On Contra Delta Generalized Pre-Continuous Functions

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Abstract- In this paper, the notion of contra δgp-continuous functions is introduced by utilizing δgp-closed sets in topological spaces. Some of their fundamental properties are studied and some of their basic properties. Relationships between contra δgp-continuous functions and other related functions are discussed.

Keywords- δgp-open set, contra continuous function, contra pre-continuous function, contra δgp-continuous function.

I. INTRODUCTION

In 1996, Dontchev [8] initiated the study of contra continuous functions. Subsequently, Jafari and Noiri [15, 16] exhibited contra α-continuous and contra pre-continuous functions in topological spaces. In this paper, a new class of generalized contra continuous functions by using δgp-closed sets, called contra δgp-continuous functions is introduced and study some of their basic properties. Relationships between contra δgp-continuous functions and other related functions are investigated.

II. PRELIMINARIES

Definition 2.1 A subset A of a topological space X is called pre-closed [19] (resp, b-closed [1], regular closed [26], semi-closed [18] and α-closed [21]) if cl(int(A))⊆ A (resp, cl(int(A))∩ int(cl(A))⊆ A, A=cl(int(A)), int(cl(A))⊆ A and int(cl(int(A)))⊆ A).

Definition 2.2 A subset A of a topological space X is called δ-closed [28] if A = clδ(A) where

\[ clδ(A) = \{ x ∈ X: int(cl(U)) \cap A = φ, U ∈ τ \text{ and } x ∈ U \} \]

Definition 2.3 A subset A of a topological space X is called ,

(i) δgp-closed [5] (resp, gp-closed [13] and gp-closed [17]) if pcl(A)⊆ U whenever A⊆ U and U is δ-open (resp, regular open and open) in X.

(ii) δσ-closed [3] if scl(A)⊆ U whenever A⊆ U and U is δ-open in X.

The complements of the above mentioned closed sets are their respective open sets.

Definition 2.4 A function f:X→Y from a topological space X into a topological space Y is called,

(i) contra continuous [8] (resp, contra pre-continuous [15], contra α-continuous [16], contra gp-continuous [7] and contra gp-continuous) if f−1(G) is closed (resp, pre-closed, α-closed, gp-closed and gpr-closed) in X for every open set G of Y.

(ii) perfectly continuous [23] if f−1(G) is clopen in X for every open set G of Y.

(iii) pre-closed [10] if for every closed subset A of X, f(A) is pre-closed in Y.

(iv) δgp-continuous [27] (resp, completely-continuous [2] and super continuous [20]) if f−1(G) is δgp-open (resp, regular-open and δ-open) in X for every open set G of Y.

Definition 2.5 A space X is called,

(a) extremely disconnected [12] if the closure of every open subset of X is open.

(b) strongly irresolvable [11] if every open subspace of X is irresolvable.

(c) semi-regular [6] if every open set is δ-open in X.

(d) Urysohn [29] if for each pair of distinct points x and y of X, there exist open sets U and V containing x and y such that cl(U)∩cl(V) = φ.

(e) regular [29] if U is open in X and x∈ U, then there is an open set V containing x such that cl(V)⊆ U.

Definition 2.5 A space X is said to be:

(i) Tδgp-space if every δgp-closed subset of X is closed.

(ii) δgpT1/2-space if every δgp-closed subset of X is pre-closed.

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3. Contra $\delta gp$-Continuous Functions.

**Definition 3.1** A function $f:X\rightarrow Y$ is called contra delta generalized pre-continuous (briefly, contra $\delta gp$-continuous) if the inverse image of every open set of $Y$ is $\delta gp$-closed in $X$.

**Theorem 3.2** A function $f:X\rightarrow Y$ is contra $\delta gp$-continuous if and only if $f^{-1}(U)$ is $\delta gp$-open in $X$ for every closed set $U$ of $Y$.

**Remark 3.3** From Definitions 2.4 and 3.1, we have the following diagram of implications for a function $f:X\rightarrow Y$

\[
\text{Perfectly continuity} \quad \downarrow \\
\text{contra pre-continuity} \quad \leftrightarrow \quad \text{contra continuity} \\
\downarrow \\
\text{contra gp-continuity} \quad \rightarrow \quad \text{contra } \delta gp\text{-continuity} \\
\downarrow \\
\text{contra gpr-continuity}
\]

None of the implications in above diagram is reversible.

**Example 3.4** Consider $X\equiv \{a,b,c,d\}$ with the topologies $T = \{X, \emptyset, \{a\}, \{b\}, \{a\}, \{a,\{a,c\}\}\}$ and $\sigma = \{\emptyset, \{a\}, \{b\}, \{a,\{a,c\}\}\}$. Define $f:(X,\tau)\rightarrow(X,\sigma)$ by $f(a)=f(b)=a, f(c)=b$ and $f(d)=c$. Then $f$ is contra gpr-continuous but not contra $\delta gp$-continuous, since $\{a\}$ is open in $Y$ but $f^{-1}(\{a\})=\{a, \{a\}\}$ is not $\delta gp$-closed in $X$. Define $g:(X,\tau)\rightarrow(X,\sigma)$ by $g(a)=g(c)=a, g(b)=b$ and $g(d)=d$. Then $g$ is contra $\delta gp$-continuous but contra gp-continuous, since $\{a\}$ is open in $Y$ but $g^{-1}(\{a\})=\{a,\{a\}\}$ is not gp-closed in $X$.

**Remark 3.5** (a) contra $\delta gp$-continuity and $\delta gp$-continuity are independent each other. (b) contra $\delta gp$-continuity and contra gôs-continuity are independent each other.

**Example 3.6** In Example 3.4, $f$ is $\delta gp$-continuous but not contra $\delta gp$-continuous.

**Example 3.7** Consider $X, Y$ as in Example 3.4. Define $h:(X,\tau)\rightarrow(X,\sigma)$ by $h(a)=d, h(b)=c, h(c)=a$ and $h(d)=b$. Then $h$ is contra $\delta gp$-continuous but not $\delta gp$-continuous, since $\{a,b\}$ is open in $Y$ but $h^{-1}(\{a,b\})=\{c,d\}$ is not $\delta gp$-open in $X$.

**Definition 3.8** A space $X$ is called locally $\delta gp$-indiscrete if every $\delta gp$-open set is $\delta gp$-closed in $X$.

**Theorem 3.9** If $f:X\rightarrow Y$ is a contra $\delta gp$-continuous and $X$ is locally $\delta gp$-indiscrete space, then $f$ is $\delta gp$-continuous.

**Proof:** Let $V$ be a closed set in $Y$. Since $f$ is contra $\delta gp$-continuous and $X$ is locally $\delta gp$-indiscrete space, then $f^{-1}(V)$ is $\delta gp$-closed in $X$. Hence $f$ is $\delta gp$-continuous.

**Definition 3.10** [22] A space $X$ is called locally indiscrete if every open set is closed in $X$.

**Theorem 3.11** If $f:X\rightarrow Y$ is a $\delta gp$-continuous and $Y$ is locally indiscrete space, then $f$ is contra $\delta gp$-continuous.

**Proof:** Let $G$ be any open set of $Y$. Since $Y$ is locally indiscrete space and $f$ is $\delta gp$-continuous, then $f^{-1}(G)$ is $\delta gp$-closed in $X$. Hence $f$ is contra $\delta gp$-continuous.

**Theorem 3.12** [27] (a) In extremely disconnected space $X$, every $gôs$-closed set is $\delta gp$-closed. (b) In strongly irresolvable space $X$, every $\delta gp$-closed set is $gôs$-closed.

As a consequence of Theorem 3.12, we have the following Theorem 3.13 and Theorem 3.14.

**Theorem 3.13** If $f:X\rightarrow Y$ is a contra $gôs$-continuous and $X$ is extremely disconnected space, then $f$ is contra $\delta gp$-continuous.

**Theorem 3.14** If $f:X\rightarrow Y$ is a contra $\delta gp$-continuous and $X$ is strongly irresolvable space, then $f$ is contra $gôs$-continuous.

**Theorem 3.15** If $f:X\rightarrow Y$ is contra $\delta gp$-continuous and $X$ is $T_{\delta gp}$-space, then $f$ is contra continuous.

**Proof:** Suppose $X$ is $T_{\delta gp}$-space and $f$ is contra $\delta gp$-continuous. Let $G$ be an open set in $Y$, by hypothesis $f^{-1}(G)$ is $\delta gp$-closed in $X$ and hence $f^{-1}(G)$ is closed in $X$. Therefore $f$ is contra continuous.

**Theorem 3.16** If $f:X\rightarrow Y$ is contra $\delta gp$-continuous and $X$ is $\delta gp T_{1/2}$-space, then $f$ is contra pre-continuous.

**Proof:** Suppose $X$ is $\delta gp T_{1/2}$-space and $f$ is contra $\delta gp$-continuous. Let $G$ be an open set in $Y$, by hypothesis $f^{-1}(G)$ is $\delta gp$-closed in $X$ and hence $f^{-1}(G)$ is pre-closed in $X$. Therefore $f$ is contra pre-continuous.

**Theorem 3.17** If $f:X\rightarrow Y$ is contra $\delta gp$-continuous and $X$ is semi regular, then $f$ is contra gp-continuous.

**Proof:** Follows from the fact that every open set is $\delta$-open in semi-regular space.

**Lemma 3.18** [27] For a subset $A$ of a space $X$, the following are equivalent:

(a) $A$ is clopen;
(b) $A$ is open and pre-closed;
(c) $A$ is open and gp-closed;
Theorem 3.20 The following statements are equivalent for a function $f:X \to Y$:

(a) $f$ is perfectly continuous.
(b) $f$ is continuous and contra pre-continuous.
(c) $f$ is continuous and contra gp-continuous.
(d) $f$ is super-continuous and contra gp-continuous.
(e) $f$ is r-continuous contra gp-continuous.
(f) $f$ is r-continuous and contra pre-continuous.
(g) $f$ is super-continuous and contra pre-continuous.

Theorem 3.21 If $f:X \to Y$ is contra gp-continuous, then the following equivalent statements hold:

(i) For each $x \in X$ and each closed set $B$ of $Y$ containing $f(x)$, there exists an open and pre-closed $A$ in $X$ containing $x$ such that $f(A) \subseteq B$.
(ii) For each $x \in X$ and each open set $G$ of $Y$ not containing $f(x)$, there exists a closed set $H$ in $X$ not containing $x$ such that $f^{-1}(G) \subseteq H$.

Proof: Let $B$ be a closed set in $Y$ such that $f(x) \in B$, then $x \in f^{-1}(B)$. By hypothesis, $f^{-1}(B)$ is gp-open set in $X$ containing $x$. Let $A = f^{-1}(F)$, then $f(A) = f(f^{-1}(B)) \subseteq B$.

Theorem 3.22 [5] Let $A \subseteq X$. Then $x \in \text{gpcl}(A)$ if and only if $U \cap A = \emptyset$ for every gp-open set $U$ containing $x$.

Recall that for a subset $A$ of a space $(X, \tau)$, the set $\bigcap\{U \in \tau : A \subseteq U\}$ is called the kernel of $A$ and is denoted by ker$(A)$.

Lemma 3.23 [14] The following properties hold for subsets $A$ and $B$ of a space $X$:

(i) $x \in \text{ker}(A)$ if and only if $A \cap F = \emptyset$ for any closed set $F$ of $X$ containing $x$.
(ii) $A \subseteq \text{ker}(A)$ and $A = \text{ker}(A)$ if $A$ is open in $X$.
(iii) If $A \subseteq B$, then ker$(A) \subseteq$ ker$(B)$.

Definition 3.24 A space $X$ is said to be $\text{gp}$-additive if $\text{GPC}(X)$ is closed under arbitrary intersections.

Theorem 3.25 Let $X$ be $\text{gp}$-additive, then the following are equivalent for a function $f:X \to Y$.

(i) $f$ is contra gp-continuous.
(ii) For each $x \in X$ and each closed set $D$ of $Y$ containing $f(x)$, there exists a gp-open set $C$ in $X$ containing $x$ such that $f(C) \subseteq D$.
(iii) $f(\text{gpcl}(C)) \subseteq \text{ker}(f(C))$ for every subset $C$ of $X$.
(iv) $\text{gpcl}(f^{-1}(D)) \subseteq f^{-1}((\text{ker}(D))$ for every subset $D$ of $Y$.

Proof: (i) $\to$ (ii) It follows from Theorem 3.21

Write up the full text as needed.
Definition 3.28 The graph G(f) of a function f:X→Y is said to be contra δgp-closed if for each (x,y)∈(X×Y)-G(f) there exist δgp-open set U in X containing x and closed set V in Y containing y such that (U×V)∩G(f)=∅.

Theorem 3.29 The graph G(f) of a function f:X→Y is contra δgp-closed if for each (x,y)∈(X×Y)-G(f) there exist δgp-open set U in X containing x and closed set V in Y containing y such that f(U)∩V=∅.

Theorem 3.30 If f(X,τ)→(Y,σ) is contra δgp-continuous and Y is Urysohn, then G(f) is contra δgp-closed in the product space X×Y.

Proof: Let (x,y)∈(X×Y)-G(f), then y=f(x) and there exist open sets U and V such that f(x)∈U,y∈V and cl(U)∩cl(V)=∅. Since f is contra δgp-continuous, there exists a δgp-open set G such that x∈G and f(G)∩cl(U) and hence we obtain f(G)∩cl(V)=∅. This shows that G(f) is contra δgp-closed.

Theorem 3.31 Let g:X→X×Y be the graph function of f:X→Y defined by g(x)=(x,f(x)) for each x∈X. Then f is contra δgp-continuous if g is contra δgp-continuous.

Proof: Let V be any open set in Y, then X×V is an open set in X×Y. It follows that f⁻¹(U)=g⁻¹(X×U) is δgp-closed in X since g is contra δgp-continuous. Hence f is contra δgp-continuous.

Definition 3.32 [24] A space X is submaximal if every pre-open set is open in X.

Theorem 3.33 If M and N are δgp-closed sets in a submaximal space X, then M∪N is δgp-closed in X.

Proof: Let U be δ-open set in X such that M∪N⊂U. Then pcI(M)⊂U and pcI(N)⊂U since M and N are δgp-closed sets. As X is submaximal, pcI(A)=cl(A) for any subset A of X. Therefore pcI(M∪N)=pcI(M)∪pcI(N)⊂U and hence M∪N is δgp-closed.

Corollary 3.34 If A and B are δgp-open sets in submaximal space X, then A∩B is δgp-open in X.

Theorem 3.35 [5] If A⊂X is δgp-closed, then A=δgpcl(A).

Remark 3.36 Converse of above theorem is true if X is δgp-additive.

Theorem 3.37 Assume that X is δgp-additive. If f:X→Y and g:X→Y are contra δgp-continuous, X is submaximal and Y is Urysohn. Then F={x∈X:f(x)=g(x)} is δgp-closed in X.

Proof: Let x∈X-F, then f(x)=g(x). Therefore, there exist open sets U and V such that f(x)∈U,g(x)∈V and cl(U)∩cl(V)=∅ because Y is Urysohn. Since f and g are contra δgp-continuous, f⁻¹(cl(U)) and g⁻¹(cl(V)) are δgp-open sets in X. Let M=f⁻¹(cl(U)) and N=g⁻¹(cl(V)), then M and N are δgp-open sets containing x. Set O=M∩N, then O is δgp-open set in X. Hence f(O)∩g(O)=f(M∩N)∩g(M∩N)=cl(M∩N)=cl(U∩cl(V)=∅ and so O∩F=∅. From Theorem 3.32, x∉δgpcl(F), hence by above remark, F is δgp-closed in X.

Definition 3.38 A space X is called δgp-connected if X is not the union of two disjoint nonempty δgp-open sets.

Theorem 3.39 For a space X the following are equivalent: (a) X is δgp-connected, (b) φ and X are the only subsets of X which are both δgp-open and δgp-closed, (c) Every contra δgp-continuous function of X into a discrete space Y with at least two points is a constant function.

Proof: (a)→(b): Suppose A is any proper δgp-open and δgp-closed subset of X. Then X-A is both δgp-closed and δgp-open in X. Then X=A∪(X-A) and A∩(X-A)=∅ which contradicts the fact that X is δgp-connected. Hence A=φ or X.

(b)→(a): Suppose X=A∪B where A and B are disjoint δgp-open subsets of X. Since A=X-B, A is both δgp-closed and δgp-open but by assumption A=φ or X which is a contradiction. Hence (a) holds.

(b)→(c): Let f:X→Y be a contra δgp-continuous function where Y is a discrete space with at least two points. Then f⁻¹({y}) is δgp-closed and δgp-open for each y∈Y and X=∪(f⁻¹({y})): y∈Y. By hypothesis, f⁻¹({y})=φ or X. If f⁻¹({y})=φ for all y∈Y, then f fails to be a function. Then there exists only one point y∈X such that f⁻¹({y})=X. This shows that f is constant.

(c)→(b): Let N be a nonempty proper δgp-open and δgp-closed subset of X. Let f:X→Y be a contra δgp-continuous function defined by f(N)=f(y} and f(X-N)=∅ for some distinct points in Y. By (c), f is constant so that f(N)=X.

Theorem 3.40 If f:X→Y is a contra δgp-continuous function and X is δgp-connected space, then Y is not a discrete space.

Proof: If possible, let Y be a discrete space. Let A be a proper non empty open and closed subset of Y. Since f is
contra δgp-continuous, then f⁻¹(A) is proper nonempty δgp-open and δgp-closed subset of X which contradicts the fact that X is δgp-connected space. Hence Y is not discrete.

**Theorem 3.41** If a surjective function f:X→Y is contra δgp-continuous and X is δgp-connected space, then Y is connected.

**Proof:** Suppose that Y is not a connected space. Then there exist disjoint open sets U and V in Y such that Y=U∪V. Therefore U and V are closed sets in Y. Since f is contra δgp-continuous, f⁻¹(U) and f⁻¹(V) are δgp-open sets in X. Also f is surjective, f⁻¹(U) and f⁻¹(V) are non empty disjoint and X=f⁻¹(U)∪f⁻¹(V) which contradicts the fact that X is δgp-connected space. Hence Y is connected.

**Theorem 3.42** Let X be a δgp-connected and Y be T₁ -space. If f:X→Y is contra δgp-continuous, then f is constant.

**Proof:** By hypothesis Y is T₁ -space, K= f⁻¹(y): y∈Y is a disjoint δgp-open partition of X. If |K|≥2, then X is the union of two nonempty δgp-open sets. This is contradiction to the fact that X is δgp-connected. Therefore |K|=1 and hence f is constant.

**Definition 3.43** A topological space X is said to be δgp-Hausdorff space if for any pair of distinct points x and y, there exist disjoint δgp-open sets G and H such that x ∈ G and y ∈ H.

**Theorem 3.44** If an injective function f:X→Y is contra δgp-continuous and Y is an Urysohn space. Then X is δgp-Hausdorff.

**Proof:** Let x and y be any two distinct points in X and f is injective, then f(x)=f(y). Since Y is an Urysohn space, there exist open sets A and B in Y containing f(x) and f(y) respectively, such that cl(A)∩cl(B)=ϕ. Then f(x) ∈ cl(A) and f(y) ∈ cl(B). Since f is contra δgp-continuous, then by Theorem 3.8, there exist δgp-open sets C and D in X containing x and y, respectively, such that f(C) ⊆ cl(A) and f(D) ⊆ cl(B). We have C ∩ D ⊆ f⁻¹(cl(A)) ∩ f⁻¹(cl(B)) = f⁻¹(ϕ) = ϕ. Hence X is δgp-Hausdorff.

**Definition 3.45** [25] A space X is called Ultra normal space, if each pair of disjoint closed sets can be separated by disjoint clopen sets.

**Definition 3.46** A topological space X is said to be δgp-normal if each pair of disjoint closed sets can be separated by disjoint δgp-open sets.

**Theorem 3.47** If f:X→Y be contra δgp-continuous closed injection and Y is ultra normal, then X is δgp-normal.

**Proof:** Let E and F be disjoint closed subsets of X. Since f is closed and injective f(E) and f(F) are disjoint closed sets in Y. Since Y is ultra normal there exist disjoint clopen sets U and V in Y such that f(E)⊂U and f(F)⊂V. This implies E∩f⁻¹(U) and F∩f⁻¹(V). Since f is contra δgp-continuous injection, f⁻¹(U) and f⁻¹(V) are disjoint δgp-open sets in X. This shows X is δgp-normal.

**Remark 3.48** The composition of two contra δgp-continuous functions need not be contra δgp-continuous as seen from the following examples.

**Example 3.49** Let X=Y=Z={ a,b,c }, τ = {X,ϕ, { a }, { b }, { a,b } } , σ = { Y,ϕ, { a } } and η= { Z,ϕ, { b,c } } be topologies on X,Y and Z respectively. Define a function f:X→Y as f(a)=a,f(b)=b and f(c)=c and a function g:Y→Z as g(a)=b,g(b)=c and g(c)=a. Then f and g are contra δgp-continuous but g*f:X→Z is not contra δgp-continuous, since there exists an open set { b,c } in Z such that(g*f)⁻¹{ b,c }={ a,b } is not δgp-closed in X.

**Theorem 3.50** For any two functions f:X→Y and g:Y→Z, the following hold:

(i)g*f is contra δgp-continuous if f is contra δgp-continuous and g is contra continuous.

(ii)g*f is contra δgp-continuous if f is δgp-continuous and g is contra continuous.

(iii)g*f is contra δgp-continuous if g is δgp-irresolute and g is contra δgp-continuous.

**Proof:** (i) Let U be an open set in Z. Then g⁻¹(V) is open in Y since g is continuous. Therefore f⁻¹{ g⁻¹(U) }=(g*f)⁻¹(U) is δgp-closed in X because f is contra δgp-continuous. Hence g*f is contra δgp-continuous.

The proofs of (ii) and (iii) are analogous to (i) with the obvious changes.

**Theorem 3.51** Let f:X→Y be contra δgp-continuous and g:Y→Z be δgp-continuous with Y is Tδgp -space, then g*f:X→Z is contra δgp-continuous.

**Proof:** Let V be any open set in Z. Since g is δgp-continuous, g⁻¹(V) is δgp-open in Y and since Y is Tδgp -space, g⁻¹(V) open in Y . Since f is contra δgp-continuous, f⁻¹(g⁻¹(V))=(g*f)⁻¹(V ) is δgp-closed set in X. Therefore g*f is contra δgp-continuous.
Definition 3.52 A function f:X→Y is called pre δgp-closed if the image of every δgp-closed set of X is δgp-closed in Y.

Theorem 3.53 Let f:X→Y be pre δgp-closed surjection and g:Y→Z be a function such that g•f:X→Z is contra δgp-continuous, then g is contra δgp-continuous.

Proof: Let U be any open set in Z. Then (g•f)−1(U)=f−1(g−1(U)) is δgp-closed in X. Since f is a pre δgp-closed surjection, f(f−1(g−1(U)))=g−1(U) is δgp-closed set in Y. Therefore, g is contra δgp-continuous.

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