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DECOMPOSITION OF $*$ - CONTINUITY IN IDEAL TOPOLOGICAL SPACES

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ABSTRACT

In this paper, we introduce and investigate the notions of $I\omega$ -continuous maps and $I\omega$ -irresolute maps in ideal topological spaces. Also we introduce the notions of slc-I -sets, $\wedge s$ -sets, λs - I -closed sets, slc* - I -continuous maps and λs - I -continuous maps. Finally, we obtain the decompositions of $*$-continuity.*

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1 INTRODUCTION AND PRELIMINARIES

The concept of ideals in topological spaces is treated in the classic text by Kuratowski [10] and Vaidyanathaswamy [16]. The notion of I -open sets in topological spaces was introduced by Jankovic and Hamlett [8]. Dontchev et al. [4] introduced and studied the notion of Ig -closed sets. Recently, Navaneethakrishnan and Paulraj Joseph [13] have studied further the properties of Ig -closed sets and Ig -open sets. An ideal I on a topological space (X, τ) is a non-empty collection of subsets of X satisfying the following properties: (1) $A \in I$ and $B \subset A$ imply $B \in I$ (heredity), (2) $A \in I$ and $B \in I$ imply $A \cup B \in I$ (finite additivity). A topological space (X, τ) with an ideal I on X is called an ideal topological space and is denoted by (X, τ, I). For a subset $A \subset X$, $A^*(I) = \{x \in X : U \cap A \notin I \text{ for every } U \in \tau(x)\}$ is called the local function [10] of A with respect to I and τ. We simply write A^* in case there is no chance for confusion. A Kuratowski closure operator $cl^*(.)$ for a topology $\tau^*(I)$ called the $*$ -topology finer than τ is defined by $cl^*(A) = A \cup A^*$ [16]. Let (X, τ) denote a topological space on which no separation axioms are assumed unless explicitly stated. In a topological space (X, τ), the closure and the interior of any subset A of X will be denoted by cl(A) and int(A), respectively. A subset A of a space is said to be semi-open [12] if $A \subset cl(int(A))$. A subset A of a topological space (X, τ) is said to be g-closed [11] (resp. ω-closed [15]) if $cl(A) \subset U$ whenever $A \subset U$ and U is open (resp. semi-open) in X. A subset A of a topological space (X, τ) is locally closed [5] (briefly LC) if $A = U \cap V$, where U is open and V is closed.

A subset A of a topological space (X, τ) is semi-locally closed [6] (briefly slc) if $A = U \cap V$ where U is semi-open and V is semi-closed. A subset A of a topological space (X, τ) is called slc* -set if $A = U \cap V$ where U is semi-open and V is closed. A function $f : (X, \tau) \to (Y, \sigma)$ is g-continuous [11] (resp. ω –continuous [15]) if $f^{-1}(V)$ is g-closed (resp. ω-closed) in (X,τ) for every closed set V of (Y, σ).

A subset A of an ideal space (X, τ, I) is $*$-closed [8] if $A^* \subset A$. A subset A of an ideal space (X, τ, I) is Ig -closed [4] (resp. $I\omega$ -closed [14]) if $A^* \subset U$ whenever $A \subset U$ and U is open (resp. semi-open). An ideal space (X, τ, I) is called a TI -space [4] (resp. $TI\omega$ -space [14]) if every Ig -closed (resp. $I\omega$ -closed) subset of X is $*$ -closed.

Lemma 1.1: [8] Let (X, τ, I) be a space with an ideal I on X, and A is a subset of X. Then,
1. Every $*$ -closed set is $I\omega$ -closed,
2. Every $I\omega$ -closed set is Ig -closed.

We denote the family of all $I\omega$ -closed (resp. $I\omega$ - open) subsets of an ideal space (X, τ, I) by $I\omega(X)$ (resp. $I\omega O(X)$).

Definition 1.2: A subset A of an ideal space (X, τ, I) is called

1. strongly- I -locally closed [7] (briefly, strongly- I -LC) if $A = U \cap V$ where U is regular open and V is $*$- closed.

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2. weakly- I -locally closed [9] (briefly, weakly- I -LC) if $A = U \cap V$, where U is open and V is ∗-closed.
3. mildly- I -locally closed [2] (briefly, mildly- I -LC) if $A = U \cap V$, where U is π -open and V is ∗-closed.

Definition 1.3: A function $f: (X, \tau, I) \to (Y, \sigma)$ is said to be
1. ∗-continuous [7] if $f^{-1}(A)$ is ∗-closed in X for every closed set A in Y.
2. Ig -continuous [7] if $f^{-1}(A)$ is Ig -closed in X for every closed set A in Y.
3. strongly- I -LC-continuous [7] if $f^{-1}(A)$ is a strongly- I -LC-set in X for every closed set A in Y.
4. weakly- I -LC-continuous [9] if $f^{-1}(A)$ is a weakly- I -LC-set in X for every closed set A in Y.
5. mildly- I -LC-continuous [2] if $f^{-1}(A)$ is a mildly- I -LC-set in X for every closed set A in Y.

Lemma 1.4: [7] Let (X, τ, I) be an ideal space and A be a subset of X. If A is ∗ -closed then A is strongly- I -LC-set but not conversely.

2. Iω -continuity and Iω –irresoluteness

Definition 2.1: A function $f : (X, \tau, I) \to (Y, \sigma)$ is said to be Iω-continuous if $f^{-1}(A)$ is Iω-closed in X for every closed set A in Y.

Remark 2.2: If $I = \{\phi\}$ in the above definition, then the notion of Iω-continuity coincides with the notion of ω -continuity.

Definition 2.3: A function $f : (X, \tau, I) \to (Y, \sigma, J)$ is said to be Iω -irresolute if $f^{-1}(A)$ is Iω-closed in (X, τ, I) for every Iω-closed set A in (Y, σ, J).

Theorem 2.4: For a function $f: (X, \tau, I) \to (Y, \sigma)$, the following hold:

1. Every continuous function is Iω-continuous,
2. Every ∗-continuous function is Iω-continuous,
3. Every ω-continuous function is Iω-continuous,
4. Every Iω-continuous function is Ig -continuous.

Proof:

(1) Let f be a continuous function and V be a closed set in (Y, σ). Then $f^{-1}(V)$ is closed in (X, τ, I). Since every closed set is ∗-closed and hence Iω-closed, $f^{-1}(V)$ is Iω-closed in (X, τ, I). Therefore, f is Iω-continuous.

(2) Let V be a closed set in (Y, σ). Then $f^{-1}(V)$ is ∗-closed in (X, τ, I) because f is ∗-continuous in X. Since every ∗-closed set is Iω-closed, $f^{-1}(V)$ is Iω-closed in (X, τ, I). Therefore, f is Iω-continuous.

(3) Let f be an ω-continuous function. Then $f^{-1}(V)$ is ω-closed in (X, τ, I) for every closed set V in (Y, σ). Since every ω-closed set is Iω -closed [14], $f^{-1}(V)$ is Iω-closed in (X, τ, I). Therefore, f is Iω-continuous.

(4) Let V be a closed set in (Y, σ) and f be an Iω-continuous function. Then $f^{-1}(V)$ is Iω-closed in (X, τ, I). Since every Iω-closed set is Ig -closed, $f^{-1}(V)$ is Ig -closed in (X, τ, I). Therefore, f is Ig -continuous.

Remark 2.5: The relationships defined above, are shown in the following diagram:

$$\begin{array}{ccccc} \text{Continuity} & \to & \omega\text{-continuity} & \to & g\text{-continuity} \\ \downarrow & & \downarrow & & \downarrow \\ *\text{-continuity} & \to & I\omega\text{-continuity} & \to & Ig\text{-continuity} \end{array}$$

None of these implications is reversible as shown by the following examples.

Example 2.6: Let $X = \{a, b, c\}$, $\tau = \{\phi, \{a\}, \{b, c\}, X\}$, $I = \{\phi, \{c\}\}$ and $\sigma = \{\phi, \{a\}, X\}$. Define $f: (X, \tau, I) \to (Y, \sigma)$ as $f(a) = b$, $f(b) = a$, $f(c) = c$. Then f is Iω-continuous but not continuous.

Example 2.7: Let $X = \{a, b, c\}$, $\tau = \{\phi, \{a\}, \{b, c\}, X\}$, $I = \{\phi , \{c\}\}$ and $\sigma = \{\phi, \{a, c\}, X\}$. The identity map $f: (X, \tau, I) \to (Y, \sigma)$ is Iω-continuous but not ∗-continuous.

Example 2.8: Let $X = \{a, b, c, d\}$, $\tau = \{\phi, \{b\}, \{b, c, d\}, X\}$, $I = \{\phi, \{a\}\}$ and $\sigma = \{\phi, \{c, d\}, X\}$. Then the identity map $f : (X, \tau, I) \to (Y, \sigma)$ is Ig - continuous but not Iω -continuous.

Theorem 2.9: A function f: (X, τ, I) → (Y, σ) is Iω-continuous if and only if $f^{-1}(V)$ is Iω-open in (X, τ, I) for every open set V in (Y, σ).

Proof: Let V be an open set in (Y, σ) and f : (X, τ, I) → (Y, σ) be Iω-continuous. Then V^c is closed in (Y, σ) and $f^{-1}(V^c)$ is Iω-closed in (X, τ, I). But $f^{-1}(V^c) = (f^{-1}(V))^c$ and so $f^{-1}(V)$ is Iω-open in (X, τ, I).

Conversely, Suppose that $f^{-1}(V)$ is Iω -open in (X, τ, I) for each open set V in (Y, σ). Let F be a closed set in (Y, σ). Then F^c is open in (Y, σ) and by hypothesis $f^{-1}(F^c)$ is Iω -open in (X, τ, I). Since $f^{-1}(F^c) = (f^{-1}(F))^c$, we have $f^{-1}(F)$ is Iω-closed in (X, τ, I) and so f is Iω-continuous.

Definition 2.10: For a function f : (X, τ, I) → (Y, σ), the subset {(x, f(x)) : x ∈ X}⊂ XxY is called the graph of f and is denoted by G(f).

Lemma 2.11: The following properties are equivalent for a graph G(f) of a function f :
1. G(f) is Iω-continuous,
2. For each (x, f(x)) ∈ XxY \G(f), there exists an Iω-open set Uω of X containing x and an open set V containing f(x) such that g(Uω) ∩ V ≠ ϕ.

Theorem 2.12: Let f: (X, τ, I) → (Y, σ) be a function and g: X → XxY be the graph function of f. If g is Iω-continuous, then f is Iω-continuous.

Proof: Suppose that g is Iω-continuous. Let x ∈ X and V be any open set of Y containing f(x). Then XxV is open in XxY and by Iω-continuity of g, there exists U ∈IωO(X, τ) containing x such that g(U) ⊂ XxV. Therefore we obtain f(U) ⊂ V. This shows that f is Iω-continuous.

Theorem 2.13: Let (X, τ, I) be an ideal topological space. If A ∈ Iω(X) and A ⊂ X_0 ⊂ Iω(X) then A ∈ Iω(X_0).

Proof: Let A ∈ Iω(X) and A ⊂ X0 ⊂ Iω(X) then cl*(A) ∩ X0 ⊂ U whenever A ⊂ U and U is semi-open.

Also cl*X_0 (A) = cl*(A) ∩ X_0 (Lemma 3.2 [1]). Hence A ∈ Iω(X_0).

Theorem 2.14: If f : (X, τ, I) → (Y, σ) is an Iω-continuous function and X0 ∈ IωO(X). Then the restriction f / X_0: (X_0, τ / X_0, I / X_0) → (Y, σ) is Iω-continuous.

Proof: Let V be any open set of (Y, σ). Since f is Iω -continuous, $f^{-1}(V)$ is Iω-open in (X, τ, I) and $f^{-1}(V) \cap X_0 = (f/X_0)^{-1}(V)$ ∈ IωO(X). Moreover by Theorem 2.13 we have $(f/X_0)^{-1}(V)$ ∈ IωO(X_0). This shows that f /X_0 is Iω-continuous.

Remark 2.15: The composition of two Iω-continuous maps need not be Iω-continuous as seen from the following example:

Example 2.16: Let X = Y = Z= {a, b, c, d}, τ = {ϕ, {a}, {a, b, c}, X} and σ = {ϕ, {c}, Y}, η = {ϕ, {b, d}, Z}, I = {ϕ, {a}, {b}, {a, b}}, J = {ϕ, {c}}. Let f: (X, τ, I) → (Y, σ, J) and g: (Y, σ, J) → (Z, η) be identity maps. Then the maps f and g are Iω-continuous but gof is not Iω-continuous.

Theorem 2.17: Let f: (X, τ, I) → (Y, σ, J) be Iω-continuous and g : (Y, σ, J) → (Z, η) be continuous. Then g o f: (X, τ, I) → (Z, η) is Iω-continuous.

Theorem 2.18: A function f: (X, τ, I) → (Y, σ, J) is Iω-irresolute if and only if the inverse image of every Iω-open set in (Y, σ, J) is Iω-open in (X, τ, I).

Theorem 2.19: Let f: (X, τ, I) → (Y, σ, J) and g : (Y, σ, J) → (Z, η, K) be Iω-irresolute. Then (g o f): (X, τ, I) → (Z, η, K) is Iω-irresolute.

Proof: Let g be an Iω-irresolute function and V be any Kω-open set in (Z, η, K). Then $g^{-1}(V)$ is Jω-open in (Y, σ, J). Since f is Iω-irresolute, $f^{-1}(g^{-1}(V)) = (g \circ f)^{-1}(V)$ is Iω-open in (X, τ, I). Hence g o f is Iω-irresolute.

Theorem 2.20: If f: (X, τ, I) → (Y, σ, J) is Iω-irresolute and g: (Y, σ, J) → (Z, η) is ∗-continuous then g o f : (X, τ, I) → (Z, η) is Iω-continuous.

Proof: Let V be any closed set of (Z, η). Then $g^{-1}(V)$ is ∗-closed in (Y, σ, J). Therefore, $f^{-1}(g^{-1}(V)) = (g \circ f)^{-1}(V)$ is Iω -closed in (X, τ, I), since every ∗-closed set is Iω-closed. Hence g o f is Iω-continuous.

Theorem 2.21: Let (X, τ, I) be an ideal topological space, (Y, σ, J) be a TIω –space and (Z, η) be a topological space. If f: (X, τ, I) → (Y, σ, J) is Iω-irresolute and g: (Y, σ, J) → (Z, η) is Iω-continuous then g o f is Iω-continuous.

Theorem 2.22: Let (X, τ, I) be an ideal topological space, (Y, σ, J) be a TI –space and (Z, η) be a topological space. If f: (X, τ, I) → (Y, σ, J) is Iω-irresolute and g: (Y, σ, J) → (Z, η) is Ig -continuous then g o f is Iω-continuous.

3 slc*- I –sets

In this section, we introduce the notions of slc* - I -sets in ideal topological spaces and study some of its properties.

Definition 3.1: A subset A of an ideal topological space (X, τ, I) is called slc* - I -set if A = U ∩ F where U is semi-open and F is ∗-closed.

Proposition 3.2: Let (X, τ, I) be an ideal space and A be a subset of X. Then the following holds.
1. If A is semi-open then A is slc* - I -set.
2. If A is ∗-closed then A is slc*- I -set.
3. If A is weakly- I -LC-set then A is slc* - I -set.

Example 3.3: Let X = {a, b, c, d}, τ = {ϕ, {a}, {a, b, c}, X} and I = {ϕ, {a}, {b}, {a, b}}. Then the set A = {c} is an slc* - I -set but not a ∗-closed set.

Example 3.4: Let X = {a, b, c, d}, τ = {ϕ, {a, b}, X} and I = {ϕ, {a}}. Then the set A = {a, c} is an slc* - I -set but not a weakly- I -LC-set.

Remark 3.5: The notions of Iω-closed sets and slc* - I -sets are independent.

Example 3.6: Let X = {a, b, c}, τ = {ϕ, {a}, {b, c}, X} and I = {ϕ, {c}}. Then the set A = {b} is Iω-closed but not an slc* - I -set.

Example 3.7: Let X = {a, b, c, d}, τ = {ϕ, {a}, {a, b, c}, X} and I = {ϕ, {a}, {b}, {a, b}}. Then the set A = {c} is slc* - I -set but not an Iω -closed set.

Theorem 3.8: A subset of an ideal topological space (X, τ, I) is *-closed if and only if it is both Iω-closed and an slc* - I -set.

Proof: Necessity is trivial. To prove the sufficiency, assume that A is both Iω-closed and an slc* - I -set. Then A = U ∩ F where U is semi-open and F is ∗-closed. Therefore A⊂ U and A ⊂ F and so by hypothesis, A* ⊂ U and A* ⊂ F. Thus A* ⊂ U ∩ F = A. Hence A is *-closed.

Remark 3.9: From [2] and Proposition 3.2, We have the following implications:

strongly- I -LC-set → mildly- I -LC-set → weakly- I -LC-set → slc* - I -set.

Theorem 3.10: For a subset A of an ideal topological space (X, τ, I), the following are equivalent.

1. A is a ∗-closed set.
2. A is a strongly- I -LC-set and an Iω -closed set.
3. A is a mildly- I -LC-set and an Iω -closed set.
4. A is a weakly- I -LC-set and an Iω -closed set.
5. A is an slc* - I -set and an Iω -closed set.

Corollary 3.11: For a subset A of an ideal topological space (X, τ, I), the following are equivalent.

1. A is a ∗-closed set.
2. A is a weakly- I -LC-set and an Iω -closed set.
3. A is a weakly- I -LC-set and an Ig -closed set. [7]

4 A new subset of an ideal topological space

Definition 4.1: [3] Let A be a subset of a topological space (X, τ). Then the s - kernel of the set A, denoted by s - ker(A) is the intersection of all semi-open supersets of A.

Definition 4.2: [3] A subset A of a topological space (X, τ) is called ∧s -set if A = s - ker(A).

Definition 4.3: A subset A of an ideal space (X, τ, I) is called λs - I -closed if A = U ∩ V where U is a ∧s -set and V is ∗-closed.

Proposition 4.4: In an ideal space (X, τ, I), every ∗-closed set is λs - I -closed but not conversely.

Example 4.5: Let X = {a, b, c}, τ = {ϕ, {a}, {c}, {a, c}, X} and I = {ϕ, {a}}. Then the set A = {b} is λs - I -closed but not *-closed.

Lemma 4.6: For a subset A of an ideal space (X, τ, I), the following are equivalent.
1. A is λs - I -closed.
2. A = U ∩ cl*(A) where U is a ∧s -set.
3. A = s - ker(A) ∩ cl*(A).

Lemma 4.7: A subset A of an ideal space (X, τ, I) is Iω-closed if and only if cl*(A) ⊂ s - ker(A).

Remark 4.8: The notions of Iω-closed sets and λs - I -closed sets are independent.

Example 4.9: Let X = {a, b, c}, τ = {ϕ, {a}, {c}, {a, c}, X} and I = {ϕ, {a}}. Then the set A = {c} is λs - I -closed but not Iω -closed.

Example 4.10: Let X = {a, b, c}, τ = {ϕ, {a}, {b, c}, X} and I = {ϕ, {c}}. Then the set A = {b} is Iω-closed but not λs - I -closed.

Theorem 4.11: A subset of an ideal topological space (X, τ, I) is ∗-closed if and only if it is both Iω-closed and λs - I - closed.

5. Decompositions of ∗-continuity

In this section, we obtain decompositions of ∗-continuity in ideal topological spaces. In order to obtain the decompositions of ∗-continuity we introduce the notion of slc* - I -continuity and λs - I -continuity in ideal topological spaces.

Definition 5.1: A function f: (X, τ, I) → (Y, σ) is said to be slc* - I -continuous (resp. λs - I -continuous) if $f^{-1}(V)$ is an slc*- I -set (resp. λs - I -closed set) in (X, τ, I) for every closed set V in (Y, σ).

Example 5.2: Let X = {a, b, c, d}, τ = {ϕ, {a}, {a, b, c}, X}, I = {ϕ, {a}, {b}, {a, b}} and σ = {ϕ, {c}, X}. Then the identity map f: (X, τ, I) → (Y, σ) is an slc* - I - continuous map.

Remark 5.3: Every ∗-continuous map is slc*- I -continuous, but the converse is not true.

Example 5.4: Let X = {a, b, c, d}, τ = {ϕ, {a}, {a, b, c}, X}, I = {ϕ, {a}, {b}, {a, b}} and σ = {ϕ, {a, b, d}, X}. Let f: (X, τ, I) → (Y, σ) be the identity map. Then f is slc*- I -continuous but not ∗-continuous.

Remark 5.5: The concepts of Iω-continuity and slc* - I -continuity are independent as seen from the following examples.

Example 5.6: Let X, τ, σ and I be defined as in Example 5.4. Then the map f: (X, τ, I) → (Y, σ) is slc* - I -continuous but not Iω-continuous.

Example 5.7: Let X = {a, b, c}, τ = {ϕ, {a}, {b, c}, X}, I = {ϕ, {c}} and σ = {ϕ, {a, c}, X}. Let the map f: (X, τ, I) → (Y, σ) be the identity map. Then f is Iω-continuous but not slc*- I -continuous.

Theorem 5.8: For a function f: (X, τ, I) → (Y, σ), the following are equivalent.

1. f is ∗-continuous.
2. f is strongly- I -LC-continuous and Iω -continuous.
3. f is mildly- I -LC-continuous and Iω -continuous.
4. f is weakly- I -LC-continuous and Iω -continuous.
5. f is slc*- I -continuous and Iω -continuous.

Corollary 5.9: For a function f: (X, τ, I) → (Y, σ), the following are equivalent.

1. f is ∗-continuous.
2. f is weakly- I -LC-continuous and Iω-continuous.
3. f is weakly- I -LC-continuous and Ig -continuous. [7]

Theorem 5.10: A function f : (X, τ, I) → (Y, σ) is ∗-continuous if and only if it is both Iω-continuous and λs - I -continuous.

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