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New Structures of Continuous Functions

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Abstract:

Continuous functions are novel concepts in topology. Many topologists contributed to the theory of continuous functions in topology. The present authors continued the study on continuous functions by utilizing the concept of gpα-closed sets in topology and introduced the concepts of weakly, subweakly and almost continuous functions. Further, the properties of these functions are established.

Keywords: Almost gpα-Continuous Function, gpα-Closed Set, gpα-Open Set, Sub-Weakly gpα-Continuous Function, Weakly gpα-Continuous Function.

Introduction:

Weak continuity due to Levine[1] is one of the most important weak forms of continuity in topological spaces. The notion of sub-weakly continuous functions is investigated in 1984 and the relationship between weak continuity and sub-weakly continuity is studied. After that some topologists has discovered additional characteristics relating to sub-weakly continuous functions. Noiri demonstrated in[4] that the graph of a function is closed if the range space of a weakly continuous function is Hausdroff. A function p:M→ N between any two topological spaces *M* and *N* is continuous only if it is also both weakly continuous and ω*-continuous, according to Levine. By substituting a strictly weaker condition known as locally weak ω*-continuity for continuity, Levines decomposition of continuity[2] was strengthened.

In the year 2018, Patil[3, 4] studied the concept and properties of gpα-closed sets. The study of gpα-closed sets continued by defining the properties of gpα-closure, gpα-interior, gpα-limit points, gpα-continuous functions and gpα-homeomorphisms. Also, continued in by studying the properties such as, gpα- separation axioms, gpα-regular and gpα-normal spaces[5].

In this paper, weakly gpα-continuous functions are introduced. Also, subweakly gpα-continuous functions and almost gpα-continuous functions[6] are introduced. Also investigate the functional properties of this type of functions[7].

Main Results:

Weakly Generalized Pre α- Continuous Functions

Definition. 1: Let p:M→ N be a map. Then p is weakly gpα-continuous (briefly w.gpα-c) if for each m ∈ M and V ∈ O(N, p(m)), ∃ U ∈ gpα-O(M, m) ∋ p(U) ⊆ gpα-cl(V).

Remark. 1: Every gpα-continuous function is w.gpα-c but not conversely.

Example. 1: Let M = N = $\{a_1, a_2, a_3\}$ and $\tau = \{M,\phi,\{a_1, a_2\}\}$, $\sigma = \{N, \phi, \{a_1\}, \{a_2, a_3\}\}$ be topologies on M and N respectively. Let p be the identity function. Then p is w.gpα-c but not gpα-continuous.

Theorem. 1: The following are coincide for a function p:M→ N

(i) p is w.gpα-c.
(ii) For each V ∈ O(N), then $p^{-1}(V)$ ∈gpα-int(p^{-1}(gpα-cl(V))).
(iii) For each F ∈ C(N), then gpα-cl(p^{-1}(gpα-int(F))) ⊆p^{-1}(F).
(iv) B ⊆ N, then gpα-cl(p^{-1}(gpα-int(cl(B)))) ⊆p^{-1}(cl(B)).
(v) B ⊆ N, then p^{-1}(int(B)) ⊆ gpα-int(p^{-1}(gpα -cl(B))).
(vi) If V ∈ O(N), then gpα-cl(p^{-1}(V)) ⊆p^{-1}(gpα-cl(V)).

Proof: (i) → (ii) Let m ∈ M, V ∈ O(N) ∋ m_2 p^{-1}(V). So p(m) ∈ V . Then, ∃ U ∈ gpα-O(M, m) with p(U) ∈ gpα-cl(V). Thus, m∈ U ⊆ p^{-1} (gpα-cl(V)). Hence, m∈ gpα-int(p^{-1} (gpα-cl(V)), so p^{-1} (V) ∈ gpα-int(p^{-1} (gpα-cl(V))).
(ii) → (iii) Let F ∈ C(N) and so N \ F ∈ O(N). From (ii), gpα-cl(p^{-1} (gpα-int(F))) ⊆ p^{-1} (F). Thus (iii) holds.
(iii) → (iv) Let B ⊂ N and so cl(B) ⊂ C(N). From (iii), gpα-cl(p^{-1}(gpα-int(cl(B)))) ⊆ p^{-1} (cl(B)). Thus (iv)holds.
(iv) → (v) Let V ∈ O(N). Assume, m ∈ p^{-1} (gpα-cl(V)). Then p(m) ∈ gpα-cl(V_1). Thus, ∃ U_1 ∈ gpα-O(N, p(m)) with U ∩ V = φ. Hence gpα-cl(U) ∩ V = φ. From (v), m ∈ p(U) ⊂ gpα-int(p^{-1}(gpα-cl(U))). So, ∃ W ∈ gpα-O(M, m) ∋ W ⊂ p^{-1}(gpα-cl(U)). But, gpα-cl(U)∩V = φ, that is W ∩p^{-1}(V) = φ. So, m ∉ gpα-cl(p^{-1} (V)). Thus gpα-cl(p^{-1}(V)) ⊆ p^{-1}(gpα-cl(V)). (v) → (i) Let m ∈ M and V ∈ O(N, p(m)). From (v), m ∈ p^{-1} (V) ⊆ p^{-1} (int(gpα-cl(V))) ⊆ p^{-1} (gpα-int(gpα-cl(V))) ⊆ gpα-cl(p^{-1}(Ngpα-cl(V))) = gpα-int(p^{-1}(gpα-cl(V))). Thus, ∃ U ∈ gpα-O(M, m) with U ⊂ gpα-cl(V).

Lemma. 1: A function p:M→ N is having a graph G(p) is gpα-closed in M ×N iff ∀ (m,n) ∈ (M ×N) \G(p), ∃ U ∈ gpα-O(M,m) and V ∈O(N,n) such that p(U) ∩V =ϕ.

Theorem. 2: Let p:M→ N be w. gpα-c function and N is T_2-space. Then the graph G(p) is gpα--closed in M ×N.

Definition. 2: A function p:M→ N is called w. gpα-c retraction, if p is w. gpα-c with A⊂ M and $p|_A$ is the identity function on set A.

Theorem. 3: Let A⊂ M and p:M→ N be w. gpα-c retraction of M onto the set A. If M is T_2-space, then A is gpα-closed.

Definition. 3: A space M is gpα-connected if it cannot be described as the disjoint union of two non-empty gpα-open sets.

Example. 2: Let M = $\{a_1, a_2, a_3\}$ and $\tau = \{M, \phi, \{a_1\}, \{a_2, a_3\}\}$ be a topology on M. Here gpα-open sets are P(M). Hence M is gpα-connected.

Theorem. 4: If p: M→ N is w.gpα-c surjective function with M is gpα-connected, then N is connected.

Proof: On the contrary assume that N is not connected. Then ∃ U,V ∈ O(N) with U ∩V = ϕ ∋ U ∩ V = N. By surjectiveness of p, p^{-1}(U), p^{-1}(V) ∈ O(M) with p^{-1}(U) ∩ p^{-1}(V) = ϕ, ∋ p^{-1} (U) ∪ p^{-1} (V) = M. But from Theorem 1, p^{-1} (U) ⊆ gpα-int(p^{-1} (gpα-cl(U))) and p^{-1} (V) ⊆ gpα-int(p^{-1} (gpα-cl(V))). As U, V ∈ O(M), implies U, V ∈ gpα-O(M)[6]. Thus, p^{-1} (U) ⊆ gpα-int(p^{-1} (U)) and p^{-1}(V) ⊆ gpα-int(p^{-1} (V)). Thus p^{-1} (U) and p^{-1} (V) are gpα-open sets in M which is contradiction to the hypothesis. Thus, N must be connected.

Definition. 4: If each gpα-open cover in a space M has a finite sub-cover, then the space is said to be a gpα-compact.

Example. 3: If M = N = {a_1, a_2, a_3} and $\tau = \{M, \phi, \{a_1, a_2\}\}$be a topology on M, then M is gpα-compact.

Definition. 5: A space M is called
(i) gpα-closed compact if every cover of M by gpα-open sets has a finite sub-cover whose gpα-closure covers M.
(ii)Let A ⊆ M. Then A is said to be gpα-closed relative to M, if every cover {Vα : α∈λ } of A by gpα-open sets, ∃ a finite sub-cover λ_0 of ∧ ∋ A ⊆ {gpα-cl(Vα),α ∈∧}.

Theorem. 5: Let p:M→ N be w.gpα-c and A is gpα-compact subset of M. Then p(A) is gpα-closed relative to N.
Proof: Let {V_i : i ∈ I} be any cover of p(K), K ⊂ M by gpα-open sets in N. Then, ∀ m ∈ M, ∃ α (m) ∈ I ∋ p(m) ∈ Vα (m). By w.gpα-c, ∃ U(m) ∈ gpα-O(M, m) such that p(U(m)) ⊂ gpα-cl(V(m)). So {U(m) : m ∈ A} is a cover of A by gpα-open sets. As A is gpα-compact, ∃ finite number of points, say m_1, m_2, m_3….m_n ∋ A ⊆ ∪{Um_k : m_k ∈ A; 1 ≤ k ≤ n}. Thus, p(A) ⊆ {p(Um_k) : m_k ∈ A, 1 ≤ k ≤ n}⊂ ∪{gpα-cl(Vα (m_k)) : m_k ∈ A; 1 ≤ k ≤ n}. Hence p(A) is gpα-closed relative to N.

Theorem. 6: The point m ∈ M at which the function p:M→ N is not w.gpα-c iff the union of gpα-frontier of the inverse images of the closure of open sets containing p(m).
Proof: On the contrary assume that p is not w.gpα-c at each point m ∈ M. Then, V ∈ O(N, p(m)) ∋ p(U) ⊄ gpα-cl(V) holds ∀ U ∈ gpα-O(M, m). Then U ∩ M \ p^{-1}(gpα-cl(V))) ≠ ϕ for every V ∈ gpα-O(M, m). Thus , m∈ gpα-cl(M \ p^{-1}(gpα-cl(V))). On the other hand, let m ∈ p^{-1}(V) ⊂ gpα-cl(p^{-1} (gpα-cl(V))). Thus, m ∈ gpα-Fr(p^{-1}(gpα-cl(V))).

Converse follows from the Theorem 1.

Theorem. 7: Let p:M→ N be w.gpα-c and q : N → S is continuous. Then q • p : M → S is w.gpα-c.

Theorem. 8: Let p_α:M→ N is weakly gpα-continuous ∀ α∈λ. Then p:M→ Π N_α defined as p(m) = $(p_\alpha(m))_\alpha$ is weakly gpα-continuous.

Theorem. 9: Let p:M→ N be w.gpα-c and K is closed subset of M × N. Suppose gpα-O(M) is closed under the finite intersections with P_1 is the projection of M × N onto M, then P_1(K \ G(p)) ∈ gpα-C(M).

Sub-Weakly Generalized Pre α- Continuous Functions

Definition. 6: A function p: M→N is said to have sub-weakly gpα-continuous (briefly sw.gpα-c) if ∃ a base β for the topology on N for which gpα-cl(p^{-1}(V)) ⊂ p^{-1} (cl(V)) ∀ V ∈ β.

Theorem. 10: If p: M→N is sw.gpα-c with N is T_2-space, then the graph G(p) is gpα-closed in M×N.
Proof: Let (m, n) ∈ (M × N) \ G(p). Then n ∈ p(m). Let β be the base for the topology on N with gpα-cl($p^{-1}(V_1)$) ⊂ p^{-1} (cl(V_1)), ∀ V ∈ β. By T_2-ness of N, ∃ V , W ∈ O(N) with n ∈ V, p(m) ∈ W and V ∩ W = φ holds for all V ∈ β. Then p(m) ∉ cl(V_1) and so m∉p^{-1} (cl(V)). By sub-weakly gpα-continuity of p, gpα-cl(p^{-1} (V)) ⊂ p^{-1} (cl(V)) and hence m ∉ gpα-cl(p^{-1}(V)). Thus, (m, n) ⊂ (M \ gpα-cl(p^{-1} (V))) × V ⊂ (M × N) \ G(p). Thus, G(p) is gpα-closed
Theorem. 11: If p: M→N is sw.gpα-c then the graph g: M → M × N is sw.gpα-c.

Theorem. 12: Let p: M→N is sub-weakly continuous injective function with N is T_2. Then M is gpα-T_2 space.

Theorem. 13: Let p: M→N be sw.gpα-c and A ∈ O(M). Then p|A: A → N is sub-weakly continuous.

Theorem. 14: Let p: M→N is sw.gpα-c and A ∈ O(M) with p(M) ⊂ A. Then p: M→A is sw.gpα-c.

Theorem. 15: Let p: M→N is continuous and g: M→N be sw.gpα-c with N is T_2-space. Then A={m ∈ M : p(m) = g(m)} is gpα-closed.
Proof: Let m ∈ M \A, then p(m) ≠ g(m). By sub-weakly gpα-continuity, ∃ a base β for the topology on N with gpα-cl(p^{-1}(V)) ⊂ p^{-1}(cl(V)) holds ∀ V ∈ β. By T_2- ness of N, ∃ V, W ∈ β ∋ p(m) ∈ V , g(m)∈ W and V ∩W = φ. Then, p(m) ∉cl(V) and so m ∉ g^{-1} (cl(V)). Then, m∈ M \gpα-cl(g^{-1} (V)). So, m ∈ p^{-1} (V)∩(M \gpα-cl(g^{-1} (V))) ⊂ (M \ A). But, M \ gpα-cl(g^{-1}(V)) which is gpα-open in M. Since p is continuous, p^{-1}(V) is open in M. So, p^{-1} (V)∩(M \gpα-cl(g^{-1}(V))) is gpα-open in M. Thus, A is gpα-closed.

Corollary. 1: Let p: M→N is continuous and g: M→N is sw.gpα-c with N is T_2-space. If p and g are open and gpα-dense then p = g.

Theorem. 16: Let p_α: M → N is sw.gpα-c ∀ α ∈ λ. Then p: M→Π N_α defined as p(m) = $(p_\alpha(m))_\alpha$ is sw.gpα-c.

Theorem. 17: If p: M→N is sw.gpα-c, then the graph of the function p is sw.gpα-c.

Almost Generalized Pre α- Continuous Functions

Definition. 7: A function p: M→N is called almost gpα-continuous (briefly a.gpα-c) at a point m ∈ M and ∀ V ∈ O(N, p(m)), ∃ U ∈ gpα-O(M, m) with p(U) ⊆ int(cl(V)). If p is a.gpα-c at every point of M, then it is a.gpα-c.

Remark. 2: Every a.gpα-c function is gpα-continuous, but not conversely.

Example. 4: Let M = N = {a_1, a_2, a_3}, τ = {M, φ, {a_1}, {a_1, a_2}} and σ = {N, φ, {a_1}, {a_1, a_2}, {a_1, a_3}}. Let p be the identity function from M to N. Then p is gpα-c but not a.gpα-c.

Theorem. 18: For p: M→N, the following coincide:
(i) p is a.gpα-c., ∀ V ∈ RO(N).
(ii) p^{-1} (F) ∈ gpα-C(M), ∀ F ∈ RC(N).
(iii) ∀ A ⊂ M, p(gpα-cl(A)) ⊂ cl_δ(p(A)).
(iv) gpα-cl(p^{-1}(B)) ⊂ p^{-1}(cl_δ(B)),∀ B ⊂ N.
(v) p^{-1} (U) ∈ gpα-C(M), ∀ U ∈ δC(N).
(vi) p^{-1} (V) ∈ gpα-O(M), ∀ V ∈ δO(N).

Theorem. 19: Every a.gpα-c function is w.gpα-c, but not conversely.

Example. 5: Let M = N = {a_1, a_2, a_3}, τ = {M, φ, {a_1, a_2}} and σ = {N, φ, {a_1}, {a_1, a_2}, {a_1, a_3}}. Let p be the identity function from M to N. Then p is w.gpα-c, but not a.gpα-c.

Theorem. 20: Following are coinciding for p: M → N:
(i) p is a.gpα-c.
(ii) P^{-1} (int(cl(V))) ∈ gpα-O(M), for each V ∈

O(N).

(iii) $p^{-1}(cl(int(F))) \in gp\alpha\text{-}C(M)$, for each $F \in C(N)$.

Theorem. 21: Let $p : M \rightarrow N$ be an a.gpα-c function and $V \in O(N)$. If $m \in gp\alpha\text{-}cl(p^{-1}(V)) \setminus p^{-1}(V)$ then $p(m) \in gp\alpha\text{-}cl(V)$.

Proof: Let $m \in M$ with $m \in gp\alpha\text{-}cl(p^{-1}(V)) \setminus p^{-1}(V)$. Let $p(m) \notin gp\alpha\text{-}cl(V)$. Then $\exists$ $H \in gp\alpha\text{-}O(N, p(m)) \ni H \cap V_1 = \varphi$. Then $cl(H) \cap V = \varphi$, that is $int(cl(H)) \cap V = \varphi$ where $int(cl(H)) \in RO(m)$. By almost gpα-continuity of p, $\exists$ $U \in gp\alpha\text{-}O(M, m) \ni p(U) \subset int(cl(H))$. Thus $p(U) \cap V = \varphi$. Since $m \in gp\alpha\text{-}cl(p^{-1}(V))$, $U \cap p^{-1}(V) = \varphi$, $\forall$ $U \in gp\alpha\text{-}O(M, m)$. So $p(U) \cap V \neq \varphi$. which is contradiction. Thus, $p(m) \in gp\alpha\text{-}cl(V)$.

Definition. 8: Let (M, τ) be a topological space and a filter base Λ is called,

(i) gpα-convergent to a point $m \in M$, if $\forall$ $U \in gp\alpha\text{-}O(M, m)$ $\exists$ $B \in \Lambda \ni B \subset U$.

(ii) r-convergent to a point $m \in M$, if for every $U \in RO(M, m)$ $\exists$ $B \in \Lambda \ni B \subset U$.

Theorem. 22: Let $p : M \rightarrow N$ be an almost continuous and $q : M \rightarrow N$ is a.gpα-c function, with N is T_2-space. Then the set $R = \{m \in M: p(m) = q(m)\}$ is gpα-closed in M.

Proof: Let $m \in M\setminus R$ then $p(m) \neq q(m)$. As N is T_2-space, $\exists$ disjoint V, $W \in O(N)$ with $p(m) \in V$ and $q(m) \in W$. As p is almost continuous and q is a.gpα-c $p^{-1}(V) \in O(M)$, $q^{-1}(W) \in gp\alpha\text{-} O(M)$ with $m \in p^{-1}(V)$ and $m \in q^{-1}(W)$. Put $A = p^{-1}(V) \cap q^{-1}(W)$ and so $A \in gp\alpha - O(M)$. Thus $p(A) \cap q(A) = \varphi$ and so $m \notin gp\alpha - cl(R)$. Hence R is gpα-closed in M.

Theorem. 23: Let $p : M \rightarrow N$ be a.gpα-c, $q : M \rightarrow N$ is w.gpα-c, with N is T_2-space. Then the set $\{m \in M : p(m) = q(m)\}$ is gpα-closed in M.

Proof: Let $A = \{m \in M : p(m) = q(m)\}$ and $m \in M \setminus A$, then $p(m) \neq q(m)$. As N is T_2-space, $\exists$ disjoint V, $W \in O(N)$ with $p(m) \in V$ and $q(m) \in W$ and $U \cap N = \varphi$, and so $int(cl(V)) \cap cl(W) = \varphi$. By almost gpα-continuity of m, $\exists$ $G \in gp\alpha - O(M, m)$ with $p(G) \subset int(cl(V))$. As q is w.gpα-c $\exists$ $H \in gp\alpha\text{-}O(M)$ with $q(H) \subset cl(W)$. Put $U = G \cap H$ then $U \in gp\alpha\text{-}O(M, m)$ and $p(U) \cap q(U) \subset int(cl(V)) \cap cl(W) = \varphi$ and so $U \cap A = \varphi$. Hence A is gpα-closed in M.

Theorem. 24: Assume that the product of two gpα-open sets is gpα-open. If $p_1 : (M, \tau) \rightarrow (N, \sigma)$ is w.gpα-c, $p_2 : (M, \tau) \rightarrow (N, \sigma)$ is a.gpα-c with N is T_2- space. Then the set $\{(m_1, m_2) \in M_1 \times M_2 : p_1(m_1) = p_2(m_2)\}$ is gpα-closed in $M_1 \times M_2$.

Theorem. 25: For each $m_1, m_2 \in M$, $\exists$ a function p on M into a T_2-space N such that $p(m_1) \neq p(m_2)$, p is w.gpα-c at m_1 and p is a.gpα-c at m_2, then M is gpα-T_2.

Proof: As N is T_2-space, for each $m_1, m_2 \in M$, $\exists$ $V_1, V_2 \in O(N)$ containing $p(m_1)$ and $p(m_2)$ respectively with $V_1 \cap V_2 = \varphi$. Then $cl(V_1) \cap int(cl(V_2)) = \varphi$. By weakly gpα-continuity at p, $\exists$ $U_1 \in gp\alpha\text{-}O(M, m_1)$ with $p(U_1) \subset cl(V_1)$. As p is a.gpα-c at the point m_2, $\exists$ $U_2 \in gp\alpha\text{-}O(M, m_2)$ with $p(U_2) \subset int(cl(V_2))$. Thus $U_1 \cap U_2 = \varphi$. Hence M is gpα-T_2-space.

Definition. 9: A function $p:M \rightarrow N$ is called gpα-strongly closed graph if for each $\{(m, n) \in M \times N \setminus G(p)\}$, $\exists$ $U \in gp\alpha$ - $O(M, m)$ and $V \in O(M, n)$ with $(U \times cl(V)) \cap G(p) = \phi$.

Lemma. 2: A function $p : M \rightarrow N$ is gpα-strongly closed graph G(p) iff for every $\{(m, n) \in M \times N \setminus G(p)\}$ $\exists$ $U_1 \in gp\alpha\text{-}O(M)$ and $V_1 \in O(N)$ respectively $\ni p(U) \cap cl(V) = \phi$.

Example. 6: Let $M = N = \{a_1, a_2, a_3\}$ and $\tau = \{M, \phi, \{a_1\}\}$ and $\sigma = \{N, \phi, \{a_1\}, \{a_2, a_3\}\}$ be topologies on M and N respectively. Let p be the identity function from M to N. Then p is gpα-strongly closed graph.

Conclusion:

In this present work, analysed new weaker form of some types of continuous functions namely weakly gpα-continuous functions and subweakly gpα-continuous functions. Also established the properties and some preservation theorems of weakly gpα-continuous functions and subweakly gpα-continuous functions. Further, almost gpα-continuous functions are studied here. There is a scope to study and extend these newly defined concepts in topological spaces.

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- We hereby confirm that all the Figures in the manuscript are ours. Besides, the Figures and images, which are not ours, have been given the permission for re-publication attached with the manuscript.
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Author's contributions:

This work was carried out in collaboration between the authors. P. G. P (Corresponding Author) gives the idea about the concept, also reviewed revised and proof reading the manuscript. And B. R. Pi has done literature survey and drafting the manuscript. All authors read and approved the final manuscript.

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الهياكل الجديدة للوظائف المستمرة

بي جي باتيل بي آر باتاناشيتي

قسم الرياضيات ، جامعة كارناتاك ، Dharwad-580 003 ، كارناتاكا ، الهند.

الخلاصة:

الدوال المستمرة هي مفاهيم جديدة في الطوبولوجيا .ساهم العديد من الطوبولوجيين في نظرية الوظائف المستمرة في الطوبولوجيا .واصل المؤلفون الحاليون الدراسة حول الوظائف المستمرة من خلال استخدام مفهوم مجموعات gpα المغلقة في الطوبولوجيا وقدموا مفاهيم الوظائف الضعيفة والضعيفة والمتواصلة تقريبًا .علاوة على ذلك، يتم إنشاء خصائص هذه الوظائف.

الكلمات المفتاحية: وظيفة **gpα**المستمرة تقريبًا، مجموعة gpα المغلقة ، مجموعة gpα-open، وظيفة gpα المستمرة شبه الضعيفة، وظيفة gpα المستمرة الضعيفة.