(g#, s)-continuous functions in topology

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***Abstract*—In this paper, we introduce (g#, s)-continuous functions between topological spaces, study some of its basic properties and discuss its relationships with other topological functions.**

***IndexTerms*— g#-closed set, regular open set, g#-T1/2 space, πg-T1/2 space, (g#, s)-continuous function.**

I. INTRODUCTION

It is well known that the concept of closedness is fundamental with respect to the investigation of general topological spaces. Levine [26] initiated the study of generalized closed sets. The concept of g#-closed sets was introduced by Veerakumar [46]. Recently, this notion is further studied by Ravi et al [40]. Initiation of contra-continuity was due to Dontchev [10]. Many different forms of contra-continuity functions have been introduced over the years by various authors [5,11,14,15,17,19,22,37,40].

In this paper, new generalizations of contra-continuity by using g#-closed sets called (g#, s)-continuity are presented. Characterizations and properties of (g#, s)-continuous functions are discussed in detail. Finally, we obtain many important results in topological spaces

II. PRELIMINARIES

In this paper, spaces X and Y mean topological spaces on which no separation axioms are assumed unless explicitly stated. For a subset A of a space X, cl(A) and int(A) represent the closure of A and interior of A respectively.

A subset A of a space X is said to be regular open (resp. regular closed) if A = int(cl(A)) (resp. A = cl(int(A))) [43]. The δ-interior [45] of a subset A of X is the union of all regular open sets of X contained in A and it is denoted by δ-int(A). A subset A is called δ-open [45] if A = δ-int(A). The complement of δ-open set is called δ-closed. The δ-closure of a set A in a space (X,τ) is defined by δ-cl(A) = { x ∈ X: A ∩int(cl(U)) ≠ϕ, U ∈τ and x ∈ U } and it is denoted by δ-cl(A).

The finite union of regular open sets is said to be π-open [48]. The complement of π-open set is said to be π-closed. A subset A is said to be semi-open [25] (resp. α-open [31], preopen [30], β-open [1] or semi-preopen [2]) if A ⊂ cl(int(A)) (resp. A ⊂int(cl(int(A))), A ⊂int(cl(A)), A ⊂ cl(int(cl(A)))). The complement of semi-open (resp. α-open, preopen, β-open) is said to be semi-closed (resp. α-closed, preclosed, β-closed). The union (resp. intersection) of all α-open (resp. α-closed) sets, each contained in (containing) a set S in a topological space X is called α-interior (resp. α-closure) of S and it is denoted by αcl(S) (resp. αint(S)). The union (resp. intersection) of all semi-open (resp. semi-closed) sets, each contained in (containing) a set S in a topological space X is called semi-interior (resp. semi-closure) of S and it is denoted by scl(S) (resp. sint(S)). The union (resp. intersection) of all preopen (resp. preclosed) sets, each contained in (containing) a set S in a topological space X is called preinterior (resp. preclosure) of S and it is denoted by pcl(S) (resp. pint(S)).

A subset A of a space X is said to be α-generalized closed (briefly, αg-closed)[29] if αcl(A) ⊆ U whenever A ⊆ U and U is open in X. The complement of αg-closed set is called αg-open. A subset A of a space X is said to be generalized closed (briefly, g-closed) [26] (resp. πg-closed [13], g#-closed [46]) if cl(A) ⊆ U whenever A ⊆ U and U is open (resp. π-open, αg-open) in X. The complement of g-closed (resp. πg-closed, g#-closed) is said to be g-open(resp. πg-open, g#-open, rg-open). The union (resp. intersection) of all g#-open (resp. g#-closed) sets, each contained in (containing) a set S in a topological space X is called g#-interior (resp. g#-closure) of S and it is denoted by g#-int(S) (resp. g#-cl(S)).

A point x ∈X is said to be a θ-semi-cluster point [23] of a subset A of X if cl(U) ∩ A ≠ϕ for every semi-open set U containing x. The set of all θ-semi-cluster points of A is called the θ-semi-closure of A and is denoted by θ-s-cl(A). A subset A is called θ-semi-closed [23] if A = θ-s-cl(A). The complement of a θ-semi-closed set is called θ-semi-open.

The family of all δ-open (resp. g#-open, g#-closed, πg-open, πg-closed, regular open, regular closed, semi-open, closed) sets of X containing a point x ∈X is denoted by δO(X, x) (resp. G#O(X, x), G#C(X, x), πGO(X, x), πGC(X, x), RO(X, x), RC(X, x), SO(X, x), C(X, x)). The family of all δ-open (resp. g#-open, g#-closed, πg-open, πg-closed, semi-open, β-open, preopen, regular open, regular closed) sets of X is denoted by δO(X) (resp. G#O(X), G#C(X), πGO(X), πGC(X), SO(X), βO(X), PO(X), RO(X), RC(X)).

Definition 1: A space X is said to be

(1) s-Urysohn [3] if for each pair of distinct points x and y in X, there exist U ∈ SO(X, x) and V ∈ SO(X, y) such that cl(U) ∩ cl(V) = ϕ.

(2) weaklyHausdorff [41] if each element of X is an intersection of regular closed sets.

Definition 2 [20]: Let B be a subset of a space X. The set ∩{ A ∈ RO(X) : B ⊂ A } is called the r-kernel of B and is denoted by r-ker (B).

Proposition 3 ***[20]: The following properties hold for subsets A, B of a space X:***

(1) x∈ r-ker(A) if and only if A ∩ K ≠ϕ for any regular closed set K containing x.
(2) A ⊂ r-ker(A) and A = r-ker(A) if A is regular open in X.
(3) A ⊂ B, then r-ker(A) ⊂ r-ker(B).

Lemma 4 [28]: If V is an open set, then scl(V) = int(cl(V)). The subset {(x, f(x)) : x ∈ X} ⊂ X X Y is called the graph of a function f : X → Y and is denoted by G(f).

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III. Characterizations of G#-open sets

Lemma 5: For any subset K of a topological space X, X\g#-cl(K) = g#-int(X\K).

Lemma 6: ***If a subset A is g#-closed in a space X, then A = g#-cl(A).***

Theorem7: If A and B are $g^{\#}$-closed sets, then A ∪ B is also a $g^{\#}$-closed set.
Proof It follows from the fact that cl(A ∪B) = cl(A) ∪ cl(B).

Theorem8: If A and B are $g^{\#}$-open sets, then A ∩ B is also a $g^{\#}$-open set.

Theorem9: A set A is $g^{\#}$-open in (X,τ) if and only if F ⊆int(A) whenever F is αg-closed in X and F ⊆ A.
Proof Assume that A is $g^{\#}$-open, F ⊆ A and F is αg-closed. Then X \ F is αg-open and X \ A⊆ X \ F. Since X \ A is $g^{\#}$-closed, cl(X \ A) ⊆ X \ F. It implies that X \ int(A) ⊆ X \ F and hence F ⊆int (A).

Conversely, put X \ A = B. Suppose B ⊆ U where U is αg-open. Now if X \ A ⊆ U, then F = X \ U ⊆ A and F is αg-closed. It implies that F ⊆int (A) and hence X \ int (A) ⊆ X \ F = U. Therefore X \ int(X \ B) ⊆ U and consequently cl(B) ⊆ U. Hence B is $g^{\#}$-closed and therefore A is $g^{\#}$-open.

Theorem 10: Suppose that A is $g^{\#}$-open in X and that B is $g^{\#}$-open in Y. Then A x B is $g^{\#}$-open in X x Y.
Proof Suppose that F is closed and hence αg-closed in X x Y and that F ⊆ A x B. By the previous theorem, it suffices to show that F ⊆int (A x B).

Let (x,y) ∈ F. Then, for each (x,y) ∈ F, cl ({x}) x cl({y}) = cl({x} x {y}) = cl ({x,y}) ⊂ cl(F) = F ⊂ A x B. Two closed sets cl({x}) and cl({y}) are contained in A and B respectively. It follows from the assumption that cl ({x}) ⊆int (A) and that cl ({y})⊆int (B). Thus {x,y} ∈ cl ({x}) x cl({y}) ⊆int (A) x int(B) ⊆int (A x B). It means that, for each (x,y) ∈ F, (x,y) ∈int (A x B) and hence F ⊆int (A x B). Therefore A x B is $g^{\#}$-open in X x Y.

Theorem 11: ***Let A be a subset of Y. The following holds:g#-cl(X X A) = X X g#-cl(A).***

Proof Since X and g#-cl(A)are g#-closed, the product X X g#-cl(A) is a g#-closed set containing X X g#-cl(A). Using definition we have g#-cl(XX A) ⊂ X X g#-cl(A).

To prove the converse containment relation: X x g#-cl(A) ⊂ g#-cl(X x A), we suppose that there exists a point (a, b) ∉ g#-cl(X x A). Then, there exists a g#-open set W containing (a, b) [similar to 38; Lemma 2] such that W ∩ (X x A) = ϕ and hence p(W) ∩ A = ϕ, where p: X xY→ Y is the projection onto Y. Since p(W) is g#-open containing b = p(a, b) ∈ p(W), b ∉ g#-cl(A). Therefore, we show (a, b) ∉ X x g#-cl(A) and hence X x g#-cl(A) ⊂ g#-cl(X x A).

Definition 12 A function f: X → Y is called pre $g^{\#}$-closed [46] if f(V) is $g^{\#}$-closed set in Y for each $g^{\#}$-closed set V in X.

Theorem13 If a function f: X → Y is pre $g^{\#}$-closed, then for each subset B of Y and each $g^{\#}$-open set U of X containing f^{-1}(B), there exists a $g^{\#}$-open set V in Y containing B such that f^{-1}(V)⊂ U.

Proof Suppose that f is pre $g^{\#}$-closed. Let B be a subset of Y and U∈$G^{\#}$O(X) containing f^{-1}(B). Put V = Y \f(X \U), then V is an $g^{\#}$-open set of Y such that B ⊂ V and f^{-1}(V)⊂U.hetemplateisusedtoformatyourpaperandstylethetext.Allmargins,columnwidths,linespaces,andtextfontsareprescribed;pleasedonotalterthem.Youmaynotepeculiarities.Forexample,theheadmargininthistemplatemeasuresproportionatelymorethaniscustomary.Thismeasurementandothersaredeliberate,usingspecificationsthatanticipateyourpaperasonepartoftheentireproceedings,andnotasanindependentdocument.Pleasedonotreviseanyofthecurrentdesignations.

IV. (G#, S)-CONTINUOUS FUNCTIONS

Definition 14 A function f: X→Y is called (g#, s)-continuous if the inverse image of each regular open set of Y is g#-closed in X.

Theorem 15 The following are equivalent for a function f: X→Y:

(1) f is (g#, s)-continuous,
(2) The inverse image of a regular closed set of Y is g#-open in X,
(3) f^{-1}(int(cl(V))) is g#-closed in X for every open subset V of Y,
(4) f^{-1}(cl(int(F))) is g#-open in X for every closed subset F of Y,
(5) f^{-1}(cl(U)) is g#-open in X for every U ∈βO(Y),
(6) f^{-1}(cl(U)) is g#-open in X for every U ∈SO(Y),
(7) f^{-1}(int(cl(U))) is g#-closed in X for every U ∈PO(Y).

Proof

(1) ⇔ (2) : Obvious.
(1) ⇔ (3) : Let V be an open subset of Y. Since int(cl(V)) is regular open, f^{-1}(int(cl(V))) is g#-closed. The converse is similar.
(2) ⇔ (4) : Similar to (1) ⇔ (3)
(2) ⇔ (5) : Let U be any β-open set of Y. By Theorem 2.4 of [2] that cl(U) is regular closed. Then by (2) f^{-1}(cl(U)) is g#-openX.
(5) ⇒ (6) : Obvious from the fact that SO(Y) ⊂βO(Y).
(6) ⇒(7) : Let U ∈PO(Y). Then Y\int (cl(U)) is regular closed and hence it is semi-open. Then we have X\ f^{-1}(int(cl(U))) = f^{-1}(Y\int (cl(U))) = f^{-1}(cl(Y\int (cl(U)))) is g#-open in X. Hence f^{-1}(int(cl(U))) is g#-closed in X.
(7) ⇒(1) : Let U be any regular open set of Y. Then U ∈PO(Y) and hence f^{-1}(U) = f^{-1}(int (cl(U))) is g#-closed in X.

Lemma 16 [35] For a subset A of a topological space (Y, σ), the following properties hold:

(1) αcl(A) = cl (A) for every A ∈βO(Y),
(2) pcl(A) = cl (A) for every A ∈SO(Y),
(3) scl(A) = int (cl(A)) for every A ∈PO(Y).

Corollary 17 The following are equivalent for a function f: X→Y:

(1) f is (g#, s)-continuous,
(2) f^{-1}(αcl(A)) is g#-open in X for every A ∈βO(Y),
(3) f^{-1}(pcl(A)) is g#-open in X for every A ∈SO(Y),
(4) f^{-1}(scl(A)) is g#-closed in X for every A ∈PO(Y).

Proof It follows from Lemma 16.

V. THE RELATED FUNCTIONS WITH (G#, S)-CONTINUOUS FUNCTIONS

Definition 20 A function f: X → Y is said to be

(1) perfectly continuous [33] if f^{-1}(V) is clopen in X for every open set V of Y,
(2) regular set -connected [12,16] if f^{-1}(V) is clopen in X for every V∈RO(Y),

(3) almost s-continuous [6,36] if for each x∈X and each V∈ SO(Y, f(x)), there exists an open set U in X containing x such that f(U) ⊂scl(V),
(4) strongly continuous [24] if the inverse image of every set in Y is clopen in X,
(5) RC-continuous [11] if $f^{-1}(V)$ is regular closed in X for each open set V of Y,
(6) contra R-map [17] if $f^{-1}(V)$ is regular closed in X for each regular open set V of Y,
(7) contra-super-continuous [22] if for each x∈X and for each F∈ C(Y, f(x)), there exists a regular open set U in X containing x such that f(U) ⊂ F,
(8) almost contra-super-continuous [15] if $f^{-1}(V)$ is δ-closed in X for every regular open set V of Y.
(9) contra continuous [10] if $f^{-1}(V)$ is closed in X for every open set V of Y,
(10) contra g-continuous [5] if $f^{-1}(V)$ is g-closed in X for every open set V of Y,
(11) (θ, s)-continuous [23,37] if for each x∈X and each V∈ SO(Y,f(x)), there exists an open set U in X containing x such that f(U) ⊂ cl(V),
(12) contraπg-continuous [19] if $f^{-1}(V)$ is πg-closed in X for each open set V of Y.
(13) contra g#-continuous [40] if $f^{-1}(V)$ is g#-closed in X for each open set V of Y,
(14) g#-continuous [46] if $f^{-1}(V)$ is g#-closed in X for each closed set V of Y,
(15) (g, s)-continuous [14] if $f^{-1}(V)$ is g-closed in X for each regular open set V of Y,
(16) (πg, s)-continuous [14] if $f^{-1}(V)$ is πg-closed in X for each regular open set V of Y.

Remark 21 The following diagram holds for a function f: X → Y:

strongly continuous ⇒ almost s-continuous

⇓ ⇓

perfectly continuous ⇒ regular set -connected

⇓⇓

RC continuous⇒ contra R-map

⇓ ⇓

contra super continuous ⇒ almost contra super continuous

⇓ ⇓

contra continuous⇒ (θ, s)-continuous

⇓ ⇓

contra g#-continuous ⇒ (g#, s)-continuous

⇓⇓

contra g-continuous ⇒ (g, s)-continuous

⇓ ⇓

contraπg-continuous⇒ (πg, s)-continuous

None of these implications is reversible as shown in the following examples and in the related papers [14,40].

Example 22 Let X = Y = {a, b, c}, τ = {ϕ, X {a}, {b, c}} and σ = { ϕ, Y, {b}, {a, c}}. Then the identity function f: X → Y is (g, s)-continuous but it is not (g#, s)-continuous.
Example 23 Let X = Y = {a, b, c}, τ = {ϕ, X {a}, {b, c}} and σ = { ϕ, Y, {a, b}}. Then the identity function f: X → Y is (g#, s)-continuous but it is not contra g#-continuous.
Example 24 Let X = Y = {a, b, c, d}, τ = σ = { ϕ, X = Y, {c},{a, d}, {a, c, d}}. Then the function f: X → Y which is defined as f(a) = c, f(b) = c, f(c) = b, f(d) = b is (g#, s)-continuous but it is not (θ, s)-continuous.
A topological space (X,τ) is said to be extremely disconnected [4] if the closure of every open set of X is open in X.

Definition 25 A function f: X → Y is said to be almost g#-continuous if $f^{-1}(V)$ is g#-open in X for every regular open set V of Y.

Theorem 26 Let (Y,σ) be extremely disconnected. Then, the following are equivalent for a function f: (X,τ)→(Y,σ):
(1) f is (g#, s)-continuous,
(2) f is almost g#-continuous.

Proof

(1) ⇒ (2) : Let x∈X and U be any regular open set of Y containing f(x). Since Y is extremely disconnected, by lemma 5.6 of [39] U is clopen and hence U is regular closed. Then f^{1}(U) is g#-open in X. Thus, f is almost g#-continuous.

(2) ⇒ (1) : Let K be any regular closed set of Y. Since Y is extremely disconnected, K is regular open and f^{1}(K) is g#-open in X. Thus, f is (g#,s)-continuous.

Definition 27 A space (X,τ) is called:

(1) Tb[9]if every gs-closed set is closed.
(2) πg-T1/2 [18] if every πg-closed set is closed.

Definition 28 A function f: X → Y is called:

(1) contra sg-continuous [11] if f^{1}(V) is sg-closed in X for each open set V of Y,
(2) contrags-continuous [11] if f^{1}(V) is gs-closed in X for each open set V of Y.

Theorem 29 Let f: X → Y be a function from an Tb-space X to a topological space Y. The following are equivalent

(1) f is (g#, s)-continuous.
(2) f is contra g#-continuous.
(3) f is contra sg-continuous.
(4) f is contra gs-continuous.
(5) f is contra-continuous.

Proof Follows by the results in [46].

Theorem 30 Let f: X → Y be a function from aπg-T1/2 -space X to a topological space Y. The following are equivalent.

(1) f is (θ, s)-continuous.
(2) f is (g#, s)-continuous.
(3) f is (g, s)-continuous.
(4) f is (πg, s)-continuous.
(5) f is contra-continuous.

Definition 31 A space is said to be PΣ [47] or strongly s-regular [21] if for any open set V of X and each x∈V, there exists K∈
RC(X,x) such that x∈ K ⊂ V.

Definition 32 A space (X,τ) is called $g^{\#}$-T½ if every $g^{\#}$-closed set is closed.

Theorem 33 Letf: X → Y be a function. Then, if f is (g#, s)-continuous, X is g#-T½ and Y is PΣ, then f is continuous.

Proof Let G be any open set of Y. Since Y is PΣ, there exists a subfamily Φof RC(Y) such that G = ∪{A: A∈Φ}. Since X is
g#-T½ and f is (g#, s)-continuous, f^{1}(G) is open in X. Thus, f is continuous.

Theorem34 Let f: X → Y be a function from a πg-T1/2 -space (X,τ) to an extremely disconnected space (Y,σ). Then the following are equivalent..

(1) f is (πg, s)-continuous.
(2) f is (g, s)-continuous.
(3) f is ($g^{\#}$, s)-continuous.
(4) f is (θ, s)-continuous.
(5) f is almost contra-super-continuous.
(6) f is contra R-map.
(7) f is regular set-connected.
(8) f is almost s-continuous.

Proof (8) ⇒(7) ⇒ (6) ⇒(5) ⇒(4) ⇒(3) ⇒(2) ⇒(1) : Obvious.

(1) ⇒ (8) Let V be any semi-open and semi-closed set of Y. Since V is semi-open, cl(V) = cl(int (V)) and hence cl(V) is open in Y. Since V is semi-closed, int (cl(V)) ⊂ V ⊂ cl(V) and hence int(cl(V)) = V = cl(V). Therefore, V is clopen in Y and V∈RO(Y) ∩ RC(Y). Since f is (πg, s)-continuous, f^{1}(V) is πg-open and πg-closed in X. Since X is πg-T1/2 -space , τ = πGO(X). Thus, f^{1}(V) is clopen in X and hence f is almost s-continuous [36, Theorem 3.1].

Definition35 A space is said to be weakly PΣ [34] if for any V ∈ RO(X) and each x∈V, there exists F ∈ RC (X,x) such that x ∈ F ⊂ V.

Theorem 36 Let f: (X,τ) →(Y,σ) be a ($g^\#$, s)-continuous function and Let $G^\#C(X)$ be closed under arbitrary intersections. If Y is weakly PΣ and X is $g^\#$-T½, then f is regular set –connected.

Proof Let V be any regular open set of Y. Since Y is weakly PΣ, there exists a subfamily Φ of RC(Y) such that V = ∪{A: A∈Φ}. Since f is ($g^\#$, s)-continuous,
$f^{-1}(V)$ is $g^\#$-open in X for each A ∈Φ and $f^{-1}(V)$ is g#-open in X. Also $f^{-1}(V)$ is $g^\#$-closed in X since f is ($g^\#$, s)-continuous. Since X is $g^\#$-T½ space, thenτ = $G^\#O(X)$. Hence $f^{-1}(V)$ is clopen in X and then f is regular set-connected.

Definition 37 A function f: X → Y is said to be $g^\#$-irresolute [46] if $f^{-1}(V)$ is $g^\#$-open in X for every V ∈ $G^\#O(X)$.

Theorem 38 Let f: X → Y and g: Y → Z be functions. Then, the following properties hold:

(1) If f is $g^\#$-irresolute and g is ($g^\#$,s)-continuous, then g o f: X → Z is ($g^\#$,s)-continuous.
(2) If f is ($g^\#$,s)-continuous and g is contra R-map, then g o f: X → Z is almost $g^\#$-continuous.
(3) If f is $g^\#$-continuous and g is (θ,s)-continuous, then g o f: X → Z is ($g^\#$,s)-continuous.
(4) If f is ($g^\#$,s)-continuous and g is RC continuous, then g o f: X → Z is $g^\#$-continuous.
(5) If f is almost $g^\#$-continuous and g is contra R-map, then g o f: X → Z is ($g^\#$,s)-continuous.

Theorem 39 Let Y be regular space and f: X → Y be a function. Suppose that the collection of g#-closed sets of X is closed under arbitrary intersections. Then if f is (g#, s)-continuous, f is g#-continuous.

Proof Let x be an arbitrary point of X and V an open set of Y containing f(x). Since Y is regular, there exists an open set G in Y containing f(x) such that cl(G) ⊂ V. Since f is (g#, s)-continuous, there exists U ∈ G#O(X, x) such that f(U) ⊂ cl(G). Then f(U) ⊂ cl(G) ⊂ V. Hence, f is g#-continuous.

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