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Almost δsp-Continuous Function

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ABSTRACT

A new class of functions is introduced in this paper. This class is called almost δsp-continuity. This type of functions is seen to be strictly weaker than almost precontinuity. By using δsp-open sets, many characterizations and properties of the said type of functions are investigated.

I. INTRODUCTION

The notion of δsp-open set was introduced by E.Hatir and T. Noiri,[7] in 2006. We introduce here a new type of functions strictly weaker than almost precontinuity. We call this the almost δsp-continuous functions. We investigate properties of such functions.

Throughout the present paper, spaces mean topological spaces and $f : (X, \tau) \rightarrow (Y, \sigma)$ (or simply $f : X \rightarrow Y$) denotes a function f of a space (X, τ) into a space (Y,σ). Let A be a subset of a space X. The closure and the interior of A are denoted by cl(A) and int(A), respectively.

II. PRELIMINARIES

A subset A of a space X is said to be **regular open**[**23**] if A = int(cl(A)) and **δ- open**[**24**] if for each $x \in A$, there exists a regular open set W such that $x \in W \subset A$.

A subset A of a space X is said to be **α-open**[**13**] (resp. **semi-open**[**8**], **preopen**

[**10**], **γ - open**[**6**] or **β - open**[**1**] or **semi-preopen**[**2**]) if $A \subset int(cl(int(A)))$ (resp. $A \subset cl(int(A))$, $A \subset cl(int(cl(A)))$).

The complement of a regular open set is said to be regular closed[**23**]. The complement of a semi-open set is said to be semi-closed[**5**]. The intersection of all

Semi-closed sets containing a subset A of X is called the semi-closure[**5**] of A and is denoted by s-cl(A). The union of all semi-open sets contained in a subset A of X is called the semi - interior of A and is denoted by s-int(A). A point $x \in X$ is called a **δ-cluster** (resp. **θ-cluster**) point of A [**24**] if $A \cap int(cl(U)) \neq \phi$(resp. $A \cap cl(U) \neq \phi$) for each open set U containing x. The set of all δ - cluster (resp. θ - cluster) points of A is called the δ - closure (resp. θ - closure) of A and is denoted by δ - cl(A) (resp. θ - cl(A)). If δ - cl(A) = A (resp. θ-cl(A) = A), then A is said to be δ - closed (resp.θ - closed). The complement of a δ - closed (resp. θ - closed) set is said to be δ - open (resp. θ- open).

A subset S of a topological space X is said to be δsp-open [**7**] iff $A \subseteq cl(int(\delta\text{-}cl(A)))$. The complement of a δsp-open set is called a δsp-closed set [**7**]. The union (resp. intersection) of all δsp-open (resp. δsp -closed) sets,each contained in (resp. containing) a set A in a topological space X is called the δsp -interior (resp. δsp - closure) of A and it is denoted by δsp -int(A) (resp. δps-cl(A)) [**7**].

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The family of all δsp-open (resp. regular open, preopen, β-open. α-open, semi-open, δ-open) sets of a space X will be denoted by δSPO(X) (resp. RO(X), PO(X), βO(X), αO(X), SO(X), δO(X)). The family of all δsp-closed (resp. regular closed,δ - closed) sets in a space X is denoted by δSPC(X) (resp. RC(X), δC(X)). The family of all δsp-open (resp. regular open, δ - open) sets containing a point $x \in X$ will be denoted by δSPO(X, x) (resp. RO(X, x), δO(X, x)).

Lemma 1.Let A be a subset of a space X. Then

(1) δsp-cl(X–A) = X–δsp-int(A),

(2) $x \in \delta$sp-**c**l(A) if and only if $A \cap U \neq \phi$for each $U \in \delta$SPO(X,x),

(3) A is δsp-closed in X if and only if A = δsp-cl(A),

(4) δsp-cl(A) is δ - pclosed in X.

Lemma 2 (Noiri [**17**], [**18**]). For a subset of a space Y, the following hold:

(1) α - cl(V) = cl(V)for every V $\in \beta$O(Y).

(2) p - cl(F) = cl(V)for every V$\in$SO(Y).

(3) s - cl(V) = int(cl(V)) for every preopen set V of a space X.

Definition 3. A function f : (X, τ)$\rightarrow$(Y,σ) is said to be **almost δsp-continuous**
if for each $x \in X$ and each $V \in$ RO(Y) containing f(x), there exists $U \in \delta$SPO(X)
containing x such that $f(U) \subset V$.

Definition 4. A function f : (X,τ)$\rightarrow$(Y,σ) is said to be

1.R - map [**4**] if f^{-1}(V)$\in$RO(X) for every V $\in$ RO(Y).

2.almost continuous [**21**], f^{-1}(V)$\in\tau$, for every V $\in$ RO(Y).

3.almost α - continuous [**16**] f^{-1}(V)$\in\alpha$O(X), for every V $\in$ RO(Y).

4.almost precontinuous [**11**], f^{-1}(V)$\in$PO(X) for every V $\in$ RO(Y).

5.δ-continuous[**14**]) if f^{-1}(V)$\in\delta$O(X) for every V $\in$ RO(Y).

Remark 5. The following implications hold:
al. contin.$\Rightarrow$al. α - contin.$\Rightarrow$al. precontin.$\Rightarrow$al. δsp-contin.
The converses are not true in general.

Example 6. Let X = {a,b,c}and τ= {X,ϕ,{a, {c},{a,c},{b,c}}. Letf :X $\rightarrow$X be a function defined by f(a) = b,f(b) = a,f(c) = c.Then,f is almost δsp-continuous but not almost precontinuous.

Theorem 7. For a function f : (X, τ)$\rightarrow$(Y,σ),the following are equivalent:

(1) f is almost δsp-continuous;

(2) for each $x \in X$ and each V$\in\sigma$ containing f(x),there exists U $\in\delta$SPO(X)

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containing x such that $f(U) \subset int(cl(V))$;

(3) $f^{-1}(F) \in \delta SPC(X)$ for every $F \in RC(Y)$;

(4) $f^{-1}(V) \in \delta SPO(X)$ for every $V \in RO(Y)$.

(5) $f(\delta sp\text{-}cl(A)) \subset \delta\text{-}cl(f(A))$ for every subset A of X ;

(6) $\delta sp\text{-}cl(f^{-1}(B)) \subset f^{-1}(\delta - cl(B))$ for every subset B of Y ;

(7) $f^{-1}(F) \in \delta SPC(X)$ for every δ - closed set F of (Y, σ);

(8) $f^{-1}(V) \in \delta SPO(X)$ for every δ - open set V of (Y, σ);

(9) $\delta sp\text{-}cl(f^{-1}(cl(int(cl(B))))) \subset f^{-1}(cl(B))$ for every subset B ofY ;

(10) $\delta sp\text{-}cl(f^{-1}(cl(int(F)))) \subset f^{-1}(F)$ for every closed set F ofY ;

(11) $\delta sp\text{-}cl(f^{-1}(cl(V))) \subset f^{-1}(cl(V))$ for every open set V of Y ;

(12) $f^{-1}(V) \subset \delta sp\text{-}int(f^{-1}(s\text{-}cl(V)))$ for every open set V ofY ;

(13) $f^{-1}(V) \subset int(\delta - cl(f^{-1}(s\text{-}cl(V))))$ for every open set V ofY ;

(14) $f^{-1}(V) \subset \delta sp\text{-}int(f^{-1}(int(cl(V))))$ for every open set V ofY ;

(15) $f^{-1}(V) \subset int(\delta - cl(f^{-1}(int(cl(V)))))$ for every open set V ofY ;

(16) $\delta sp\text{-}cl(f^{-1}(V)) \subset f^{-1}(cl(V))$ for each $V \in \beta O(Y)$;

(17) $\delta sp\text{-}cl(f^{-1}(V)) \subset f^{-1}(cl(V))$ for each $V \in SO(Y)$;

(18) $f^{-1}(V) \subset \delta sp\text{-}pint(f^{-1}(int(cl(V))))$ for each $V \in PO(Y)$;

(19) $\delta sp\text{-}cl(f^{-1}(V)) \subset f^{-1}(\alpha\text{-}cl(V))$ for each $V \in \beta O(Y)$;

(20) $\delta sp\text{-}cl(f^{-1}(V)) \subset f^{-1}(p\text{-}cl(V))$ for each $V \in SO(Y)$;

(21) $f^{-1}(V) \subset \delta sp\text{-}int(f^{-1}(s\text{-}cl(V)))$ for each $V \in PO(Y)$.

Proof. (1))⇒(2). Let $x \in X$ and $V \in \sigma$ containing f(x). We have $int(cl(V)) \in RO(Y)$. Since f is almost δsp-continuous, then there exists $U \in \delta SPO(X, x)$ such thatf$(U) \subset int(cl(V))$.

(2)⇒(1). Obvious.

(3)⇔(4). Obvious.

(1))⇒(4). Let $x \in X$ and $V \in RO(Y,f(x))$. Since f is almostδsp-continuous, then there exists $U_x \in \delta SPO(X,x)$ such that $f(U_x) \subset V$. We have $U_x \subset f^{-1}(V)$. Thus,$f^{-1}(V) = \cup U_x \in \delta SPO(X)$.

(4))⇒(1). Obvious.

(1))⇒(5). Let A be a subset of X. Since $\delta\text{-}cl(f(A))$ is δ-closed in Y ,it is denoted by$\cap \{ F_i: F_i \in RC(Y), i \in I\}$,where I is an index set. By (1)⇔(3), we have $A \subset f^{-1}(\delta - cl(f(A))) = \cap\{f^{-1}(F_i) : i \in I\} \in \delta SPC(X)$ and hence $\delta sp\text{-}cl(A) \subset f^{-1}(\delta\text{-}cl(f(A)))$. Therefore,we obtain $f(\delta sp\text{-}cl(A)) \subset \delta - cl(f(A))$.

(5)⇒(6). Let B be a subset of Y. We have $f(\delta sp\text{-}cl(f^{-1}(B))) \subset \delta - cl(f(f^{-1}(B))) \subset \delta - cl(B)$ and hence $\delta sp\text{-}cl(f^{-1}(B)) \subset f^{-1}(\delta - cl(B))$.

(6)⇒(7). Let F be any δ - closed set of (Y, σ). We have $\delta sp\text{-}cl(f^{-1}(F)) \subset$

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$f^{-1}(\delta\text{ - cl}(F)) = f^{-1}(F)$ and hence $f^{-1}(F)$ is δsp-closed in (X,τ).

(7)⇒(8). Let V be any δ - open set of (Y, σ). We have $f^{-1}(Y - V) = X - f^{-1}(V) \in$ δSPC(X) and hence $f^{-1}(V) \in$ δSPO(X).

(8)⇒(1). Let V be any regular open set of (Y,σ). Since V is δ - open in (Y,σ), $f^{-1}(V) \in$ δSPO(X) and hence,by (1), (4),f is almost δsp-continuous.

(1)⇒(9). Let B be any subset of Y. Assume that $x \in X - f^{-1}(cl(B))$. Then $f(x) \in Y - cl(B)$ and there exists an open set V containing f(x) such that $V - B = \phi$ hence $int(cl(V)) \cap cl(int(cl(B))) = \phi$. Since f is almost δps-continuous, there exists $U \in$ δSPO(X,x) such that $f(U) \subset int(cl(V))$. Therefore,we have $U \cap f^{-1}(cl(int(cl(B)))) = \phi$ and hence $x \in X - \delta sp\text{-}cl(f^{-1}(cl(int(cl(B)))))$.

Thus we obtain $\delta sp\text{-}cl(f^{-1}(cl(int(cl(B))))) \subset f^{-1}(cl(B))$.

(9)⇒(10). Let F be any closed set of Y. Then we have

$\delta sp\text{-}cl(f^{-1}(cl(int(F))) = \delta sp\text{-}cl(f^{-1}(cl(int(cl(F)))))\subset f^{-1}(cl(F)) = f^{-1}(F)$.

(10)⇒(11). For any open set V of Y,cl(V) is regular closed in Y and we have

$\delta sp\text{-}cl(f^{-1}(cl(V)) = \delta sp\text{-}cl(f^{-1}(cl(int(cl(V))))) \subset f^{-1}(cl(V))$.

(11)⇒(12). Let V be any open set of Y. Then $Y - cl(V)$ is open in Y and by using

Lemma 2 we have $X - \delta sp\text{-}int(f^{-1}(s\text{ - }cl(V)))=$

$\delta sp\text{-}cl(f^{-1}(Y - int(cl(V)))) \subset f^{-1}(cl(Y - cl(V))) \subset X - f^{-1}(V)$.

Therefore,we obtain $f^{-1}(V) \subset \delta sp\text{-}int(f^{-1}(s\text{ - }cl(V)))$.

(12)⇒(13). Let V be any open set of Y. We obtain

$f^{-1}(V) \subset \delta sp\text{-}int(f^{-1}(s\text{ - }cl(V))) \subset int(\delta\text{ - }cl(f^{-1}(s\text{ - }cl(V))))$.

(13)⇒(1). Let x be any point of X and V any open set of Y containing f(x). Then $x \in f^{-1}(int(cl(V))) \subset int(\delta - cl(f^{-1}(s - cl(int(cl(V)))))) = int(\delta - cl(f^{-1}(int(cl(V)))))$. Thus,$f^{-1}(int(cl(V))) \in$ δSPO(X). Take $U = f^{-1}(int(cl(V)))$.

We obtain $x \in U$ and $f(U) \subset int(cl(V))$. Therefore,f is almost δsp-continuous.

(12)⇒(14) and (13), (15). Obvious.

(1)⇒(16). Let V be any β - open set of Y. It follows from [**2, Theorem 2.4**] that cl(V) is regular closed in Y. Since f is almost δsp-continuous, by (1), (3), $f^{-1}(cl(V))$ is δsp-closed in X. Therefore, we obtain $\delta sp\text{-}cl(f^{-1}(V)) \subset f^{-1}(cl(V))$.

(16)⇒)(17). This is obvious since $SO(Y) \subset \beta O(Y)$.

(17)⇒(1). Let F be any regular closed set of Y. Then F is semi - open in Y and hence $\delta sp\text{-}cl(f^{-1}(F)) \subset f^{-1}(cl(F)) = f^{-1}(F)$. This shows that $f^{-1}(F)$ is δsp-closed. Therefore,by (1),(3),f is almost δsp-continuous.

(1)⇒(18). Let V be any semi-preopen set of Y. Then $V \subset int(cl(V))$ and int(cl(V)) is regular open in Y. Since f is almost δsp-continuous,by (1), (4),$f^{-1}(int(cl(V)))$

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is δsp-open in X and hence we obtain that $f^{-1}(V) \subset f^{-1}(int(cl(V))) \subset$ δsp-int $(f^{-1}(int(cl(V))))$.

(18)⇒(1). Let V be any regular open set of Y. Then V is semi -preopen and $f^{-1}(V) \subset$ δsp-int$(f^{-1}(int(cl(V))))$ = δsp-int$(f^{-1}(V))$. Therefore,$f^{-1}(V)$ is δsp-preopen in X and hence,by (1), (4),f is almost δsp-continuous.

(16)⇒(19)⇒ (17)⇒(20)⇒ (18)v, (21). Obvious.

Lemma 8.A set S in X is δsp-open if and only if S ⋂ G ∈δSPO(X) for every δ - open set G of X.

Definition 9. The δsp-frontier of a subset A of X,denoted by δsp-fr(A),is defined by δsp-fr(A) = δsp-cl(A) ∩ δsp-cl(X – A) = δsp-cl(A) – δsp-int(A).

Theorem 10. The set of all points x of X at which a function f :X → Y is not almost δsp-continuous is identical with the union of the δsp-frontiers of the inverse images of regular open sets containing f(x).

Proof. Let x be a point of X at which f is not almost δsp-continuous Then,there exists a regular open set V of Y containing f(x) such that $U \cap (X - f^{-1}(V)) \neq \phi$ for every U ∈δSPO(X,x). Therefore,we have x ∈ δsp-cl$(X – f^{-1}(V))$ = X – δsp-int$(f^{-1}(V))$ and $x \in f^{-1}(V)$. Thus,we obtain x ∈δsp-fr$(f^{-1}(V))$.

Conversely,suppose that f is almost δsp-continuous at x ∈Xand let V be a regular open set containing f(x). Then there exists U ∈δSPO(X,x) such thatU $\subset f^{-1}(V)$; hence x ∈δsp-int$(f^{-1}(V))$. Therefore,it follows that x ∈ X – δspfr$(f^{-1}(V))$. This completes the proof.

Definition 11. A function f :X → Y is said to be weakly δsp-continuous if for eachx ∈X and each open set V of Y containing f(x),there exists U ∈δSPO(X,x) such that f(U) ⊂cl(V).

Definition 12. Let (X,τ) be a topological space. The collection of all regular open sets forms a base for a topology τ_s. It is called the **semi regularization**. In case when $\tau = \tau_s$, the space (X,τ) is called semi-regular [**23**].

Theorem 13. Let (X,τ) be a semi-regular space. Then a function f : (X,τ) → (Y,σ) is almost sp-continuous if and only if it is almost δsp-continuous**.**

Definition 14. A function f :X → Y is said to be **δ - almost continuous** [**20**] if for Each x ∈X and each open set V of Y containing f(x),there exists U ∈δPO(X,x) such that f(U) ⊂ V.

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Definition 15. A function f : X → Y is said to be **δsp-irresolute** if for each x ∈X and each δsp-open set V of Y containing f(x),there exists U ∈δSPO(X,x) such that f(U) ⊂ V.

Definition 16. A function f :X → Y is said to be **almost δsp-open** if f(U) ⊂ int(cl(f(U))) for every δsp-open set U of X.

Theorem 17. If f :X → Y is an almost δsp-open and weakly δsp-continuous function, then f is almost δsp-continuous.

Proof. Let x ∈X and let V be an open set of Y containing f(x). Since f is weakly δsp-continuous,there exists U ∈δSPO(X,x) such that f(U) ⊂ cl(V). Since f is almost δsp-open,f(U) ⊂int(cl(f(U))) ⊂int(cl(V)) and hence f is almost δsp-continuous.

Definition 18. A space X is said to be (1) **almost regular** [**22**] if for any regular closed set F of X and any point x ∈ X–F there exist disjoint open sets U and V such that x ∈ U and F ⊂ V , (2) **semi - regular** if for any open set U of X and each point x ∈ U there exists a regular open set V of X such that x ∈ V ⊂ U.

Theorem 19. If f :X → Y is a weakly δsp-continuous function and Y is almost regular,then f is almost δsp-continuous.

Proof. Let x ∈ X and let V be any open set of Y containing f(x). By the almost regularity of Y ,there exists a regular open set G of Y such that f(x) ∈ G ⊂ cl(G) ⊂ int(cl(V)) [**22**,**Theorem 2.2**]. Since f is weakly δsp-continuous,there exists U ∈δSPO(X,x) such that f(U) ⊂cl(G) ⊂int(cl(V)). Therefore, f is almost δsp-continuous.

Theorem 20. If f :X → Y is an almost δsp-continuous function and Y is semi regular,then f is δ - almost continuous.

Proof. Let x ∈ X and let V be an open set of Y containing f(x). By the semi regularity of Y, there exists a regular open set G of Y such that f(x) ∈ G ⊂ V. Since f is almost δsp-continuous,there exists U ∈δSPO(X,x) such that f(U) ⊂ int(cl(G)) = G ⊂ V and hence f is δ - almost continuous.

Theorem 21. Let f :X → Y and g : Y→Z be functions. Then the following hold:

(1) If f is almost δsp-continuous and g is an R - map,then the composition go f : X → Z is almost δsp-continuous,

(2) If f is δsp-irresolute and g is almost δsp-continuous, the composition go f: X → Z is almost δsp-continuous.

Definition 22. A function f :X → Y is said to be **faintly δsp-continuous** if for

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each $x \in X$ and each θ - open set V of Y containing f(x),there exists $U \in \delta SPO(X,x)$ such that $f(U) \subset V$.

Theorem 23. Let $f : X \to Y$ be a function. Suppose that Y is regular. Then, the following properties are equivalent:

(1) f is δ - almost continuous,

(2) $f^{-1}(\delta\text{-cl}(B))$ is δsp-closed in X for every subset B of Y ,

(3) f is almost δsp-continuous,

(4) f is weakly δsp-continuous,

(5) f is faintly δsp-continuous.

Proof. (1)$\Rightarrow$(2). Since δ-cl(B) is closed in Y for every subset B of Y,$f^{-1}(\delta\text{-cl}(B))$ is δsp-closed in X.

(2)$\Rightarrow$(3). For any subset B of Y,$f^{-1}(\delta\text{-cl}(B))$ is δsp-closed in X and hence we have $\delta\text{sp-cl}(f^{-1}(B)) \subset \delta\text{sp-cl}(f^{-1}(\delta\text{-cl}(B))) = f^{-1}(\delta\text{ - cl}(B))$. It follows that

f is almost δsp-continuous

(3)$\Rightarrow$(4). This is obvious.

(4)$\Rightarrow$(5). Let A be any subset of X. Let $x \in \delta\text{sp-cl}(A)$ and V be any open set of Y containing f(x). There exists $U \in \delta SPO(X,x)$ such that $f(U) \subset cl(V)$. Since $x \in \delta\text{sp-cl}(A)$,we have $U \cap A \neq \phi$ and hence $\phi \neq f(U) \cap f(A) \subset cl(V) \cap f(A)$.

Therefore,we have $f(x) \in \theta\text{-cl}(f(A))$ and hence $f(\delta\text{sp-cl}(A)) \subset \theta\text{-cl}(f(A))$.

Let B be any subset of Y. We have $f(\delta\text{sp-cl}(f^{-1}(B))) \subset \theta\text{-cl}(B)$ and $\delta\text{sp-cl}(f^{-1}(B)) \subset f^{-1}(\theta\text{-cl}(B))$.Let F be any θ-closed set of Y. It follows that $\delta\text{sp-cl}(f^{-1}(F)) \subset f^{-1}(\theta - cl(F)) = f^{-1}(F)$. Therefor $f^{-1}(F)$ is δsp-closed in X and hence f is faintly δsp-continuous.

(5)$\Rightarrow$(1). Let V be any open set of Y. Since Y is regular,V is θ - open in Y. By the faint δsp-continuity of f, $f^{-1}(V)$ is δsp-open in X. Therefore, f is δ - almost continuous.

Recall that a space (X,τ) is said to be (1) submaximal [**3**] if every dense subset of X is open in X,(2) extremally disconnected [**3,15**] if $cl(U) \in \tau$ for every $U \in \tau$.

Definition 24. A function $f : X \to Y$ is said to be

1.faintly continuous [**9**], if $f^{-1}(V)$ is open in X for each θ - open set V of Y.

2.faintly semi – continuous [**19**], if $f^{-1}(V)$ is semi-open in X for each θ - open set V of Y

3.faintly precontinuous [**19**], if $f^{-1}(V)$ is pre-open in X for each θ - open set V of of Y

4.faintly β - continuous [**12**], [**19**], if $f^{-1}(V)$ is β-open in X for each θ - open set V of of Y

5.faintly α - continuous [**12**] if $f^{-1}(V)$ is α-open in X for each θ - open set V of of Y.

Theorem 25. If (X,τ) is submaximal extremally disconnected semi-regular and (Y,σ) is regular, then the following are equivalent for a function $f : (X, \tau) \to (Y,\sigma)$:

(1) f is faintly continuous,

(2) f is faintly α - continuous,

(3) f is faintly semi - continuous,

(4) f is faintly precontinuous,

(5) f is faintly δsp-continuous,

(6) f is faintly γ - continuous,

(7) f is faintly β - continuous,

(8) f is δ - almost continuous,

(9) f is almost δsp-continuous,

(10) f is weakly δsp-continuous.

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