\sigma_1\sigma_2$-Cl (B))) $\subseteq f^{-1}$($\sigma_1\sigma_2$-Cl(B)) and f^{-1}($\sigma_1\sigma_2$-Cl(B)) = $\bigcap_{i \in \Delta} V_i$ where V_i ∈ (1,2)P-O(X). Hence, τ_1-Int($\tau_1\tau_2$-Cl(f^{-1}($\sigma_1\sigma_2$-Cl (B))) $\subseteq f^{-1}$($\sigma_1\sigma_2$-Cl(B)) where V_i ∈ (1,2)P-O(X).

(ii) ⇒ (i) Let B be a σ_1-closed subset of Y, then by (ii), τ_1-Int($\tau_1\tau_2$-Cl($f^{-1}(B)$)) ⊂ f^{-1}($\sigma_1\sigma_2$-Cl(B)) = $f^{-1}(B)$ and $f^{-1}(B)$ = $\bigcap_{i \in \Delta} V_i$ where V_i ∈ (1,2)P-O(X) which implies that $f^{-1}(B)$ ∈ (1,2)SCL(X) and $f^{-1}(B)$ = $\bigcap_{i \in \Delta} V_i$ where V_i ∈ (1,2)PO(X). Thus $f^{-1}(B)$ is (1,2)S_p-closed in X. Hence, by Theorem 3.7, f is (1,2)S_p-continuous.

(i) ⇒ (iii) Let $B \subseteq$ Y, σ_1-Int(B) is σ_1-open in Y. Since f is (1,2)S_p-continuous. Therefore f^{-1}(σ_1-Int(B)) is (1,2)S_p-open in X which implies that f^{-1}(σ_1-Int(B)) ∈ (1,2)S-O(X) and f^{-1}(σ_1-Int(B)) = $\bigcup_{i \in \Delta} F_i$, where F_i ∈ (1,2)P-CL(X). Thus f^{-1}(σ_1-Int(B)) ⊂ τ_1-Cl($\tau_1\tau_2$-Int($f^{-1}(B)$)) and f^{-1}(σ_1-Int(B)) = $\bigcup_{i \in \Delta} F_i$, where F_i ∈ (1,2)P-CL(X).

(iii) ⇒ (i) Let B be subset of Y, then σ_1-Int(B) = B and by (iii), $f^{-1}(B)$ ⊂ τ_1-Cl($\tau_1\tau_2$-Int($f^{-1}(B)$)) and $f^{-1}(B)$ = $\bigcup_{i \in \Delta} F_i$, where F_i ∈ (1,2)P-CL(X) implies $f^{-1}(B)$ ∈ (1,2)S_p-O(X). Hence, f is (1,2)S_p-continuous.

(ii) ⇒ (iv) Let $A \subseteq$ X, then $f(A) \subseteq$ Y and then by (ii), τ_1-Int($\tau_1\tau_2$-Cl($f^{-1}(f(A))$)) ⊂ f^{-1}($\sigma_1\sigma_2$-Cl($f(A)$)) and f^{-1}($\sigma_1\sigma_2$-Cl($f(A)$))) = $\bigcap_{i \in \Delta} V_i$ where V_i ∈ (1,2)P-O(X). Therefore τ_1-Int($\tau_1\tau_2$-Cl($f^{-1}(f(A))$)) ⊂ f^{-1}($\sigma_1\sigma_2$-Cl($f(A)$)) and f^{-1}($\sigma_1\sigma_2$-Cl($f(A)$)) = $\bigcap_{i \in \Delta} V_i$ where V_i ∈ (1,2)P-O(X). Hence, f(τ_1-Int($\tau_1\tau_2$-Cl(A))) ⊂ $\sigma_1\sigma_2$-Cl($f(A)$) and f^{-1}($\sigma_1\sigma_2$-Cl($f(A)$)) = $\bigcap_{i \in \Delta} V_i$ where V_i ∈ (1,2)P-O(X).

(iv) ⇒ (ii) Let $B \subseteq$ Y, then $f^{-1}(B) \subseteq$ X. Therefore by (iv), f^{-1}(τ_1-Int($\tau_1\tau_2$-Cl($f^{-1}(B)$))) ⊂ ($\sigma_1\sigma_2$-Cl(f ($f^{-1}(B)$)) ⊂ $\sigma_1\sigma_2$-Cl(B) and f^{-1}($\sigma_1\sigma_2$-Cl($f(f^{-1}(B)$))) = $\bigcap_{i \in \Delta} V_i$ where V_i ∈ (1,2)P-O(X) which implies that τ_1-Int($\tau_1\tau_2$-Cl($f^{-1}(B)$)) ⊂ f^{-1}($\sigma_1\sigma_2$-Cl(B)) and f^{-1}($\sigma_1\sigma_2$-Cl(B)) = $\bigcap_{i \in \Delta} V_i$ where V_i ∈ (1,2)P-O(X).

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CONCLUSION

In this paper, the new notion of (1,2)S_p-continuous function was introduced and some of its characterizations are discussed. Later Research be reached out with certain applications.

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