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DECOMPOSITIONS OF πg-CONTINUITY VIA IDEAL NANO TOPOLOGICAL SPACES

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ABSTRACT. In this paper, we introduce and discuss some notions of $I_{n\pi g}$-closed sets, $I_{n\pi g}$-continuity in ideal nano spaces.

1. INTRODUCTION AND PRELIMINARIES

According to [14], an ideal I on a topological space (X, τ) is a non-empty collection of subsets of X which satisfies the following conditions.

(i) $A \in I$ and $B \subseteq A$ imply $B \in I$ and
(ii) $A \in I$ and $B \in I$ imply $A \cup B \in I$.

Given a topological space (X, τ) with an ideal I on X. If $\wp(X)$ is the family of all subsets of X, a set operator $(.)^\star : \wp(X) \to \wp(X)$, called a local function of A with respect to τ and I is defined as follows: for $A \subset X$, $A^\star(I, \tau) = \{x \in X : U \cap A \notin I \text{ for every } U \in \tau(x)\}$ where $\tau(x) = \{U \in \tau : x \in U\}$, [3].

The closure operator defined by $cl^\star(A) = A \cup A^\star(I, \tau)$, [13] is a Kuratowski closure operator which generates a topology $\tau^\star(I, \tau)$ called the $\star$-topology finer than τ. The topological space together with an ideal on X is called an ideal topological space or an ideal space denoted by (X, τ, I). We will simply write $A^\star$ for $A^\star(I, \tau)$ and $\tau^\star$ for $\tau^\star(I, \tau)$.

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In this paper, we introduce and discuss some notions of $I_{n\pi g}$-closed sets, $I_{n\pi g}$-continuity in ideal nano spaces.

We denote a nano topological space by $(U, \mathcal{N})$, where $\mathcal{N} = \tau_R(X)$. The nano-interior, nano-closure and nano α-closure of a subset A of U are denoted by $I_n(A)$, $C_n(A)$ and $C_{n\alpha}(A)$, respectively.

An ideal nanotopological space is denoted by $(U, \mathcal{N}, I)$. The nano-interior and nano-closure of a subset A of U are denoted by $I_n^\star(A)$ and $C_n^\star(A)$, respectively.

Definition 1.1. *A subset A of a space $(U, \mathcal{N})$ is called*

(i) *nano α-open if $A \subseteq I_n(C_n(I_n(A)))$, [4];*
(ii) *nano semi-open if $A \subseteq C_n(I_n(A))$, [4];*
(iii) *nano pre-open if $A \subseteq I_n(C_n(A))$, [4];*
(iv) *nano b-open if $A \subseteq I_n(C_n(A)) \cup C_n(I_n(A))$, [5];*
(v) *nano β-open if $A \subseteq C_n(I_n(C_n(A)))$, [12].*

The complements of the above mentioned sets are called their respective closed sets.

Definition 1.2. *[4] A subset A of a nano space $(U, \mathcal{N})$ is called nano regular-open(written in short as nr-open) $A = I_n(C_n(A))$.*

The complement of nr-open set is said to be a nr-closed set.

Definition 1.3. *[1] Let A be a subset of a space $(U, \mathcal{N})$ is nano π-open(written in short as $n\pi$-open) if the finite union of nr-open sets.*

The complement of $n\pi$-open set is said to be a $n\pi$-closed set.

Definition 1.4. *A subset A of a space $(U, \mathcal{N})$ is called*

(i) *nano g-closed (written in short as ng-closed) if $C_n(A) \subseteq B$, whenever $A \subseteq B$ and B is n-open, [2];*
(ii) *nano πg-closed (written in short as $n\pi g$-closed) if $C_n(A) \subseteq B$, whenever $A \subseteq B$ and B is $n\pi$-open, [9];*
(iii) *nano αg-closed (written in short as $n\alpha g$-closed) if $C_{n\alpha}(A) \subseteq B$, whenever $A \subseteq B$ and B is n-open, [9];*
(iv) *nano $\pi g\alpha$-closed (written in short as $n\pi g\alpha$-closed) if $C_{n\alpha}(A) \subseteq B$ whenever $A \subseteq B$ and B is $n\pi$-open, [10].*

The complements of the above mentioned sets are called their respective open sets.

Definition 1.5. *[6] A subset A of a space $(U, \mathcal{N}, I)$ is $n\star$-dense in itself (resp. $n\star$-perfect and $n\star$-closed) if $A \subseteq A_n^\star$ (resp. $A = A_n^\star$, $A_n^\star \subseteq A$).*

The complement of a $n\star$-closed set is said to be a $n\star$-open set.

Definition 1.6. *[7] An ideal I in a space $(U, \mathcal{N}, I)$ is called $\aleph$-codense ideal if $\aleph \cap I = \{\phi\}$.*

Definition 1.7. *[11] A subset A of space $(U, \mathcal{N}, I)$ is said to be*

(i) *nano α-I-open (written in short as α-nI-open) if $A \subseteq I_n(C_n^\star(I_n(A)))$,*
(ii) *nano semi-I-open (written in short as semi-nI-open) if $A \subseteq C_n^\star(I_n(A))$,*
(iii) *nano pre-I-open (written in short as pre-nI-open) if $A \subseteq I_n(C_n^\star(A))$,*
(iv) *nano b-I-open (written in short as b-nI-open) if $A \subseteq I_n(C_n^\star(A)) \cup C_n^\star(I_n(A))$,*
(v) *nano β-I-open (written in short as β-nI-open) if $A \subseteq C_n^\star(I_n(C_n^\star(A)))$.*

The complements of the above mentioned sets are called their respective closed sets.

Definition 1.8. *A subset A of a space $(U, \mathcal{N}, I)$ is called a*

(i) *nano I_g-closed (written in short as I_{ng}-closed) if $A_n^\star \subseteq B$ whenever $A \subseteq B$ and B is n-open, [6];*
(ii) *nano I_ω-closed (or) nano $I_{\hat{g}}$-closed(written in short as $I_{n\omega}$-closed) if $A_n^\star \subseteq B$ whenever $A \subseteq B$ and B is ns-open, [8].*

The complements of the above mentioned sets are called their respective open sets.

2. πg-CLOSED SETS IN IDEAL NANOTOPOLOGICAL SPACES

Definition 2.1. *A subset A of an ideal nano space $(U, \mathcal{N}, I)$ is called a nano $I_{\pi g}$-closed (written in short as $I_{n\pi g}$-closed) if $A \subseteq H$, $H \in n\pi$-open $\Longrightarrow A_n^\star \subseteq H$.*

Nano $I_{\pi g}$-open (written in short as $I_{n\pi g}$-open) if $\mathcal{A} = H - A$ (where $\mathcal{A}$ denotes the complement operator and A is $I_{n\pi g}$-closed).

Definition 2.2. *A subset A of an ideal nano space $(U, \mathcal{N}, I)$ is called a*

(i) *nano $\mathfrak{D}_I$-set if $A = H \cap V$, where H is a $n\pi$-open set and V is a $n\star$-perfect set.*
(ii) *nano $\mathfrak{B}_I$-set if $A = H \cap V$, where H is a $n\pi$-open set and V is a $n\star$-closed set.*

Theorem 2.1. *Each $n\pi g$-closed set is $I_{n\pi g}$-closed.*

Proof. Let A be a every $n\pi g$- closed set. Then $A \subseteq H$, $H \in n\pi$-open $\Longrightarrow C_n(A) \subseteq H$. Since $A_n^\star \subseteq C_n(A) \subseteq H$, we have $A_n^\star \subseteq H$ and hence A is $I_{n\pi g}$-closed. □

Theorem 2.2. *If $(U, \mathcal{N}, I)$ is any ideal nano space and $A \subseteq U$, then the following hold.*

(i) *If $I = \phi$, then A is $I_{n\pi g}$-closed $\iff$ A is $n\pi g$-closed.*
(ii) *If $I = \aleph$, then A is $I_{n\pi g}$-closed $\iff$ A is $n\pi g\alpha$-closed.*

Proof. The proof follows from the fact that $A_n^\star(\{\phi\}) = C_n(A)$ and $A_n^\star(\aleph) = C_{n\alpha}(A)$. □

Theorem 2.3. *If A and B is $I_{n\pi g}$-closed then $A \cup B$ is $I_{n\pi g}$-closed.*

Proof. Suppose that $A \cup B \subseteq H$ and H is $n\pi$-open, then $A, B \subseteq H$. Since A and B are $I_{n\pi g}$-closed, $A_n^\star \subseteq H$ and $B_n^\star \subseteq H$. $(A \cup B)_n^\star = A_n^\star \subseteq B_n^\star$, $(A \cup B)_n^\star = A_n^\star \cup B_n^\star \subseteq H$. Thus, $A \cup B$ is also $I_{n\pi g}$-closed. □

Theorem 2.4. *If a subset A of $(U, \mathcal{N}, I)$ is $I_{n\pi g}$-closed, then $C_n^\star(A) - A$ contains no nonempty $n\pi$-closed set.*

Proof. Suppose that A is $I_{n\pi g}$-closed and F be a $n\pi$-closed subset of $C_n^\star(A) - A$. Then $A \subseteq U - F$. Since $U - F$ is $n\pi$-open and A is $I_{n\pi g}$-closed, $C_n^\star(A) \subseteq U - F$.

Consequently, $F \subseteq U - C_n^\star(A)$. We have $F \subseteq C_n^\star(A)$. Thus, $F \subseteq C_n^\star(A) \cap (U - C_n^\star(A)) = \phi$ and so $C_n^\star(A) - A$ contains no nonempty $n\pi$-closed set. □

Corollary 2.1. *Let $(U, \mathcal{N}, I)$ be an ideal nano space and A be an $I_{n\pi g}$-closed set. Then the following are equivalent.*

(i) *A is a $n\star$-closed set.*
(ii) *$C_n^\star(A) - A$ is a $n\pi$-closed set.*
(iii) *$A_n^\star - A$ is a $n\pi$-closed set.*

Proof. (i) $\Longrightarrow$ (ii) : If A is $n\star$-closed set, then $C_n^\star(A) - A = \phi$ and so $C_n^\star(A) - A$ is $n\pi$-closed.

(ii) $\Longrightarrow$ (i) : suppose $C_n^\star(A) - A$ is $n\pi$-closed. Since A is $I_{n\pi g}$-closed, By Theorem 2.4 $C_n^\star(A) - A = \phi$ and so A is $n\star$-closed.

(ii) $\Leftrightarrow$ (iii) : Follows from the fact that $C_n^\star(A) - A = A_n^\star - A$. □

Theorem 2.5. *In a space $(U, \mathcal{N}, I)$, every subset is $I_{n\pi g}$-closed $\iff$ every $n\pi$-open set is $n\star$-closed.*

Proof. Suppose every subset of U is $I_{n\pi g}$-closed. If H is $n\pi$-open then by hypothesis, H is $I_{n\pi g}$-closed and so $H_n^\star \subseteq H$. Hence, H is $n\star$-closed.

Conversely, suppose every $n\pi$-open set is $n\star$-closed. Let A be a subset of U. If H is a $n\pi$-open set such that $A \subseteq H$ then $A_n^\star \subseteq H_n^\star \subseteq H$ and so A is $I_{n\pi g}$-closed. □

Remark 2.1. *If A is $n\pi$-open and $I_{n\pi g}$-closed, then A is $n\star$-closed.*

Theorem 2.6. *For each $x \in (U, \mathcal{N}, I)$ either $\{x\}$ is $n\pi$-closed or $\{x\}^c$ is $I_{n\pi g}$-closed.*

Proof. Suppose that $\{x\}$ is not $n\pi$-closed, then $\{x\}^c$ is not $n\pi$-open and the only $n\pi$-open set containing $\{x\}^c$ is the space $(U, \mathcal{N}, I)$ itself.

Therefore, $C_n^\star(\{x\}^c) \subseteq U$ and so $\{x\}^c$ is $I_{n\pi g}$-closed. □

Theorem 2.7. *If A is an $I_{n\pi g}$-closed set such that $A \subseteq B \subseteq A_n^\star$, then B is also an $I_{n\pi g}$-closed set.*

Proof. Let H be any $n\pi$-open set such that $B \subseteq H$, then $A \subseteq H$. Since A is $I_{n\pi g}$-closed, we have $A_n^\star \subseteq H$. Now, $B_n^\star \subseteq (A_n^\star)_n^\star \subseteq A_n^\star \subseteq H$. Therefore, B is $I_{n\pi g}$-closed. □

Theorem 2.8. *A subset A of an ideal nano space $(U, \mathcal{N}, I)$ is $I_{n\pi g}$-open $\iff$ $F \subseteq I_n^\star(A)$ whenever F is $n\pi$-closed and $F \subseteq A$.*

Proof. Suppose that $F \subseteq I_n^\star(A)$ whenever F is $n\pi$-closed and $F \subseteq A$. Let $A^c \subseteq H$, whenever H is $n\pi$-open. Then $H^c \subseteq A$ and H^c is $n\pi$-closed, therefore $H^c \subseteq I_n^\star(A)$, which implies that $C_n^\star(A^c) \subseteq H$. Hence, A^c is $I_{n\pi g}$-closed and so A is $I_{n\pi g}$-open. Conversely, suppose that A is $I_{n\pi g}$-open, $F \subseteq A$ and F is $n\pi$-closed. Then F^c is $n\pi$-open and $A^c \subseteq F^c$. Therefore, $C_n^\star(A^c) \subseteq F^c$ and so $F \subseteq I_n^\star(A)$. □

Theorem 2.9. *A subset A of an ideal nano space $(U, \mathcal{N}, I)$ is a nano $\mathfrak{D}_I$-set and a $I_{n\pi g}$-closed set, then A is a $n\star$-closed set.*

Proof. Let A be a nano $\mathfrak{D}_I$-set and a $I_{n\pi g}$-closed set. Since A is a nano $\mathfrak{D}_I$-set, $A = H \cap V$, where H is a $n\pi$-open set and V is a $n\star$-perfect set. Now, $A = H \cap V \subseteq H$ and A is a $I_{n\pi g}$-closed set implies that $A_n^\star \subseteq H$. Also, $A = H \cap V \subseteq V$ and V is $n\star$-perfect set implies that $A_n^\star \subseteq V$. Thus, $A_n^\star \subseteq H \cap V = A$. Hence, A is a $n\star$-closed set. □

Theorem 2.10. *For a subset A of an ideal nano space $(U, \mathcal{N}, I)$, A is a $n\star$-closed set $\iff$ A is a nano $\mathfrak{B}_I$-set and a $I_{n\pi g}$-closed set.*

Proof. Assuming that A is a $n\star$-closed set and $A = U \cap V$, where U is $n\pi$-open set and V is a $n\star$-closed set. Hence, A is a nano $\mathfrak{B}_I$-set. Suppose that A is a $n\star$-closed set and H is a $n\pi$-open set such that $A \subseteq H$. Then $A_n^\star \subseteq H$ and hence A is a $I_{n\pi g}$-closed set.

Conversely, let A be a nano $\mathfrak{B}_I$-set and a $I_{n\pi g}$-closed set. Since A is a nano $\mathfrak{B}_I$-set, $A = H \cap V$, where H is a $n\pi$-open set and V is a $n\star$-closed set. Now, $A \subseteq H$ and A is a $I_{n\pi g}$-closed set implies that $A_n^\star \subseteq H$. Also, $A \subseteq V$ and V is a $n\star$-closed set implies that $A_n^\star \subseteq V$. Thus, $A_n^\star \subseteq H \cap V = A$. Hence, A is a $n\star$-closed set. □

3. On nano $I_{\pi g}$-continuous maps

Definition 3.1. *A map $f : (U, \mathcal{N}, I) \to (F, \mathcal{X})$ is called nano $I_{\pi g}$-continuous (written in short as $I_{n\pi g}$-continuous) if $f^{-1}(A)$ is $I_{n\pi g}$-closed in $(U, \mathcal{N}, I)$ for every n-closed set A of F.*

Definition 3.2. *A map $f : (U, \mathcal{N}) \to (F, \mathcal{X})$ is called a*

(i) *a nano π-space (written in short as $n\pi$-space) if $f(A)$ is $n\pi$-closed in $(F, \mathcal{X})$ for every $n\pi$-closed set A in $(U, \mathcal{N})$.*
(ii) *a nano regular map (written in short as nr-map) if $f^{-1}(A)$ is nr-closed in $(U, \mathcal{N})$ for every nr-closed set K of F.*

Theorem 3.1. *For a map $f : (U, \mathcal{N}, I) \to (F, \mathcal{X})$, the following hold.*

(i) *f is $n\pi g$-continuous $\Rightarrow$ f is $I_{n\pi g}$-continuous.*
(ii) *f is I_{ng}-continuous $\Rightarrow$ f is $I_{n\pi g}$-continuous.*

Definition 3.3. *A map $f : (U, \mathcal{N}, I) \to (F, \mathcal{X}, I)$ is called nano $I_{\pi g}$-irresolute (written in short as $I_{n\pi g}$-irresolute) if $f^{-1}(A)$ is $I_{n\pi g}$-closed in $(U, \mathcal{N}, I)$ for every $I_{n\pi g}$-closed set A of $(F, \mathcal{X}, I)$.*

Theorem 3.2. *If $f : (U, \mathcal{N}, I) \to (F, \mathcal{X}, I)$ is $I_{n\pi g}$-continuous and $n\pi$-space, then f is $I_{n\pi g}$-irresolute.*

Proof. Assume that A is $I_{n\pi g}$-closed in F. Let $f^{-1}(A) \subseteq H$, where H is $n\pi$-open in U. Then $(U - H) \subseteq f^{-1}(F - A)$ and hence $f(U - H) \subseteq F - A$. Since f is $n\pi$-space, $f(U - H)$ is $n\pi$-closed. Then, since $F - A$ is $I_{n\pi g}$-open. By Theorem 2.8, $f(U - H) \subseteq I_n^\star(F - A) = F - C_n^\star(A)$. Thus, $f^{-1}(C_n^\star(A)) \subseteq H$. Since f is $I_{n\pi g}$-continuous, $f^{-1}(C_n^\star(A))$ is $I_{n\pi g}$-closed. Therefore, $C_n^\star(f^{-1}(C_n^\star(A))) \subseteq H$

and hence $C_n^\star(f^{-1}(A)) \subseteq C_n^\star(f^{-1}(C_n^\star(A))) \subseteq H$ which proves that $f^{-1}(A)$ is $I_{n\pi g}$-closed and therefore f is $I_{n\pi g}$-irresolute. □

Definition 3.4. *A map $f : (U, \mathcal{N}, I) \to (F, \mathcal{X})$ is called almost nano $I_{\pi g}$-continuous (written in sort as almost $I_{n\pi g}$-continuous) if $f^{-1}(A)$ is $I_{n\pi g}$-closed in $(U, \mathcal{N}, I)$ for every A is n-regular closed in F.*

Theorem 3.3. *For a map $f : (U, \mathcal{N}, I) \to (F, \mathcal{X})$, the following are equivalent.*

(i) *f is almost $I_{n\pi g}$-continuous.*
(ii) *$f^{-1}(A) \in I_{n\pi g}$-open for every A is nr-open in F.*
(iii) *$f^{-1}(I_n^\star(C_n^\star(A))) \in I_{n\pi g}$-open for every $A \in \mathcal{X}$.*
(iv) *$f^{-1}(C_n^\star(I_n^\star(A))) \in I_{n\pi g}$-closed for every n-closed set A of F.*

Proof. (i) $\Longleftrightarrow$ (ii) : Obvious.

(ii) $\Longleftrightarrow$ (iii) : Assuming that A is n-regular open in F, we have $A = I_n(C_n(A))$ and $f^{-1}(I_n(C_n(A))) \in I_{n\pi g}$-open. Conversely, suppose $A \in \mathcal{X}$, we have $I_n(C_n(A)) \in$ n-regular open (F) and $f^{-1}(I_n(C_n(A))) \in I_{n\pi g}$-open.

(iii) $\Longleftrightarrow$ (iv) : Let A be a n-closed set in F. Then $F - A \in \mathcal{X}$. We have $f^{-1}(I_n(C_n(F - A))) = f^{-1}(F - (C_n(I_n(A)))) = U - f^{-1}(C_n(I_n(A))) \in I_{n\pi g}$-open. Hence, $f^{-1}(I_n(C_n(A))) \in I_{n\pi g}$-closed. Converse can be obtained similarly. □

Theorem 3.4. *The following hold for the maps $f : (U, \mathcal{N}, I) \to (F, \mathcal{X}, J)$ and $g : (F, \mathcal{X}, J) \to (G, \mathcal{M})$,*

(i) *$g \circ f$ is $I_{n\pi g}$-continuous, if f is almost $I_{n\pi g}$-continuous and g is completely nano continuous.*
(ii) *$g \circ f$ is $I_{n\pi g}$-continuous, if f is $I_{n\pi g}$-continuous and g is nano continuous.*
(iii) *$g \circ f$ is $I_{n\pi g}$-continuous, if f is $I_{n\pi g}$-irresolute and g is $I_{n\pi g}$-continuous.*
(iv) *$g \circ f$ is almost $I_{n\pi g}$-continuous, if f is almost $I_{n\pi g}$-continuous and g is nano nr-map.*
(v) *$g \circ f$ is almost $I_{n\pi g}$-continuous, if f is $I_{n\pi g}$-irresolute and g is almost $I_{n\pi g}$-continuous.*
(vi) *$g \circ f$ is almost $I_{n\pi g}$-continuous, if f is $I_{n\pi g}$-continuous and g is almost $I_{n\pi g}$-continuous.*

Definition 3.5. *A map $f : (U, \mathcal{N}, I) \to (F, \mathcal{X})$ is called nano $\mathfrak{B}_I$-continuous (written in sort as $\mathfrak{B}_{nI}$-continuous) if $f^{-1}(A)$ is nano $\mathfrak{B}_I$-set in $(U, \mathcal{N}, I)$ for every n-closed set A of F.*

Theorem 3.5. *A map $f : (U, \mathcal{N}, I) \to (F, \mathcal{X})$ is $n\star$-continuous $\iff$ $\mathfrak{B}_{nI}$-continuous and $I_{n\pi g}$-continuous.*

Proof. This is an immediate consequence of Theorem 2.10. □

Remark 3.1. *The concepts of $\mathfrak{B}_{nI}$-continuity and the concepts of $I_{n\pi g}$-continuity are independent of each other as shown in the following Example.*

Example 1. *Let $U = \{a, b, c\}$ be a non empty finite set with*

(i) $U/R = \{\{a\}, \{b\}, \{c\}\}$ *and* $X = \{a, b\}$ *then* $\mathcal{N} = \{\phi, U, \{a\}, \{b\}, \{a, b\}\}$.
(ii) $U/R = \{\{a, b\}, \{c\}\}$ *and* $X = \{b, c\}$ *then* $\mathcal{X} = \{\phi, U, \{c\}, \{a, b\}\}$.
(iii) $U/R = \{\{b, c\}, \{a\}\}$ *and* $X = \{b, c\}$ *then* $\mathcal{M} = \{\phi, U, \{b, c\}\}$.

And let ideal be $I = \{\phi, \{c\}\}$.
In the ideal nano space $(U, \mathcal{N}, I)$, then

(i) *the identity function $F : (U, \mathcal{N}, I) \to (U, \mathcal{M})$ is $\mathfrak{B}_{nI}$-continuous but not -continuous.*
(ii) *the identity function $G : (U, \mathcal{X}, I) \to (U, \mathcal{M})$ is $I_{n\pi g}$-continuous but not $\mathfrak{B}_{nI}$-continuous.*

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