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On strongly α-I-*Open* sets and a new mapping

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ABSTRACT

In this paper, we introduce the notion of strongly α-I-*open* sets in ideal topological spaces and investigate some of their properties. Further we study the continuous functions for the above set and derive the some of their properties.

RESUMEN

En este trabajo, se introduce la noción del gran conjunto α-I-*abierto* ideal en espacios topológicos y se investigan algunas de sus propiedades. Además se estudian las funciones continuas para el conjunto y parte de sus propiedades.

Keywords: α-I-open set, Strongly α-I-open set and B_I set.

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1 Introduction

The notion of *α-open* sets was introduced and investigated by Njastad [16]. By using *α-open* sets. Mashhour et al. [14] defined and studied *α-continuity* and *α-openness* in topological spaces. Ideals in topological spaces have been considered since 1930. This topic has won its importance by the paper of Vaidyanathaswamy [19]. In 2002, Hatir and Noiri [6] have introduced the notion of *α-I-continuous* functions and used it to obtain a decomposition of continuity. The notion of B_I sets introduced by Hatir and Noiri [6] and provided a decomposition of continuity. In this paper, we introduce strongly *α-I-open* sets and establish a decomposition of continuity.

In 1990, Jankovic and Hamlett [9] introduced the notion of *I-open* sets in ideal topological spaces. An ideal is defined as a non-empty collection I of subsets of X satisfying the following two conditions. (1) If $A \in I$ and $B \subset A$, then $B \in I$. (2) If $A \in I$ and $B \in I$, then $A \cup B \in I$. An ideal topological space is a topological space (X, τ) with an ideal I on X and it is denoted by (X, τ, I). For a subset $A \subset X$, $A^*(I) = \{x \in X : U \cap A \notin I$ for each neighbourhood U of $x\}$ is called the local function of A with respect to I and τ [9]. We simply write A^* instead of $A^*(I)$ to be brief. For every ideal topological space (X, τ, I), there exists a topology $\tau^*(I)$, finer than τ, generated by $\beta(I, \tau) = \{U - i : U \in \tau$ and $i \in I\}$, but in general $\beta(I, \tau)$ is not always a topology [9]. Additionally, $cl^*(A) = A \cup A^*$ defines a kuratowski closure operator for $\tau^*(I)$. Given a space (X, τ, I) and $A \subset X$, A is called *I-open* if $A \subset int(A^*)$ and a subset K is called *I-closed* if its complement is *I-open* [8,9].

2 Preliminaries

First we will recall some definitions used in sequel.

Definition 2.1. A subset A of an ideal topological space (X, τ, I) is said to be

1. *α-I-open* [6] (resp. *α-open* [16]) if $A \subset int(cl^*(int(A)))$ (resp. $A \subset int(cl(int(A))))$,
2. *semi-I-open* [6] (resp. *semi-open* [12]) if $A \subset cl^*(int(A))$ (resp. $A \subset cl(int(A)))$,
3. *pre-I-open* [1] (resp. *pre-open* [13]) if $A \subset int(cl^*(A))$ (resp. $A \subset int(cl(A)))$,
4. *b-I-open* [3] (resp. *b-open* [2]) if $A \subset int(cl^*(A)) \cup cl^*(int(A))$ (resp. $A \subset int(cl(A)) \cup cl(int(A))$),
5. *t-I*-set [6] (resp. *t*-set [18]) if $int(cl^*(A)) = int(A)$ (resp. $int(cl(A)) = int(A)$),
6. B_I-set [6] if $A = U \cap V$, where $U \in \tau$ and V is a *t-I*-set,
7. C_I-set [6] if $A = U \cap V$, where $U \in \tau$ and $int(cl^*(int(V))) = int(V)$,
8. A_I-set [11] if $A = U \cap V$, where $U \in \tau$ and $V = (int(V))^*$,

9. strongly *pre-I-open* [17] if A is *pre-I-open* as well as a C_I-set,
10. strongly *b-I-open* [4] if A is *b-I-open* as well as a C_I-set and
11. I-locally closed set [5] if $A = U \cap V$, where $U \in \tau$ and $V = V^*$.

Definition 2.2. A subset A of an ideal topological space (X, τ, I) is said to be I-nowhere dense if $int(cl^*(A)) = \phi$.

Observe that if A is rare, then a t-I-set (resp. t-set) is I-nowhere dense (resp. nowhere dense). Recall that a set A of X is rare if it has no interior points. Also notice that if A is rare, then b-I-open sets and b-open sets are pre-I-open and preopen, respectively.

Definition 2.3. A function $f : (X, \tau, I) \to (Y, \sigma)$ is said to be

1. *semi-I-continuous* [6] if for every $V \in \sigma$, $f^{-1}(V)$ is *semi-I-open*,
2. *pre-I-continuous* [5] if for every $V \in \sigma$, $f^{-1}(V)$ is *pre-I-open*,
3. *b-I-continuous* [3] if for every $V \in \sigma$, $f^{-1}(V)$ is *b-I-open*,
4. A_I-*continuous* [11] if for every $V \in \sigma$, $f^{-1}(V)$ is A_I-set,
5. B_I-*continuous* [6] if for every $V \in \sigma$, $f^{-1}(V)$ is B_I-set.
6. I-locally *continuous* [5] if for every $V \in \sigma$, $f^{-1}(V)$ is I-locally *closed*,
7. strongly *pre-I-continuous* [17] if for every $V \in \sigma$, $f^{-1}(V)$ is strongly *pre-I-open* and
8. strongly *b-I-continuous* [4] if for every $V \in \sigma$, $f^{-1}(V)$ is strongly *b-I-open*.

3 Stongly α-I-*Open* Sets

Definition 3.1. A subset A of an ideal space (X, τ, I) is said to be strongly α-*I-open* set if A is *b-I-open* as well as a B_I-set.

The family of all strongly α-*I-open* sets in (X, τ, I) is denoted by S-$\alpha IO(X, \tau)$ or S-$\alpha IO(X)$. For a subset A of (X, τ, I), $int_{s\alpha}(A)=\bigcup\{U \subset A, U \in S\text{-}\alpha IO(X, \tau)\}$. Clearly $\tau \subset S$-$\alpha IO(X) \subset \alpha IO(X)$. The following examples 3.2 and 3.3 show that these inclusions are not reversible.

Example 3.2. Let $X = \{a, b, c, d\}$, $\tau = \{X, \phi, \{a\}, \{c\}, \{a, c\}\}$ and $I = \{\phi, \{a\}\}$. If $A = \{c\}$, then $A^* = \{b, c, d\}$ and so $int(cl^*(int(A))) = int(cl^*(\{c\})) = int(\{b, c, d\}) = \{c\} = A$. Therefore A is α-*I-open*. Since X is the only open set containing A, $A = X \cap A$ is the only possibility to write A as the intersection with X. Since $int(cl^*(A)) = int(cl^*(\{c\})) = int(\{b, c, d\}) = int(A)$. This shows that A is a B_I-set and hence A is strongly α-*I-open* set, but A is not *I-open*. This shows the existence of non trivial strongly α-*I-open* sets.

Example 3.3. Let $X = \{a,b,c,d\}$, $\tau = \{X, \phi, \{a\}, \{c\}, \{a,c\}\}$ and $I = \{\phi, \{a\}\}$. If $A = \{a,b,c\}$, then $A^* = \{a,c,d\}$ and so $int(cl^*(int(A))) = int(cl^*(\{a,c\})) = int(X) = X \supset A$. Therefore A is α-*I-open*. Since X is the only open set containing A, $A = X \cap A$ is the only possibility to write A as the intersection with X. Since $int(cl^*(A)) = int(cl^*(\{a,b,c\})) = int(X) = X \neq int(A)$, A is not a B_I-set and hence A is not a strongly α-*I-open* set.

The following example shows that α-*I-open* sets and B_I sets are independent concepts.

Example 3.4. Consider the ideal space (X, τ, I) of Example 3.3.
(a) If $A = \{a,b,d\}$, then $int(A) = \{a\}$ and $int(cl^*(int(A))) = int(cl^*(\{a\})) = int(\{a\})$ does not contains A. Therefore A is not a α-I-open set. But $int(cl^*(A)) = int(cl^*(\{a,b,d\})) = int(\{a,b,d\}) = \{a\} = int(A)$ and $A = X \cap A$. Therefore A is a B_I-set.
(b) If $B = \{a,b,c\}$, then $int(B) = \{a,c\}$ and so $int(cl^*(int(B))) = int(cl^*(\{a,c\})) = X \supset B$. Therefore B is α-*I-open* set. But B is not a B_I-set, since $int(cl^*(B)) = int(X) = X \neq int(B)$.

Theorem 3.5. Every strongly α-*I-open* set is strongly *pre-I-open*.
Proof. It follows from the fact that every α-*I-open* set is *pre-I-open* and let A be a B_I set. Then $A = U \cap V$, where $U \in \tau$ and V is a *t-I*-set. Then $int(V) = int(cl^*(V)) \supset int(cl^*(int(V))) \supset int(V)$ and hence $int(V) = int(cl^*(int(V)))$. This shows that A is a C_I-set. Therefore A is strongly *pre-I-open* set.

The converse of the above theorem need not be true by the following example.

Example 3.6. Consider R, the set of all real numbers with the usual topology and the ideal I_f consisting of all finite subsets of R. If $A = Q$, the set of all rational numbers, then $A^* = R$. Since $int(cl^*(A)) = R \supset A$, A is *pre-I-open*. Since $A = R \cap A$ where R is *open* and $int(cl^*(int(A))) = \phi = int(A)$, it follows that A is strongly *pre-I-open* but A is not strongly α-*I-open*, since $int(cl^*(int(A))) = \phi$ does not contains A.

Theorem 3.7. Every strongly α-*I-open* set is strongly *b-I-open*.
Proof. It follows from Theorem 3.5. and [4, Theorem 3.7].

The converse of the above theorem need not be true by the following example.

Example 3.8. Let $X = \{a,b,c\}$, $\tau = \{X, \phi, \{a\}, \{b\}, \{a,b\}\}$ and $I = \{\phi, \{b\}\}$. Then $A = \{a,c\}$ is strongly *b-I-open*, but it is not strongly α-*I-open*. For $int(cl^*(A)) \cup cl^*(int(A)) = int(\{a,c\}^* \cup \{a,c\}) \cup cl^*(\{a\}) = \{a,c\} \supset A$. Therefore, A is *b-I-open*. Since X is the only *open* set containing A, $A = X \cap A$ is the only possibility to write A as the intersection with X. Since $int(cl^*(int(A))) = int(cl^*(\{a\})) = int(\{a,c\}) = int(A)$ and hence A is strongly *b-I-open* set. Since $int(cl^*(int(A))) = int(cl^*(\{a\})) = int(\{a,c\}) = \{a\}$ is not contains A. Hence A is not strongly α-I-*open*.

Proposition 3.9. Let (X, τ, I) be an ideal topological space. A subset A of X is I-locally closed set if A is both *open* and A_I-set.
Proof. Let A be an *open* and A_I-set, then $A = G \cap V$, where $G \in \tau$ and $V = (int(V))^* = V^*$. This shows that A is I-locally closed set.

Observe that if V is rare, then A is empty.

The following theorem gives a characterization of *open* sets in terms of strongly α-I-*open* sets and A_I-sets.

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

(a) *A is open.*

(b) *A is open, strongly α-I-open and A_I-set.*

(c) *A is strongly α-I-open and I-locally closed set.*

(d) *A is strongly pre-I-open and I-locally closed set.*

(e) *A is strongly pre-I-open and A_I-set.*

Proof.
(a) $\Rightarrow$ (b) is obvious.
(b) $\Rightarrow$ (c) It follows from Proposition 3.9.
(c) $\Rightarrow$ (d) It follows from Theorem 3.5.
(d) $\Rightarrow$ (e) If A is I-locally closed, then $A = G \cap A^*$ for some *open* set G. Since $A \subset A^*$, by [17, Lemma 2.5] $A^* = cl^*(A)$. Now $A \subset int(cl^*(A)) = int(A^*)$ and so $A^* \subset (int(A^*))^* \subset (A^*)^* \subset A^*$. Therefore $A^* = (int(A^*))^*$ which implies that A is an A_I set.
(e) $\Rightarrow$ (a) Suppose A is strongly *pre-I-open* and A_I-set.

$$\begin{aligned} A &\subset int(cl^*(A)) \\ &= int(cl^*(U \cap V)) \end{aligned}$$

where U is *open* and $V = (int(V))^*$. By [10, Theorem 2.1.]

$$\begin{aligned} A &\subset U \cap (int(cl^*(V))) \\ &\subset U \cap int(V^*) \\ &\subset U \cap int(int(V))^* \\ &\subset U \cap int(cl^*(int(V))) \\ &\subset U \cap int(V) \\ &= int(A) \end{aligned}$$

Theorem 3.11. *Let (X, τ, I) be an ideal topological space. A subset A of (X, τ, I) is pre-I-open and B_I-set if A is strongly α-I-open.*
Proof. Let A be strongly α-*I-open* set. Since every α-*I-open* set is *pre-I-open*, then A is *pre-I-open* and B_I-set.

Theorem 3.12. *Let (X, τ, I) be an ideal topological space. A subset A of (X, τ, I) is strongly α-I-open if and only if it is semi-I-open, pre-I-open and B_I-set.*
Proof.
Necessity. It follows from the fact that every α-*I-open* set is *semi-I-open* and *pre-I-open*.
Sufficiency. Let A be *semi-I-open*, *pre-I-open* and B_I-set. Then, we have $A \subset int(cl^*(A)) \subset int(cl^*(cl^*(int(A)))) = int(cl^*(int(A)))$. This shows that A is α-*I-open* set and also A is B_I-set. Therefore A is a strongly α-*I-open* set.

4 Strongly α-I-Ccontinuous Maps

Definition 4.1. A mapping $f : (X, \tau, I) \to (Y, \sigma)$ is said to be strongly α-*I-continuous* if for every $V \in \sigma$, $f^{-1}(V)$ is strongly α-*I-open*.

Theorem 4.2. *Every strongly α-I-continuous map is strongly pre-I-continuous.*
Proof. It follows from Theorem 3.5.

Theorem 4.3. *Every strongly α-I-continuous map is strongly b-I-continuous.*
Proof. It follows from Theorem 3.7.

Theorem 4.4. *Let $f : (X, \tau, I) \to (Y, \sigma)$ be any mapping. Then f is I-locally continuous map if it is both continuous and A_I-continuous.*
Proof. It follows from Proposition 3.9.

Theorem 4.5. *Let $f : (X, \tau, I) \to (Y, \sigma)$ be any mapping. Then the following conditions are equivalent.*

(a) *f is continuous.*

(b) *f is continuous, strongly α-I-continuous and A_I-continuous.*

(c) *f is strongly α-I-continuous and I-locally continuous.*

(d) *f is strongly pre-I-continuous and I-locally continuous.*

(e) *f is strongly pre-I-continuous and A_I-continuous.*

Proof. It follows from Theorem 3.10.

Theorem 4.6. *Let $f : (X, \tau, I) \to (Y, \sigma)$ be any mapping. Then f is pre-I-continuous and B_I-continuous if f is strongly α-I-continuous.*
Proof. It follows from Theorem 3.11.

Theorem 4.7. *Let $f : (X, \tau, I) \to (Y, \sigma)$ be any mapping. Then f is strongly α-I-continuous if and only if it is semi-I-continuous, pre-I-continuous and B_I-continuous.*
Proof. It follows from Theorem 3.12. **Definition 4.8.** A mapping $f : (X, \tau, I) \to (Y, \sigma, I)$ is said to be strongly α-*I-irresolute* if $f^{-1}(V)$ is strongly α-*I-open* in X for every strongly α-*I-open* set V of Y.

Theorem 4.9. *Let $f : (X, \tau, I) \to (Y, \sigma)$ and $g : (Y, \sigma) \to (Z, \eta)$ be mappings. Then the composition $g \circ f : X \to Z$ is strongly α-I-continuous if g is continuous and f is strongly α-I-continuous.*
Proof. Let W be any *open* subset of Z. Since g is *continuous*, $g^{-1}(W)$ is *open* in Y. Since f is strongly α-*I-continuous*, then $(g \circ f)^{-1}(W) = f^{-1}(g^{-1}(W))$ is strongly α-*I-open* in X and hence $g \circ f$ is strongly α-*I-continuous*.

Theorem 4.10. *Let $f : (X, \tau, I_1) \to (Y, \sigma, I_2)$ and $g : (Y, \sigma, I_2) \to (Z, \eta, I_3)$ be mappings. Then the composition $g \circ f : X \to Z$ is strongly α-I-continuous if g is strongly α-I-continuous and f is strongly α-I-irresolute.*
Proof. Let W be any *open* subset of Z. Since g is strongly α-*I-continuous*, $g^{-1}(W)$ is strongly α-*I-open* in Y. Since f is strongly α-*I-irresolute*, then $(g \circ f)^{-1}(W) = f^{-1}(g^{-1}(W))$ is strongly α-*I-open* in X and hence $g \circ f$ is strongly α-*I-continuous*.

Theorem 4.11. *Let $f : (X, \tau, I_1) \to (Y, \sigma, I_2)$ and $g : (Y, \sigma, I_2) \to (Z, \eta, I_3)$ be mappings. Then the composition $g \circ f : X \to Z$ is strongly α-I-irresolute if both f and g are strongly α-I-irresolute.*
Proof. Let W be any strongly α-*I-open* subset of Z. Since g is strongly α-*I-irresolute*, $g^{-1}(W)$ is strongly α-*I-open* in Y. Since f is strongly α-*I-irresolute*, then $(g \circ f)^{-1}(W) = f^{-1}(g^{-1}(W))$ is strongly α-*I-open* in X and hence $g \circ f$ is strongly α-*I-irresolute*.

Definition 4.12. [15] Let A be a subset of a space (X, τ) then the set $\cap\{U \in \tau : A \subset U\}$ is called the kernel of A and denoted by $ker(A)$.

Lemma 4.13. [7] *Let A be a subset of a space (X, τ), then*

(a) *$x \in ker(A)$ if and only if $A \cap F \neq \phi$ for any closed subset F of X with $x \in F$;*

(b) *$A \subset ker(A)$ and $A = ker(A)$ if A is open in X;*

(c) *if $A \subset B$, then $ker(A) \subset ker(B)$.*

Definition 4.14. Let N be a subset of a space (X, τ, I) and $x \in X$. Then N is called strongly α-I-neighbourhood of x, if there exists a strongly α-*I-open* set U containing x such that $U \subset N$.

Theorem 4.15. *The following statements are equivalent for a mapping $f : (X, \tau, I) \to (Y, \sigma)$.*

1. f *is strongly α-I-continuous.*

2. *for each $x \in X$ and each open set V in Y with $f(x) \in V$, there exists a strongly α-I-open set U containing x such that $f(U) \subset V$.*

3. *for each $x \in X$ and each open set V in Y with $f(x) \in V$, $f^{-1}(V)$ is a strongly α-I-neighbourhood of x.*

Proof.
(1) $\Rightarrow$ (2) Let $x \in X$ and V be an *open* set in Y such that $f(x) \in V$. Since f is strongly α-I-*continuous*, $f^{-1}(V)$ is a strongly α-I-*open* containing x. Set $U = f^{-1}(V)$. Then we have $f(U) \subset V$.
(2) $\Rightarrow$ (3) Let V be an *open* set in Y and let $f(x) \in V$. Then by (2), there exists a strongly α-I-*open* set U containing x such that $f(U) \subset V$. So $x \in U \subset f^{-1}(V)$. Hence $f^{-1}(V)$ is a strongly α-I-neighbourhood of x.
(3) $\Rightarrow$ (1) Let V be an *open* set in Y and let $f(x) \in V$ then by (3), $f^{-1}(V)$ is a strongly α-I-neighbourhood of x. Thus for each $x \in f^{-1}(V)$ there exists a strongly α-I-*open* set U_x containing x such that $x \in U_x \subset f^{-1}(V)$. Hence $f^{-1}(V) \subset \cup_{x \in f^{-1}(V)} U_x$ so $f^{-1}(V) \in S\text{-}\alpha IO(X)$.

Theorem 4.16. *The following mappings are equivalent for a mapping $f : (X, \tau, I) \to (Y, \sigma)$.*

1. f *is strongly α-I-continuous.*

2. *for every subset A of X, $f(int_{s\alpha} I(A)) \subset ker(f(A))$.*

3. *for every subset B of Y, $int_{s\alpha} I(f^{-1}(B)) \subset f^{-1}(ker(B))$.*

Proof.
(1) $\Rightarrow$ (2) Let A be any subset of X. Suppose that $y \notin ker(f(A))$. Then by Lemma 4.13. there exists a *closed* subset F of Y such that $y \in F$ and $f(A) \cap F = \phi$. Thus we have $A \cap f^{-1}(F) = \phi$ and $(int_{s\alpha}(I(A))) \cap f^{-1}(F) = \phi$. Therefore, we obtain $f(int_{s\alpha}(I(A))) \cap F = \phi$ and $y \notin f(int_{s\alpha} I(A))$. This implies that $f(int_{s\alpha} I(A)) \subset ker(A)$.
(2) $\Rightarrow$ (3) Let B be any subset of Y by (2) and Lemma 4.13., we have $f(int_{s\alpha} I(f^{-1}(B))) \subset ker(f(f^{-1}(B))) \subset ker(B)$ and $int_{s\alpha} I(f^{-1}(B)) \subset f^{-1}(ker(B))$.
(3) $\Rightarrow$ (1) Let V be an *open* set of Y. Then by Lemma 4.13. and (3), we have $int_{s\alpha} I(f^{-1}(V)) \subset f^{-1}(ker(V)) = f^{-1}(V)$ and $int_{s\alpha} I(f^{-1}(V)) = f^{-1}(V)$. This implies $f^{-1}(V)$ is strongly α-I-*open*.

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