on Λ-generalized continuous functions*

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Abstract

In this paper, we introduce a new class of continuous functions as an application of Λ-generalized closed sets (namely Λ_g-closed set, Λ-g-closed set and $g\Lambda$-closed set) namely Λ-generalized continuous functions (namely Λ_g-continuous, Λ-g-continuous and $g\Lambda$-continuous) and study their properties in topological space.

1 Introduction and Preliminaries

Levine [7] introduced g-closed set. Maki [8] introduced the notion of Λ-sets in topological spaces. A subset A of a topological space (X, τ) is called a Λ-set if it coincides with its kernel (the intersection of all open supersets of A). In [1], Arenas et al. introduced the notions of λ-open sets, and λ-closed sets and presented fundamental results for these sets. They also introduced [1] λ- continuity, which is weaker than continuity. Recently, M. Caldas, S. Jafari and T. Noiri [3] introduced Λ-generalized closed sets in topological space. The aim of this paper is to introduce a weak form of continuous functions called Λ-generalized continuous functions. Moreover, the relationships and properties of Λ-generalized continuous functions are obtained.

Throughout this paper, by (X, τ) and (Y, σ) (or X and Y) we always mean topological spaces. Let A be a subset of X. We denote the interior, the closure and the complement of a set A by $Int(A)$, $Cl(A)$ and $X \backslash A$ or A^c, respectively. A subset A of a space (X, τ) is

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called λ-closed [1] if $A = L \cap D$, where L is a Λ-set and D is a closed set. The intersection of all λ-closed sets containing a subset A of X is called the λ-closure of A and is denoted by $Cl_\lambda(A)$. The complement of a λ-closed set is called λ-open. We denote the collection of all λ-open sets by $\lambda O(X, \tau)$.

Recall that a subset A of a topological space (X, τ) is called generalized closed (briefly g-closed) [7] if $Cl(A) \subset U$ whenever $A \subset U$ and U is open in (X, τ). B is a g-open set of (X, τ) if and only if B^c is g-closed.

Definition 1 *A subset A of a topological space (X, τ) is called a Λ-generalized closed, briefly Λ_g-closed [3], (resp. Λ-g-closed, $g\Lambda$-closed) if $Cl(A) \subseteq U$ (resp. $Cl_\lambda(A) \subset U$, $Cl_\lambda(A) \subset U$) whenever $A \subset U$ and U is λ-open (resp. U is λ-open, U is open) in (X, τ).*

Remark 1.1 *From the above definitions, we have the following.*
(1) Λ_g-closed sets and λ-closed sets are independent concepts.
(2) Λ-g-closed sets and g-closed sets are independent concepts.
(3) λ-closed sets and g-closed sets are also independent concepts.

From the above definitions and remark 1.1, we have the following diagram.

$$\begin{array}{ccccc} \text{closed} & \Rightarrow & \Lambda_g\text{-closed} & \Rightarrow & g\text{-closed} \\ \Downarrow & & \Downarrow & & \Downarrow \\ \lambda\text{-closed} & \Rightarrow & \Lambda\text{-}g\text{-closed} & \Rightarrow & g\Lambda\text{-closed} \end{array}$$

Example 1.2 *(i) Let $X = \{a, b, c\}$ with a topology $\tau = \{\emptyset, \{a\}, \{a, b\}, X\}$. Thus $\lambda O(X, \tau) = \{\emptyset, \{a\}, \{c\}, \{a, b\}, \{a, c\}, \{b, c\}, X\}$. Take $A = \{a, c\}$. Observe that A is a g-closed set but it is not Λ-g-closed.*
(ii) Let $X = \{a, b, c\}$ with a topology $\tau = \{\emptyset, \{a\}, \{b\}, \{a, b\}, X\}$. Then, $A = \{b\}$ is a λ-closed set but it is not g-closed.
(iii) Let $X = \{a, b, c\}$ with a topology $\tau = \{\emptyset, \{a\}, X\}$. Then, $A = \{a, b\}$ is a Λ_g-closed set but it is not λ-closed.

Definition 2 *A function $f : (X, \tau) \to (Y, \sigma)$ is called :*
(1) g-continuous [7] if $f^{-1}(V)$ is g-closed in (X, τ) for every closed set V of (Y, σ).
(2) λ-continuous [1] if $f^{-1}(V)$ is λ-closed in (X, τ) for every closed set V of (Y, σ).

2 Λ-generalized continuous functions

We introduce the following notions:

Definition 3 *A function $f : (X, \tau) \to (Y, \sigma)$ is called:*
(1) Λ_g-continuous if $f^{-1}(V)$ is Λ_g-closed in X, for every closed set in Y.
(2) Λ-g-continuous if $f^{-1}(V)$ is Λ-g-closed in X, for every closed set in Y.
(3) $g\Lambda$-continuous if $f^{-1}(V)$ is $g\Lambda$-closed in X, for every closed set in Y.

Example 2.1 *Let $X = \{a, b, c, d\} = Y$, $\tau = \{\phi, X, \{b\}, \{b, c\}, \{a, b\}, \{a, b, c\}\}$ and $\sigma = \{\phi, Y, \{a\}, \{b, c\}, \{a, b, c\}, \{b, c, d\}\}$. Define the function $f : (X, \tau) \to (Y, \sigma)$ by $f(a) = b = f(b)$, $f(c) = c$, $f(d) = d$. Then f is Λ_g-continuous, Λ-g-continuous and $g\Lambda$-continuous.*

Proposition 2.2 *Every continuous function is Λ_g-continuous (resp. Λ-g-continuous, $g\Lambda$-continuous).*

Proof. By [3], every closed set is Λ_g-closed (resp Λ-g-closed, $g\Lambda$-closed) and the proof follows.

Example 2.3 *Let $X = Y = \{a, b, c, d\}$,$\tau = \{\phi, X, \{a\}, \{b, c\}, \{a, b, c\}, \{b, c, d\}\}$ and $\sigma = \{\phi, Y, \{b\}, \{b, c\}, \{a, b\}, \{a, b, c\}\}$. Define the function $f : (X, \tau) \to (Y, \sigma)$ by $f(a) = f(b) = b$, $f(c) = c$, $f(d) = d$. Then f is Λ_g-continuous, Λ-g-continuous and $g\Lambda$-continuous but not continuous.*

Proposition 2.4 *Every Λ_g-continuous function is g-continuous.*

Proof. It follows from the fact that every Λ_g-closed set is g-closed set [3].

Example 2.5 *The function f in Example 2.3 with $\tau = \{\phi, X, \{b\}, \{b,c\}, \{a,b\}, \{a,b,c\}\}$, $\sigma = \{\phi, Y, \{a\}, \{a,c\}, \{a,b\}, \{a,b,c\}\}$ is g-continuous but not Λ_g-continuous since for the closed set $U = \{b,d\}$ in (Y,σ), $f^{-1}(U) = \{a,b,d\}$ which is not Λ_g-closed in (X,τ).*

Proposition 2.6 *Every λ-continuous function and Λ_g-continuous function are Λ-g-continuous function.*

Proof. By [3], every λ-closed set is Λ-g-closed set and every Λ_g-closed set is Λ-g-closed set, the proof follows.

Example 2.7 *Let (X,τ) and (Y,σ) be as in Example 2.3.*
(i) Define a function $f : (X,\tau) \to (Y,\sigma)$ by $f(a) = a$, $f(c) = c$, $f(b) = d = f(d)$. Then f is Λ-g-continuous but not λ-continuous since for the closed set $U = \{c,d\}$ in (Y,σ), $f^{-1}(U) = \{b,c,d\}$ which is not λ-closed in (X,τ).
(ii) Define a function $f : X \to Y$ by $f(a) = b$, $f(b) = a$, $f(c) = d$ and $f(d) = c$. Then f is Λ-g-continuous but not Λ_g-continuous since for the closed set $U = \{d\}$ in (Y,σ), $f^{-1}(U) = \{c\}$ which is not Λ_g-closed in (X,τ).

Remark 2.8 *(1) Λ_g-continuous and λ-continuous are independent.*
(2) Λ-g-continuous and g-continuous are independent.
(3) λ-continuous and g-continuous are independent.

Example 2.9 *(i) The function f in Example 2.7(i) is Λ_g-continuous but not λ-continuous.*
(ii) Let (X,τ) and (Y,σ) be as in Example 2.5. Then f in Example 2.7(ii) is λ-continuous but not Λ_g-continuous.
(iii) f is λ-continuous but not g-continuous.
(iv) f is Λ-g-continuous but not g-continuous.
(v) Let (X,τ) and (Y,σ) be as in Example 2.5 and the function f be an identity function from X to Y. Then f is g-continuous but neither Λ-g-continuous nor λ-continuous.

We get the following diagram:

continuous	$\Rightarrow$	Λ_g-*continuous*	$\Rightarrow$	g-*continuous*
$\Downarrow$		$\Downarrow$		$\Downarrow$
λ-*continuous*	$\Rightarrow$	Λ-g-*continuous*	$\Rightarrow$	$g\Lambda$-*continuous*

3 Properties of Λ-generalized continuous functions

Theorem 3.1 *If a function $f : (X, \tau) \to (Y, \sigma)$ is Λ_g-continuous and X is T_1 then f is continuous.*

Proof. Let f be Λ_g-continuous and X be T_1. Assume that V is closed in Y. Hence $f^{-1}(V)$ is Λ_g-closed set in X. Since every Λ_g-closed is closed in a T_1 space X [3], then $f^{-1}(V)$ is closed set in X. This shows that f is continuous.

Corollary 3.2 *If a function $f : (X, \tau) \to (Y, \sigma)$ is Λ_g-continuous and X is T_1 then f is λ-continuous.*

Theorem 3.3 *If a function $f : (X, \tau) \to (Y, \sigma)$ is Λ-g-continuous and X is T_0 then f is λ-continuous.*

Proof. Let f be Λ-g-continuous and X be T_0. Let V be closed in Y. $f^{-1}(V)$ is Λ-g-closed in X. Since Λ-g-closed is λ-closed in a T_0 space X [9], then $f^{-1}(V)$ is λ-closed in X. This shows that f is λ-continuous.

Definition 4 *A function $f : (X, \tau) \to (Y, \sigma)$ is said to be:*
(i) Λ_g-irresolute if $f^{-1}(V)$ is Λ_g-closed in X for every Λ_g-closed set V in Y.
(ii) Λ-g-irresolute if $f^{-1}(V)$ is Λ-g-closed in X for every Λ-g-closed set V in Y.
(iii) $g\Lambda$-irresolute if $f^{-1}(V)$ is $g\Lambda$-closed in X for every $g\Lambda$-closed set V in Y.

Recall that a function $f : (X, \tau) \to (Y, \sigma)$ is said to be λ-closed if $f(F)$ is λ-closed in Y for every λ-closed set F of X.

Lemma 3.4 *[3]. A function $f : (X, \tau) \to (Y, \sigma)$ is λ-closed if and only if for each subset B of Y and each $U \in \lambda O(X, \tau)$ containing $f^{-1}(B)$, there exists $V \in \lambda O(Y, \sigma)$ such that $B \subset V$ and $f^{-1}(V) \subset U$.*

Theorem 3.5 *Let $f : (X, \tau) \to (Y, \sigma)$ be a continuous λ-closed function. Then f is Λ_g-irresolute.*

Proof. Let B be Λ_g-closed in (Y, σ) and U a λ-open set of (X, τ) containing $f^{-1}(B)$. Since f is λ-closed, by Lemma 3.4 there exists a λ-open set V of (Y, σ) such that $B \subset V$ and $f^{-1}(V) \subset U$. Since B is Λ_g-closed in (Y, σ), $Cl(B) \subset V$ and hence $f^{-1}(B) \subset f^{-1}(Cl(B)) \subset f^{-1}(V) \subset U$. Since f is continuous, $f^{-1}(Cl(B))$ is closed and hence $Cl(f^{-1}(B)) \subset U$. This shows that $f^{-1}(B)$ is Λ_g-closed in (X, τ). Therefore f is Λ_g-irresolute.

Theorem 3.6 *If a function $f : (X, \tau) \to (Y, \sigma)$ is Λ_g-irresolute and Y is T_1 then f is Λ_g-continuous.*

Proof. Let f be Λ_g-irresolute and Y be T_1. Suppose V is Λ_g-closed in Y. Then $f^{-1}(V)$ is Λ_g-closed set in X. Since Y is T_1, V is closed in Y. Thus f is Λ_g-continuous.

Theorem 3.7 *If a function $f : (X, \tau) \to (Y, \sigma)$ is Λ-g-irresolute and Y is T_0 then f is Λ-g-continuous.*

Proof. Let f be Λ-g-irresolute, Y a T_0 space and V be Λ-g-closed in Y. Then $f^{-1}(V)$ is Λ-g-closed set in X. Since Y is T_0, V is closed in Y. Thus f is Λ-g-continuous.

Theorem 3.8 *If $f : (X, \tau) \to (Y, \sigma)$ is a λ-g-irresolute bijection and f is λ-open, then f is Λ-g-irresolute.*

Proof. Let V be Λ-g-closed and let $f^{-1}(V) \subset U$, where $U \in \lambda O(X, \tau)$. Clearly, $V \subseteq f(U)$. Since $f(U) \in \lambda O(X, \tau)$ and since V is Λ-g-closed in Y, then $Cl_\lambda(V) \subset f(U)$ and thus $f^{-1}(Cl_\lambda(V)) \subset U$. Since f is λ-irresolute and $Cl_\lambda(V)$ is a λ-closed set, then $f^{-1}(Cl_\lambda(V))$ is λ-closed in X. Thus $Cl_\lambda(f^{-1}(V)) \subset Cl_\lambda(f^{-1}(Cl_\lambda(V))) = f^{-1}(Cl_\lambda(V)) \subset U$. Therefore, $Cl_\lambda(f^{-1}(V)) \subseteq U$. So, $f^{-1}(V)$ is Λ-g-closed and f is a Λ-g-irresolute bijection.

Definition 5 *A topological space* (X, τ) *is called:*
(1) a $T_g\Lambda$*-space if every* $g\Lambda$*-closed is* g*-closed.*
(2) a T_{Λ_g}*-space if every* Λ*-*g*-closed is* Λ_g*-closed.*

Recall that a function $f : (X, \tau) \to (Y, \sigma)$ is said to be gc-irresolute [2] if $f^{-1}(V)$ is g-closed in X for every g-closed set V in Y. It is clear that a function $f : (X, \tau) \to (Y, \sigma)$ is gc-irresolute if and only if $f^{-1}(V)$ is g-open in X for every g-open set V in Y.

Theorem 3.9 *If a function* $f : (X, \tau) \to (Y, \sigma)$ *is* Λ_g*-irresolute and closed, then* f *is gc-irresolute.*

Proof. It follows immediately from ([4], Proposition 2).

Theorem 3.10 *If a function* $f : (X, \tau) \to (Y, \sigma)$ *is* $g\Lambda$*-irresolute and* X *is a* $T_g\Lambda$*-space, then* f *is gc-irresolute.*

Proof. Let f be $g\Lambda$-irresolute and V a g-closed set in X. Then V is $g\Lambda$-closed in Y. Since f is $g\Lambda$-irresolute, $f^{-1}(V)$ is $g\Lambda$-closed in X. But X is a $T_g\Lambda$-space. Therefore $f^{-1}(V)$ is g-closed in X and this implies that f is gc-irresolute.

Remark 3.11 *The condition that* X *is a* $T_g\Lambda$*-space cannot be omitted in above theorem as shown in the following example.*

Example 3.12 *Let* $X = \{a, b, c, d\}$*,* $\tau = \{\phi, X, \{a\}, \{b, c\}, \{a, b, c\}, \{b, c, d\}\}$ *and* $\sigma = \{\phi, Y, \{b\}, \{a, b\}, \{b, c\}, \{a, b, c\}\}$*. Note that* (X, τ) *is not a* $T_g\Lambda$*-space. Let* $f : (X, \tau) \to (Y, \sigma)$ *be the function defined as follows* $f(a) = b$*,* $f(b) = a$*,* $f(c) = d$ *and* $f(d) = c$*. Then* f *is* $g\Lambda$*-irresolute but not gc-irresolute, since* $f^{-1}(\{d\}) = \{c\}$ *is not* g*-closed in* (X, τ)*.*

Theorem 3.13 *If a function function* $f : (X, \tau) \to (Y, \sigma)$ *is* Λ*-*g*-irresolute and* X *is a* T_{Λ_g}*-space then* f *is* Λ_g*-irresolute.*

Proof. Let B be any Λ_g-closed set in Y. Then B is Λ-g-closed in Y. Since, f is Λ-g-irresolute, then $f^{-1}(B)$ is Λ-g-closed in X. But X is T_{Λ_g}-space. Therefore ,$f^{-1}(B)$ is Λ_g-closed in X which implies that f is Λ_g-irresolute.

Remark 3.14 *The condition that X is a T_{Λ_g}-space can not be omitted in Theorem 3.13 as it is shown in our next example.*

Example 3.15 *Let f be as in Example 3.12. Then f is Λ-g-irresolute but not Λ_g-irresolute, where X is not T_{Λ_g}-space. $f^{-1}(\{d\}) = \{c\}$ is not Λ_g-closed in (X, τ).*

We recall that the space X is called a λ-space [1] if the set of all λ-open subsets form a topology on X. Clearly a space X is a λ- space if and only if the intersection of two λ-open sets is λ-open. An example of a λ-space is a $T_{\frac{1}{2}}$-space, where a space X is called $T_{\frac{1}{2}}$ [5] if every singleton is open or closed .

Theorem 3.16 *If $f_i : (X, \tau_i) \to (Y, \sigma_i)(i \in I)$ is a family of functions, where X is a λ-space and Y is any topological space, then every f_i is Λ-g-continuous.*

Proof. It follows from ([9], Theorem 2.4).

Theorem 3.17 *(i) If a function $f : (X, \tau) \to (Y, \sigma)$ is Λ-g-continuous then $f(Cl_\lambda(A)) \subset Cl_\lambda(f(A))$ for every A of X.*
(ii) If a function $f : (X, \tau) \to (Y, \sigma)$ is Λ-g-irresolute then for every subset A of X, $f(Cl_{\Lambda-g}(A)) \subset Cl_\lambda(f(A))$ (where $Cl_{\Lambda-g}(A)$ is the intersection of the smallest Λ-g-closed set containing A.)

Proof. (i) It follows from the fact that every λ-continuous is Λ_g-continuous.
(ii) If $A \subset X$, then consider $Cl_\lambda(f(A))$ which is λ-closed in Y. Thus by Definition 4, $f^{-1}Cl_\lambda(f(A))$ is Λ-g-closed in X. Furthermore, $A \subset f^{-1}(f(A)) \subset f^{-1}(Cl_\lambda(f(A)))$. Therefore $Cl_{\Lambda-g}(A) \subset f^{-1}(Cl_\lambda(f(A)))$ and consequently, $f(Cl_{\Lambda-g}(A)) \subset f(f^{-1}(Cl_\lambda(f(A)))) \subset Cl_\lambda(f(A))$.

Theorem 3.18 *If a map $f : X \to Y$ is Λ_g-irresolute, then it is Λ_g -continuous but not conversely.*

Proof. Since every closed set is Λ_g-closed, it is proved that f is Λ_g-continuous. The converse need not be true as it is seen from the following example.

Example 3.19 *Let $X = Y = \{a, b, c, d\}$, $\sigma = \{\phi, X, \{b\}, \{d\}, \{b, d\}\}$, $\tau = \{\phi, Y, \{a\}, \{b\}, \{a, b\}, \}$. Define a function $f : (X, \tau) \to (Y, \sigma)$ by $f(a) = d = f(d), f(b) = b$ and $f(c) = c$. Then f is Λ_g-continuous but not Λ_g-irresolute.*

Theorem 3.20 *Let (X, τ) and (Z, η) be topological spaces and (Y, σ) be a T_1 space. The composition $g \circ f : (X, \tau) \to (Z, \eta)$ is Λ_g-continuous function where $f : (X, \tau) \to (Y, \sigma)$ and $g : (Y, \sigma) \to (Z, \eta)$ are Λ_g-continuous.*

Proof. Let F be any closed set in Z. Since g is Λ_g-continuous, $g^{-1}(F)$ is Λ_g-closed in Y. But Y is a T_1-space and so $g^{-1}(F)$ is closed in Y. Since f is Λ_g-continuous, $f^{-1}(g^{-1}(F))$ is Λ_g-closed in X. Hence, $g \circ f$ is Λ_g-continuous.

Theorem 3.21 *Let (X, τ) and (Z, η) be topological spaces and (Y, σ) be a T_1 space.*
(1) The composition $g \circ f : (X, \tau) \to (Z, \eta)$ is λ-continuous function where $f : (X, \tau) \to (Y, \sigma)$ is λ-continuous and $g : (Y, \sigma) \to (Z, \eta)$ is Λ_g-continuous.
(2) The composition $g \circ f : (X, \tau) \to (Z, \eta)$ is g-continuous function where $f : (X, \tau) \to (Y, \sigma)$ is g-continuous and $g : (Y, \sigma) \to (Z, \eta)$ is Λ_g-continuous.
(3) The composition $g \circ f : (X, \tau) \to (Z, \eta)$ is Λ-g-continuous function where $f : (X, \tau) \to (Y, \sigma)$ is Λ-g-continuous and $g : (Y, \sigma) \to (Z, \eta)$ is Λ_g-continuous.

Proof. Similar to the proof of Theorem 3.20.

Theorem 3.22 *Let (X, τ) and (Z, η) be any topological spaces and (Y, σ) be a T_0 space. The composition $g \circ f : (X, \tau) \to (Z, \eta)$ is λ-continuous function where $f : (X, \tau) \to (Y, \sigma)$ is λ-irresolute and $g : (Y, \sigma) \to (Z, \eta)$ is Λ-g-continuous.*

Proof. Let V be any closed set in Z. Since g is Λ-g-continuous, $g^{-1}(V)$ is Λ-g-closed in Y. But Y is a T_0-space and so $g^{-1}(V)$ is λ-closed in Y. Since f is λ-irresolute, $f^{-1}(g^{-1}(V))$ is λ-closed in X. Hence, $g \circ f$ is λ-continuous.

Theorem 3.23 *Let (X, τ) and (Z, η) be topological spaces and (Y, σ) be a $T_g\Lambda$ space. The composition $g \circ f : (X, \tau) \to (Z, \eta)$ is g-continuous function where $f : (X, \tau) \to (Y, \sigma)$ is gc-irresolute and $g : (Y, \sigma) \to (Z, \eta)$ is $g\Lambda$-continuous.*

Proof. This follows from the definitions.

Theorem 3.24 *Let* (X, τ) *and* (Z, η) *be topological spaces and* (Y, σ) *be a* T_{Λ_g} *space. The composition* $g \circ f : (X, \tau) \to (Z, \eta)$ *is* Λ_g*-continuous function, where* $f : (X, \tau) \to (Y, \sigma)$ *is* Λ_g*-irresolute and* $g : (Y, \sigma) \to (Z, \eta)$ *is* Λ*-*g*-continuous.*

Proof. This follows from definitions.

Recall that a space X is called locally indiscrete if and only if every open set is closed if and only if every λ-open set of X is open in X.

Finally, we get the following diagram:

continuous	$\Rightarrow$	Λ_g*-continuous*	$\Rightarrow$	g*-continuous*
$S_1 \Updownarrow$		$T_{\Lambda_g} \Updownarrow$		$T_g \Updownarrow$
λ*-continuous*	$\Rightarrow$	Λ*-*g*-continuous*	$\Rightarrow$	$g\Lambda$*-continuous*

where S_1 is a locally indiscrete space.

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