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On Antipodal Single Valued Neutrosophic Graph

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Abstract. In this paper we define Antipodal single valued neutrosophic graph and some Isomorphic properties of Antipodal single valued neutrosophic graph are discussed.

Keywords: Single valued neutosophic graph, antipodal single valued neutrosophic graph

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1. Introduction

Graph theory has been highly successful in certain academic fields, including natural sciences and engineering. Graph theoretic models can sometimes provide a useful structure upon which analytical techniques can be used. It is often convenient to depict the relationships between pairs of elements of a system by means of a graph or a digraph. The vertices of the graph represent the system elements and its edges or arcs represent the relationships between the elements. This approach is especially useful for transportation, scheduling, sequencing, allocation, assignment, and other problems which can be modelled as networks. Such a graph theoretic model is often useful as an aid in communicating. Zadeh introduced the concept of fuzzy set. Attanassov introduced the intuitionistic fuzzy sets which is a generalization of fuzzy sets. Fuzzy set theory and intuitionistic fuzzy sets theory are useful models for dealing with uncertainty and incomplete information. But they may not be sufficient in modeling of indeterminate and inconsistent information encountered in real world. In order to cope with this issue, neutrosophic set theory was proposed by Smarandache as a generalization of fuzzy sets and intuitionistic fuzzy sets. Neutrosophic set proposed by Smarandache is a powerful tool to deal with incomplete, indeterminate and inconsistent information in real world. It is a generalization of the theory of fuzzy set, intuitionistic fuzzy sets, interval-valued fuzzy sets and interval-valued intuitionistic fuzzy sets, then the neutrosophic set is characterized by a truth-membership degree (T), an indeterminacy-membership degree (I) and a falsity-membership degree (F) independently, which are within the real standard or nonstandard unit interval $]^-0, 1^+[$. There are some difficulties in modeling of some problems in Engineering and Sciences. To overcome these difficulties, in 2010, concept of single-valued neutrosophic sets and its operations were defined by Wang et al. as a generalization of intuitionistic fuzzy sets.

In crisp graph theory the concept of antipodal graph of a given graph G was introduced by Smith. In fuzzy graph theory the concept of antipodal fuzzy graph of a given fuzzy graph was introduced [1].

In this paper we define Antipodal single valued neutrosophic graph and some Isomorphic properties of Antipodal single valued neutrosophic graph are discussed.

2. Preliminaries
Definition 2.1. [5] Let G: (σ, μ) be a fuzzy graph with the underlying set V.
$A(G) : (\sigma A(G), \mu A(G))$ is defined as follows:

The node set of G is taken as the node set of A(G) also. Two nodes in A(G) are made as neighbors if the μ - distance between them is diam(G).i.e.,

$\sigma_{A(G)}(u) = \sigma(u)$ for all $u \in V$ and if $\delta(u,v) = \text{diam}(G)$ then

$\mu_{A(G)}(u,v) = \mu(u,v)$ if u and v are neighbors in G

$\qquad = \sigma(u) \wedge \sigma(v)$ if u and v are not neighbors in G

$\mu_{A(G)}(u,v) = 0$ otherwise.

This pair A(G) is a fuzzy graph, because $\sigma_{A(G)}(u) = \sigma(u)$ for all $u \in V$ implies $\sigma_{A(G)}$ is a fuzzy subset on V and by the definition of $\mu_{A(G)}$, it is a fuzzy relation on $\sigma_{A(G)}$, such that, $\mu_{A(G)}(u,v) \leq \sigma(u) \wedge \sigma(v) = \sigma_{A(G)}(u) \wedge \sigma_{A(G)}(v)$ for all u,v in V. This fuzzy graph A(G) is termed as Antipodal fuzzy graph of G.

Definition 2.2. [8] Let X be a space of points (objects). A neutrosophic set A in X is characterized by a truth-membership function $T_A(x)$, an indeterminacy-membership function $I_A(x)$ and a falsity-membership function $F_A(x)$. The functions $T_A(x)$, $I_A(x)$, and $F_A(x)$ are real standard or non-standard subsets of $]0^-, 1^+[$. That is, $T_A(x) : X \rightarrow]0^-, 1^+[$, $I_A(x) : X \rightarrow]0^-, 1^+[$ and $F_A(x) : X \rightarrow]0^-, 1^+[$ and $0^- \leq T_A(x) + I_A(x) + F_A(x) \leq 3^+$.

Definition 2.3. [7] A Single-Valued Neutrosophic graph(SVN graph)is a pair G = (A,B) of the crisp graph $G^* = (V, E)$(i.e., with underlying set V), where A : V $\rightarrow$ [0, 1] is single-valued neutrosophic set in V and B : V $\times$ V $\rightarrow$ [0, 1] is single-valued neutrosophic relation on V such that

$T_B(xy) \leq \min\{T_A(x), T_A(y)\}$,

$I_B(xy) \leq \min\{I_A(x), I_A(y)\}$,

$F_B(xy) \leq \max\{F_A(x), F_A(y)\}$

for all x, y $\in$ V . A is called single-valued neutrosophic vertex set of G and B is called single-valued neutrosophic edge set of G, respectively.
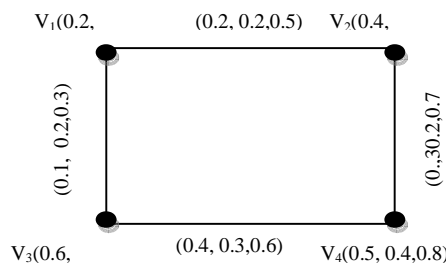
Example 1.

$V_1(0.2,$ $\qquad (0.2, 0.2, 0.5) \qquad V_2(0.4,$

$(0.1, 0.2, 0.3)$ $\qquad (0.,30.2,0.7)$

$V_3(0.6,$ $\qquad (0.4, 0.3, 0.6) \qquad V_4(0.5, 0.4, 0.8)$

Figure 1: Single valued neutrosophic graph

Definition 2.4. A partial single valued neutrosophic subgraph of a single valued neutrosophic graph $G = (A, B)$ is a single valued neutrosophic graph $H = (A', B')$ such that

i) $A' \subseteq A$ where $T_{A'}(v_i) \leq T_A(v_i)$, $I_{A'}(v_i) \leq I(v_i)$, $F_{A'}(v_i) \leq F_A(v_i)$ for all $v_i \in A'$

ii) $B' \subseteq B$ where $T_{B'}(v_i, v_j) \leq T_B(v_i, v_j)$, $I_{B'}(v_i, v_j) \leq I_B(v_i, v_j)$, $F_{B'}(v_i, v_j) \leq F_B(v_i, v_j)$ for every $(v_i, v_j) \in B'$.

Definition 2.5. A single valued neutrosophic subgraph of a single valued neutrosophic graph $G = (A, B)$ is a single valued neutrosophic graph $H = (A', B')$ such that

i) $A' \subseteq A$ where $T_{A'}(v_i) = T_A(v_i)$, $I_{A'}(v_i) = I(v_i)$, $F_{A'}(v_i) = F_A(v_i)$ for all $v_i \in A'$

ii) $B' \subseteq B$ where $T_{B'}(v_i, v_j) = T_B(v_i, v_j)$, $I_{B'}(v_i, v_j) = I_B(v_i, v_j)$, $F_{B'}(v_i, v_j) = F_B(v_i, v_j)$ for every $(v_i, v_j) \in B'$.

Definition 2.6. The two vertices are said to be adjacent in a single valued neutrosophic graph $G = (A, B)$ if $T_B(x,y) = \min\{T_A(x), T_A(y)\}$,

$\quad\quad I_B(x,y) = \min\{I_A(x), I_A(y)\}$,

$\quad\quad F_B(x,y) = \max\{F_A(x), F_A(y)\}$.

In this case, x and y are said to be neighbors and (x, y) is incident on x and y .

Definition 2.7. [7] A single-valued neutrosophic graph $G = (A,B)$ is called completeif the following conditions are satisfied:

$\quad\quad T_B(x,y) = \min\{T_A(x), T_A(y)\}$,

$\quad\quad I_B(x,y) = \min\{I_A(x), I_A(y)\}$,

$\quad\quad F_B(x,y) = \max\{F_A(x), F_A(y)\}$

for all x, y $\in V$.

Definition 2.8. [4] A single valued neutrosophic path P in a single valued neutrosophic graph $G=(A, B)$ is a sequence of distinct vertices $v_0, v_1, v_2, \dots v_n$ such that $T_B(v_{i-1}, v_i) > 0$, $I_B(v_{i-1}, v_i) > 0$ and $F_B(v_{i-1}, v_i) > 0$ for $0 \leq i \leq 1$. Here $n \geq 1$is called the length of the path P. The consecutive pairs (v_{i-1}, v_i) are called edges of the path.

$\quad\quad$ A single node or vertex v_i may also be considered as a path. In this case the path is of the length 0.

$\quad\quad$ We call P a cycle if $v_0 = v_n$ and$n \geq 3$.

Definition 2.9. [4] A single valued neutrosophic graph $G= (A, B)$ is said to be connected if every pair of vertices has at least one single valued neutrosophic path between them, otherwise it is disconnected.

Definition 2.10. Let G be a connected single valued neutrosophic graph.

$\quad\quad$ The T – distance$\delta(u, v)$, is the smallest T – length of any u – v path

$P : u = v_0, v_1, v_2, \dots v_n = v$ in G is $\ell_T(P) = \sum_{i=1}^{n} \frac{1}{T_B(v_{i-1}, v_i)}$, where $v_i \in V$,

i.e., $\delta_T(u, v) = \min(\ell_T(P))$.

$\quad\quad$ The I – distance $\delta(u, v)$, is the smallest I – length of any u – v path

$P : u = v_0, v_1, v_2, \dots v_n = v$ in G is $\ell_I(P) = \sum_{i=1}^{n} \frac{1}{I_B(v_{i-1}, v_i)}$, where $v_i \in V$,

i.e., $\delta_I(u, v) = \min(\ell_I(P))$.

The F – distance $\delta(u, v)$, is the smallest F – length of any $u - v$ path $P : u = v_0, v_1, v_2, \ldots v_n = v$ in G is $\ell_F(P) = \sum_{i=1}^{n} \frac{1}{F_B(v_{i-1}, v_i)}$, where $v_i \in V$,

i.e., $\delta_F(u, v) = \min(\ell_F(P))$.

The distance $\delta(u, v)$ is defined as $\delta(u, v) = \left(\delta_T(u, v), \delta_I(u, v), \delta_F(u, v) \right)$.

For each $v_i \in V$, the T – eccentricity of v_i is denoted by $e_T(v_i)$ and is defined as $e_T(v_i) = \max\{\delta_T(v_i, v_j) \mid v_j \in V, v_i \neq v_j\}$.

For each $v_i \in V$, the I – eccentricity of v_i is denoted by $e_I(v_i)$ and is defined as $e_I(v_i) = \max\{\delta_I(v_i, v_j) \mid v_j \in V, v_i \neq v_j\}$.

For each $v_i \in V$, the F – eccentricity of v_i is denoted by $e_F(v_i)$ and is defined as $e_F(v_i) = \max\{\delta_F(v_i, v_j) \mid v_j \in V, v_i \neq v_j\}$.

For each $v_i \in V$, the eccentricity of v_i is denoted by $e(v_i)$ and is defined as $e(v_i) = \left(e_T(v_i), e_I(v_i), e_F(v_i) \right)$.

The T – radius of G is denoted by $r_T(G)$ and is defined as $r_T(G) = \min\{e_T(v_i) \mid v_i \in V\}$.
The I – radius of G is denoted by $r_I(G)$ and is defined as $r_I(G) = \min\{e_I(v_i) \mid v_i \in V\}$.
The F – radius of G is denoted by $r_F(G)$ and is defined as $r_F(G) = \min\{e_F(v_i) \mid v_i \in V\}$.
The radius of G is denoted by $r(G)$ and is defined by $r(G) = (r_T(G), r_I(G), r_F(G))$.

The T – diameter of G is denoted by $d_T(G)$ and is defined as $d_T(G) = \max\{e_T(v_i) \mid v_i \in V\}$. The I – diameter of G is denoted by $d(G)$ and is defined as $d_I(G) = \max\{e_I(v_i) \mid v_i \in V\}$. The F – diameter of G is denoted by $d_F(G)$ and is defined as $d_F(G) = \max\{e_F(v_i) \mid v_i \in V\}$. The diameter of G is denoted by $d(G)$ and is defined by $d(G) = (d_T(G), d_I(G), d(G))$.

A connected single valued neutrosophic graph is a self centred graph, if every vertex of G is a central vertex, that is $r_T(G) = e_T(v_i), r_I(G) = e_I(v_i)$ and $r_F(G) = e_F(v_i)$.

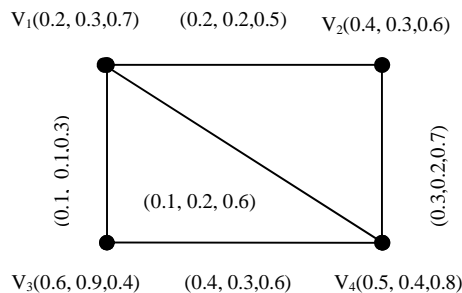**Example 2.** An SVN graph with $r(G) = (5.5, 5, 1.7)$, $d(G) = (10, 10, 3.3)$

$V_1(0.2, 0.3, 0.7)$ $(0.2, 0.2, 0.5)$ $V_2(0.4, 0.3, 0.6)$

$(0.1, 0.1, 0.3)$

$(0.1, 0.2, 0.6)$

$(0.3, 0.2, 0.7)$

$V_3(0.6, 0.9, 0.4)$ $(0.4, 0.3, 0.6)$ $V_4(0.5, 0.4, 0.8)$

Figure 2:

Definition 2.11. Let G and G′ be single valued neutrosophic graphs with underlying sets V and V′ respectively. A homomorphism of single valued neutrosophic graphs, $h : G \to G'$ is a map $h : V \to V'$ which satisfies

$T_A(u) \leq T_{A'}(h(u)), I_A(u) \leq I_{A'}(h(u)), F_A(u) \leq F_{A'}(h(u))$ for all $u \in V$
$T_B(u,v) \leq T_{A'}(h(u),h(v)), I_B(u,v) \leq I_{B'}(h(u),h(v)), F_B(u,v) \leq F_{B'}(h(u),h(v))$
for all $u, v \in V$.

Definition 2.12. Let G and G' be single valued neutrosophic graphs with underlying sets V and V' respectively. An isomorphism of single valued neutrosophic graphs, $h : G \rightarrow G'$ is a bijective map $h : V \rightarrow V'$ which satisfies
$T_A(u) = T_{A'}(h(u)), I_A(u) = I_{A'}(h(u)), F_A(u) = F_{A'}(h(u))$ for all $u \in V$
$T_B(u,v) = T_{B'}(h(u),h(v)), I_B(u,v) = I_{B'}(h(u),h(v)), F_B(u,v) = F_{B'}(h(u),h(v))$ for all $u, v \in V$.
Then G is said to be isomorphic to G'.

Definition 2.13. A weak isomorphism of single valued neutrosophic graphs, $h : G \rightarrow G'$ is a map $h : V \rightarrow V'$ which is a bijective homomorphism that satisfies
$\qquad T_A(u) = T_{A'}(h(u)), I_A(u) = I_{A'}(h(u)), F_A(u) = F_{A'}(h(u))$ for all $u \in V$

Definition 2.14. A co-weak isomorphism of single valued neutrosophic graphs, $h : G \rightarrow G'$ is a map $h : V \rightarrow V'$ which is a bijective homomorphism that satisfies $T_B(u,v) = T_{B'}(h(u),h(v)), I_B(u,v) = I_{B'}(h(u),h(v)), F_B(u,v) = F_{B'}(h(u),h(v))$ for all $u, v \in V$.

3. Main results
Definition 3.1. Let $G = (A,B)$ be a single valued neutrosophic graph. An *antipodal single valued neutrosophic graph* $A(G) = (P, Q)$ is a single valued neutrosophic graph of $G = (A,B)$ in which:
(a) An single valued neutrosophic vertex set of G is taken as single valued neutrosophic vertex set of $A(G)$, that is,
$\qquad T_P(x) = T_A(x),$
$\qquad I_P(x) = I_A(x),$
$\qquad F_P(x) = F_A(x)$ for all $x \in V$,
(b) If $\delta(x, y) = d(G)$, then x and y are made as neighbours in $A(G)$ such that
$\qquad T_Q(x,y) = T_B(x,y) \qquad\qquad$ if x and y are neighbors in G
$\qquad T_Q(x,y) = \min(T_A(x), T_A(y)) \qquad$ if x and y are not neighbors in G
$\qquad I_Q(x,y) = I_B(x,y) \qquad\qquad$ if x and y are neighbors in G
$\qquad I_Q(x,y) = \min(I_A(x), I_A(y)) \qquad$ if x and y are not neighbors in G
$\qquad F_Q(x,y) = F_B(x,y) \qquad\qquad$ if x and y are neighbors in G
$\qquad F_Q(x,y) = \max(F_A(x), F_A(y)) \qquad$ if x and y are not neighbors in G
That is, two vertices in $A(G)$ are made as neighborhood if the T,I,F –distance between them is diameter of G.

Example 3.2.

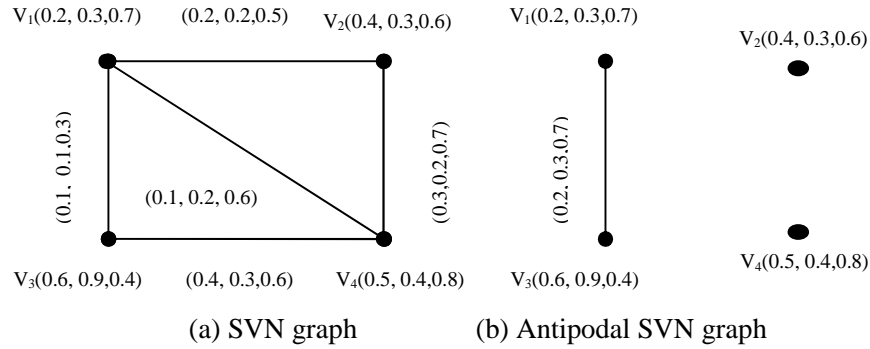
(a) SVN graph   (b) Antipodal SVN graph

Figure 3:

Theorem 3.3. Let $G = (A,B)$ be a complete single valued neutrosophic graph where (T_A, I_A, F_A) is constant function then G is isomorphic to $A(G) = (P, Q)$.

Proof: Given that $G = (A,B)$ be a complete single valued neutrosophic graph with $(T_A, I_A, F_A) = (k_1, k_2, k_3)$, where k_1, k_2, and k_3 are constants, which implies that $\delta(v_i, v_j) = (l_1, l_2, l_3)$ $\forall v_i, v_j \in V$. Therefore, eccentricity $e(v_i) = (l_1, l_2, l_3)$, $\forall v_i \in V$, which implies that $d(G) = (l_1, l_2, l_3)$. Hence $\delta(v_i, v_j) = (l_1, l_2, l_3) = d(G)$, $\forall v_i, v_j \in V$. Hence those vertices which are neighbous in G are also neighbors in A(G) such that

(a) A single valued neutrosophic vertex set of G is taken as single valued neutrosophic vertex set of A(G), that is,

$$T_P(v_i) = T_A(v_i),$$
$$I_P(v_i) = I_A(v_i),$$
$$F_P(v_i) = F_A(v_i)$$

for all $v_i \in V$,

(b) $T_Q(v_iv_j) = T_B(v_iv_j)$ since v_i and v_j are neighbors in G

$I_Q(v_iv_j) = I_B(v_iv_j)$ since v_i and v_j are neighbors in G

$F_Q(v_iv_j) = F_B(v_iv_j)$ since v_i and v_j are neighbors in G

Taking the mapping from $G \rightarrow A(G)$ as $i : A \rightarrow P$, $G \cong A(G)$.

Theorem 3.4. If G_1 and G_2 are isomorphic to each other, then $A(G_1)$ and $A(G_2)$ are also isomorphic.

Proof: As G_1 and G_2 are isomorphic, the isomorphism h, between them pre-serves the edge weights, so the T,I,F - length and T,I,F- distance will also be pre-served. Hence, if the vertex v_i has the maximum T – eccentricity, maximum I – eccentricity and minimum F - eccentricity, in G_1, then $h(v_i)$ has the maximum T – eccentricity, maximum I – eccentricity and minimum F - eccentricity, in G_2. So, G_1 and G_2 will have the same diameter. If the T,I,F - distance between v_i and v_j is (k_1, k_2, k_3) in G_1, then $h(v_i)$ and $h(v_j)$ will also have their T,I,F - distance as (k_1, k_2, k_3) in G_2. The same mapping h itself is a bijection between $A(G_1)$ and $A(G_2)$ satisfying the isomorphism condition.

(i) $T_{P_1}(v_i) = T_{A_1}(v_i) = T_{A_2}(h(v_i)) = T_{P_2}(h(v_i))$ $\forall v_i \in G_1$

(ii) $I_{P_1}(v_i) = I_{A_1}(v_i) = I_{A_2}(h(v_i)) = I_{P_2}(h(v_i))$ $\forall v_i \in G_1$

(iii) $F_{P_1}(v_i) = F_{A_1}(v_i) = F_{A_2}(h(v_i)) = F_{P_2}(h(v_i))$ $\forall v_i \in G_1$

(iv) $T_{Q_1}(v_i, v_j) = T_{B_1}(v_i, v_j)$ if v_i and v_j are neighbors in G_1

       $T_{Q_1}(v_i, v_j) = \min\left(T_{P_1}(v_i), T_{P_1}(v_j)\right)$ if v_i and v_j are not neighbors in G_1

(v) $I_{Q_1}(v_i, v_j) = I_{B_1}(v_i, v_j)$ if v_i and v_j are neighbors in G_1

      $I_{Q_1}(v_i, v_j) = \min\left(I_{P_1}(v_i), I_{P_1}(v_j)\right)$ if v_i and v_j are not neighbors in G_1

(vi) $F_{Q_1}(v_i, v_j) = F_{B_1}(v_i, v_j)$ if v_i and v_j are neighbors in G_1

      $F_{Q_1}(v_i, v_j) = \max\left(F_{P_1}(v_i), F_{P_1}(v_j)\right)$ if v_i and v_j are not neighbors in G_1

As $h : G_1 \rightarrow G_2$ is an isomorphism,

$T_{Q_1}(v_i, v_j)$

$= T_{B_2}\left(h(v)_i, h(v_j)\right)$ if v_i and v_j are neighbors in G_1 $T_{Q_1}(v_i, v_j)$

$= \min\left(T_{B_2}(h(v_i)), T_{B_2}(h(v_j))\right)$ if v_i and v_j are not neighbors in G_1 $I_{Q_1}(v_i, v_j)$

$= I_{B_2}\left(h(v)_i, h(v_j)\right)$ if v_i and v_j are neighbors in G_1 $I_{Q_1}(v_i, v_j)$

$= \min\left(I_{B_2}(h(v_i)), I_{B_2}(h(v_j))\right)$ if v_i and v_j are not neighbors in G_1

$F_{Q_1}(v_i, v_j) = F_{B_2}\left(h(v)_i, h(v_j)\right)$ if v_i and v_j are neighbors in G_1

Hence $T_{Q_1}(v_i, v_j) = T_{Q_2}\left(h(v)_i, h(v_j)\right)$, $I_{Q_1}(v_i, v_j) = I_{Q_2}\left(h(v)_i, h(v_j)\right)$ and

$F_{Q_1}(v_i, v_j) = \max\left(F_{B_2}(h(v_i)), F_{B_2}(h(v_j))\right)$ if v_i and v_j are not neighbors in G_1

$F_{Q_1}(v_i, v_j) = F_{Q_2}\left(h(v)_i, h(v_j)\right)$. So, the same h is an isomorphism between $A(G_1)$ and $A(G_2)$.

Theorem 3.5. If $G_1 = (A_1, B_1)$ and $G_2 = (A_2, B_2)$ are complete single valued neutrosophic graph such that G_1 is co-weak isomorphic to G_2 then $A(G_1)$ is co-weak isomorphic to $A(G_2)$.

Proof: As G_1 is co-weak isomorphic to G_2, there exists a bijection $h : G_1 \rightarrow G_2$ satisfying,

$T_{A_1}(v_i) \leq T_{A_2}(h(v_i))$, $T_{B_1}(v_i, v_j) = T_{B_2}\left(h(v_i), h(v_j)\right)$, $\forall v_i, v_j \in V_1$.

If G_1 has n vertices, arrange the vertices of G_1 in such a way that $T_{A_1}(v_1) \leq T_{A_1}(v_2) \leq T_{A_1}(v_3) \leq \cdots \leq T_{A_1}(v_n)$. As G_1 and G_2 are complete, co-weak isomorphic single valued neutrosophic graph $T_{B_1}(v_i, v_j) = T_{B_2}\left(h(v_i), h(v_j)\right)$, $\forall v_i, v_j \in V_1$. By Theorem 3.4 and the definition of antipodal single valued neutrosophic graph, we have $A(G_i)$ contains all the vertices of G, where i = 1, 2. That is, $T_{P_1}(x) = T_{A_1}(x), I_{P_1}(x) = I_{A_1}(x)$ and $F_{P_1}(x) = F_{A_1}(x)$ for all $x \in V$ and $T_{Q_1}(v_i, v_j) = T_{Q_2}\left(h(v_i), h(v_j)\right)$, $\forall v_i, v_j \in V_1$. So, the same bijection h is a co-weak isomorphism between $A(G_1)$ and $A(G_2)$.

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