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Intuitionistic fuzzy signed graphs of the second type *

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Abstract The aim of this paper is to introduce a new concept of intuitionistic fuzzy signed graph of second type as an extension of the intuitionistic fuzzy graph of second type defined by Sheik and Srinivasan (Sheik Dhavudh, S. and Srinivasan, R. (2017), Intuitionistic fuzzy graphs of second type, Advances in Fuzzy Mathematics, 12, 197–204; Sheik Dhavudh, S. and Srinivasan, R. (2017), A study on intuitionistic fuzzy graphs of second type, International Journal of Mathematical Archive, 8(8), 31–33; Sheik Dhavudh, S. and Srinivasan, R. (2017), Properties of intuitionistic fuzzy graphs of second type, International Journal of Computational and Applied Mathematics, 12(3), 815–823) and the intuitionistic fuzzy signed graph defined by Mishra and Pal (Mishra, S.N. and Pal, A. (2016), Intuitionistic fuzzy signed graphs, International Journal of Pure and Applied Mathematics,106 (6), 113–122). Also we establish some of its properties.

Key words Intuitionistic Fuzzy Graph, Intuitionistic fuzzy graphs of second type, Intuitionistic fuzzy signed graphs of second type, Balanced Intuitionistic fuzzy signed graphs of second type.

2020 Mathematics Subject Classification 05C72, 03E72.

1 Introduction

In 1953, Harary [6] introduced the notion of balance of a signed graph. After that Cartwright and Harary [4] introduced the notion of signed graph as an application to the problems in social psychology. Afterwards many authors like, Zaslavsky [16] established sequential results on this concept. In 1965, Zadeh [15] introduced the concept of fuzzy set as an extension of the crisp set. After that Bhattacharya [3] introduced some new notions on fuzzy graph and Nirmala and Prabavathi [9] introduced signed fuzzy graph. Atanassov [2] introduced the intuitionistic fuzzy set as an extension of the fuzzy set. Karunambigai and Parvathi [7] and Parvathi et. al [11] studied intuitionistic fuzzy graphs and their properties and Gani and Begum [5] defined the degree, order and size in an intuitionistic fuzzy graph. Akrum and Akmal [1] defined certain operations on intuitionistic fuzzy graph structures. Recently,

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Mishra and Pal [8] introduced the concept of intuitionistic fuzzy signed graph and obtained some of its properties.
In 2004, Parvathi and Palaniappan [10] introduced the concept of intuitionistic fuzzy set of second type. Recently, Sheik and Srinivasan [12–14] established intuitionistic fuzzy graphs of second type as an extension of the intuitionistic fuzzy set of second type. Motivated by the concept of intuitionistic fuzzy signed graph and intuitionistic fuzzy graphs of second type, we introduce a new concept of intuitionistic fuzzy signed graph of the second type and also we establish some of its properties.

2 Preliminaries

In this section, we give some basic definitions.

Definition 2.1. An intuitionistic fuzzy set (IFS) A in a universal set E is defined as an object of the form $A = \{(x, \mu_A(x), \gamma_A(x)) \,|x \in E\}$, where the functions $\mu_A : E \to [0,1]$ and $\gamma_A : E \to [0,1]$ denote the degree of membership and the degree of non - membership of the element $x \in E$ respectively, satisfying the condition $0 \le \mu_A(x) + \gamma_A(x) \le 1$.

Definition 2.2. An intuitionistic fuzzy set of second type (IFSST) A in a universal set E is defined as an object of the form $A = \{(x, \mu_A(x), \gamma_A(x)) \,|x \in E\}$, where the functions $\mu_A : E \to [0,1]$ and $\gamma_A : E \to [0,1]$ denote the degree of membership and the degree of non - membership of the element $x \in E$ respectively satisfying the relation $0 \le \mu_A^2(x) + \gamma_A^2(x) \le 1$.

Definition 2.3. An intuitionistic fuzzy graph (IFG) is of the form $G = (V, E)$, where

(i) $V = \{v_1, v_2, \ldots, v_n\}$ such that $\mu_A : V \to [0,1]$ and $\gamma_A : V \to [0,1]$ denote the degree of membership and non-membership of the element $v_i \in V$respectively and $0 \le \mu_A(v_i) + \gamma_A(v_i) \le 1$, for every $v_i \in V\,(i = 1,,2,\ldots,n)$.

(ii) $E \in V \times V$, where $\mu_B : V \times V \to [0,1]$ and $\gamma_B : V \times V \to [0,1]$ are such that

$$\mu_B(v_i, v_j) \le \min[\mu_A(v_i), \mu_A(v_j)],$$

$$\gamma_B(v_i, v_j) \le \max[\gamma_A(v_i), \gamma_A(v_j)]$$

and $0 \le \mu_B(v_i, v_j) + \gamma_B(v_i, v_j) \le 1$ for every $(v_i, v_j) \in E\,(i, j = 1,,2,\ldots,n)$.

Definition 2.4. An intuitionistic fuzzy graph of second type (IFGST) is of the form $G = (V, E)$, where

(i) $V = \{v_1, v_2, \ldots, v_n\}$ such that $\mu_A : V \to [0,1]$ and $\gamma_A : V \to [0,1]$ denote the degree of membership and non-membership of the element $v_i \in V$ respectively and $0 \le \mu_A^2(x) + \gamma_A^2(x) \le 1$ for every $v_i \in V\,(i = 1,,2,\ldots,n)$.

(ii) $E \in V \times V$, where $\mu_B : V \times V \to [0,1]$ and $\gamma_B : V \times V \to [0,1]$ are such that

$$\mu_B(v_i, v_j) \le \min\left[\mu_A^2(v_i), \mu_A^2(v_j)\right],$$

$$\gamma_B(v_i, v_j) \le \max\left[\gamma_A^2(v_i), \gamma_A^2(v_j)\right]$$

and $0 \le \mu_B^2(v_i, v_j) + \gamma_B^2(v_i, v_j) \le 1$ for every $(v_i, v_j) \in E\,(i, j = 1,,2,\ldots,n)$.

Definition 2.5. Let G be an IFGST and H be its subgraph. An IFGST, $H = (V', E')$ is said to be an intuitionistic subgraph of an IFGST, $G = (V, E)$ if $V' \subseteq V$ and $E' \subseteq E$ that is $\mu'_{Aj} \le \mu_{Aj}$; $\gamma'_{Aj} \ge \gamma_{Aj}$ and $\mu'_{Bij} \le \mu_{Bjj}$; $\gamma'_{Bij} \ge \gamma_{Bij}$ for every $i, j = 1, 2, \ldots, n$.

Definition 2.6. In an IFGST, $G = (V, E)$ the set of all triples $(V_t, \mu_{At}, \gamma_{At})$, where, $\mu_{At} = \{v_i \in V : \mu_{At}^2 \ge t\}$ or $\gamma_{At} = \left\{v_i \in V : \gamma_{At}^2 \le t\right\}$ for some $i = 1, 2, \ldots, n$ is subset of $V, 0 \le t \le 1$ and the set of all triples $(E_t, \mu_{Bt}, \gamma_{Bt})$, where, $\mu_{Bt} = \left\{(v_i, v_j) \in V \times V : \mu_{Bt}^2 \ge t\right\}$ or $\gamma_{Bt} = \left\{(v_i, v_j) \in V \times V : \gamma_{Bt}^2 \le t\right\}$ for some $i = 1, 2, \ldots, n$ is subset of $E, 0 \le t \le 1$. It may be noted that (V_t, E_t) is a subgraph of G.

Definition 2.7. Let $G = (V, E)$ be an IFGST then the degree of a vertex v is denoted by $d(v)$ and is defined as, $d(v) = (d_\mu(v), d_\gamma(v))$, where, $d_\mu(v) = \sum_{u \ne v} d_B(v, u)$ is the degree of the membership function and $d_\gamma(v) = \sum_{u \ne v} d_B(v, u)$ is the degree of the non membership function for all $u, v \in V$.

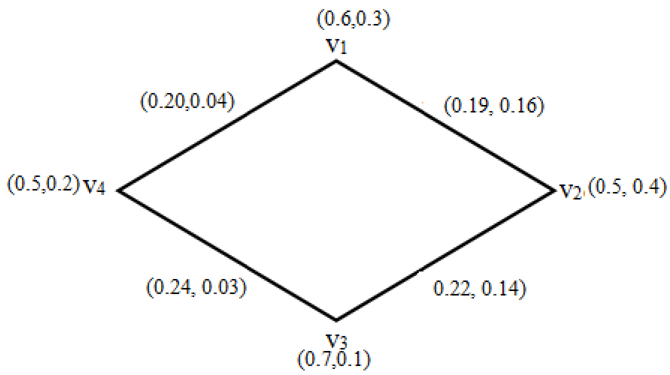

Fig. 1: Figure of Example 2.10.

Definition 2.8. The minimum degree of G , denoted by $\delta(G)$, is defined as $\delta(G) = [\delta_\mu(G), \delta_\gamma(G)]$, where, $\delta_\mu(G) = \min\{d_\mu(v) : v \in V\}$ and $\delta_\gamma(G) = \min\{d_\gamma(v) : v \in V\}$.

Definition 2.9. The maximum degree of G, denoted by $\Delta(G)$, is defined as $\Delta(G) = [\Delta_\mu(G), \Delta_\gamma(G)]$, where, $\Delta_\mu(G) = \max\{d_\mu(v) : v \in V\}$ and $\Delta_\gamma(G) = \max\{d_\gamma(v) : v \in V\}$.

Example 2.10. In Fig. 1 above we see that the degree of vertices of G are

$$d(v_1) = (0.39, 0.20), d(v_2) = (0.41, 0.30), d(v_3) = (0.46, 0.17), d(v_4) = (0.44, 0.07)$$

and the mimimum degree of G is $\delta(G) = (0.39, 0.07)$, while the maximum degree of G is $\Delta(G) = (0.46, 0.30)$.

3 Intuitionistic fuzzy signed graphs of the second type

Definition 3.1. An intuitionistic fuzzy graph of second type (IFGST) G is said to be an intuitionistic fuzzy signed graph of the second type (IFSGST) if $\sigma : E(G) \to \{+1, -1\}$ is a function associated from $E(G)$ of G such that each edge is signed to $\{+, -\}$ or all the edges and nodes are signed to $\{+, -\}$.

We assign $E(G) \to \{+1, -1\}$ on the comparison basis of its membership and non-membership values. If the membership value is greater than the non-membership values, we assign it positive and in the reverse case we assign it negative and in case of equality we keep it unsigned.

Definition 3.2. Let G be an IFSGST and H be its subgraph. An IFSGST, $H = (V', E')$ is said to be an intuitionistic subgraph of an IFSGST, $G = (V, E)$ if $V' \subseteq V$ and $E' \subseteq E$, that is, $\mu'_{Aj} \le \mu_{Aj}, \gamma'_{Aj} \ge \gamma_{Aj}$ and $\mu'_{Bij} \le \mu_{Bij}, \gamma'_{Bij} \ge \gamma_{Bij}$ for every $i, j = 1, 2, \ldots, n$.

Definition 3.3. In an IFSGST, $G = (V, E)$ the set of all triples $(V_t, \mu_{At}, \gamma_{At})$, where $\mu_{At} = \{v_i \in V : \mu^2_{At} \ge t\}$ or $\gamma_{At} = \left\{v_i \in V : \gamma^2_{At} \le t\right\}$for some $i = 1, 2, \ldots, n$ is subset of $V, 0 \le t \le 1$ and the set of all triples $(E_t, \mu_{Bt}, \gamma_{Bt})$, where, $\mu_{Bt} = \left\{(v_i, v_j) \in V \times V : \mu^2_{Bt} \ge t\right\}$ or $\gamma_{Bt} = \left\{(v_i, v_j) \in V \times V : \gamma^2_{Bt} \le t\right\}$ for some $i = 1, 2, \ldots, n$ is subset of $E, 0 \le t \le 1$.

Theorem 3.4. *Let $G = (V, E)$ be an IFSGST, then (V_x, E_x) is an intuitionistic fuzzy signed subgraph of second type of (V_y, E_y) for any x, y if $0 \le x \le y \le 1$.*

Proof. Let $v_i \in V_x$then $\gamma^2_{Ai} \le x$, so we have $\gamma^2_{Ai} \le y$, as $x \le y$. $\Rightarrow v_i \in V_y$, hence $V_x \subseteq V_y$. Let $(v_i, v_j) \in E_x$ then $\gamma^2_{Bij} \le x$, so we have $\gamma^2_{Bij} \le y$, since $x \le y$.$\Rightarrow (v_i, v_j) \in E_y$, hence $E_x \subseteq E_y$. Hence (V_x, E_x) is an intuitionistic fuzzy signed subgraph of second type of (V_y, E_y). □

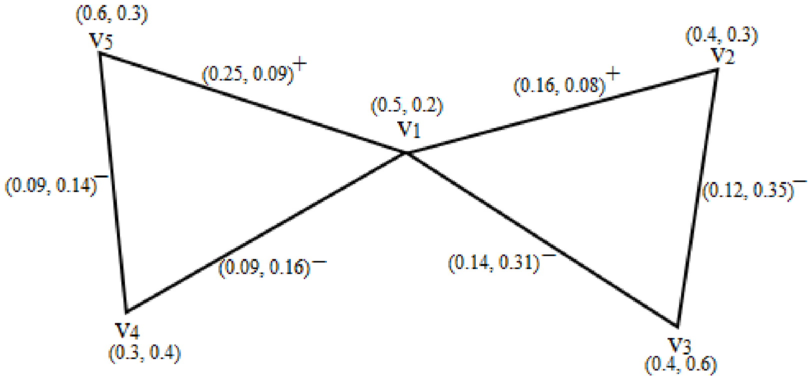

Fig. 2: Figure of Example 3.9.

Theorem 3.5. *If $H = (V', E')$ be an intuitionistic fuzzy signed subgraph second type of an IFSGST, $G = (V, E)$ then for any $0 \leq x \leq 1$, (V'_x, E'_x) is an intuitionistic fuzzy signed subgraph of second type of (V_x, E_x).*

Proof. From the given condition we have $V' \subseteq V$ and $E' \subseteq E$. To prove that (V'_x, E'_x) is an intuitionistic fuzzy signed subgraph of (V_x, E_x), it is enough to prove that $V'_x \subseteq V_x$ and $E'_x \subseteq E_x$. Let $v_i \in V'_x \Rightarrow ({\mu'}_{Ai})^2 \geq x$, or, $\mu^2_{Ai} \geq x$ as $({\mu'}_{Ai})^2 \leq \mu^2_{Ai}$. Thus, $v_i \in V_x$, which yields, $V'_x \subseteq V_x$. Now, let $(v_i, v_j) \in E'_x$, which means that $({\mu'}_{Bij})^2 \geq x$. This lends $\mu^2_{Bij} \geq x$ as $({\mu'}_{Bij})^2 \leq \mu^2_{Bij}$, which gives, $(v_i, v_j) \in E_x$, i.e., $E'_x \subseteq E_x$. Therefore (V'_x, E'_x) is an intuitionistic fuzzy signed subgraph of (V_x, E_x). □

Definition 3.6. Let $G = (V, E)$ be an IFSGST, then the degree of values of all incident positive edge to v is known as the positive degree of any vertex v, that is, $\deg^+(v) = \left(d^+_\mu(v), d^+_\gamma(v)\right)$, where,

$$d^+_\mu(v) = \sum_{(v,v_i)\in E} \mu^+_B(v, v_i), d^+_\gamma(v) = \sum_{(v,v_i)\in E} \gamma^+_B(v, v_i).$$

Similarly, by negative degree we mean $\deg^-(v) = \left(d^-_\mu(v), d^-_\gamma(v)\right)$, where, $d^-_\mu(v) = \sum_{(v,v_i)\in E} \mu^-_B(v, v_i)$, $d^-_\gamma(v) = \sum_{(v,v_i)\in E} \gamma^-_B(v, v_i)$. The sign degree of any vertex v is the difference between $\deg^+(v)$ and $\deg^-(v)$, it is denoted by $sd(v)$, that is $sd(v) = (sd_\mu(v), sd_\gamma(v))$, where, $sd_\mu(v) = \left|d^+_\mu(v) - d^-_\mu(v)\right|$ and $sd_\gamma(v) = \left|d^+_\gamma(v) - d^-_\gamma(v)\right|$.

Definition 3.7. The minimum degree of G is denoted by $s\delta(G)$ and is defined as, $s\delta(G) = [s\delta_\mu(G), s\delta_\gamma(G)]$, where, $s\delta_\mu(G) = \min\{sd_\mu(v) : v \in V\}$ and $s\delta_\gamma(G) = \min\{sd_\gamma(v) : v \in V\}$.

Definition 3.8. The maximum degree of G is denoted by $s\Delta(G)$ and is defined as, $s\Delta(G) = [s\Delta_\mu(G), s\Delta_\gamma(G)]$, where, $s\Delta_\mu(G) = \max\{sd_\mu(v) : v \in V\}$ and $s\Delta_\gamma(G) = \max\{sd_\gamma(v) : v \in V\}$.

Example 3.9. The sign degree of vertices for the intuitionistic fuzzy signed graph of second type shown in Fig. 2 is calculated as illustrated below:
Noting that $sd(v) = (sd_\mu(v), sd_\gamma(v))$, where, $sd_\mu(v) = \left|d^+_\mu(v) - d^-_\mu(v)\right|$ and $sd_\gamma(v) = \left|d^+_\gamma(v) - d^-_\gamma(v)\right|$, we have,

$$sd_\mu(v_1) = |(0.25 + 0.16) - (0.09 + 0.14)| = 0.18, sd_\gamma(v_1) = |(0.09 + 0.08) - (0.16 + 0.31)| = 0.30$$

$$\Rightarrow sd(v_1) = (sd_\mu(v_1), sd_\gamma(v_1)) = (0.18, 0.30).$$

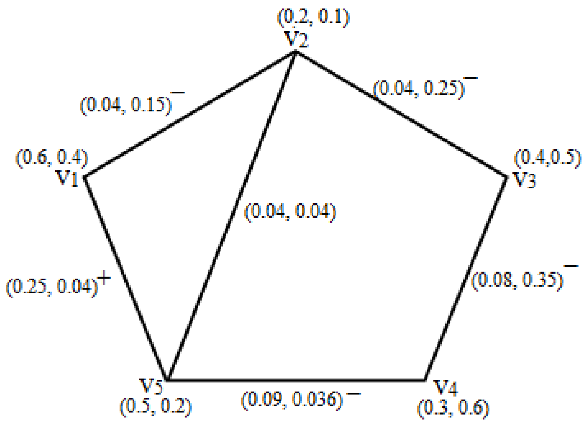

Fig. 3: A signed intutionistic fuzzy graph of the second type.

$$sd_{\mu}(v_2) = |0.16 - 0.12| = 0.04, sd_{\gamma}(v_2) = |0.08 - 0.35| = 0.27$$
$$\Rightarrow sd(v_2) = (sd_{\mu}(v_2), sd_{\gamma}(v_2)) = (0.04, 0.27).$$
$$sd_{\mu}(v_3) = |0.0 - (0.12 + 0.14)| = 0.26, sd_{\gamma}(v_3) = |0.0 - (0.31 + 0.35)| = 0.66$$
$$\Rightarrow sd(v_3) = (sd_{\mu}(v_3), sd_{\gamma}(v_3)) = (0.26, 0.66).$$
$$sd_{\mu}(v_4) = |0.0 - (0.09 + 0.09)| = 0.18, sd_{\gamma}(v_4) = |0.0 - (0.14 + 0.16)| = 0.30$$
$$\Rightarrow sd(v_4) = (sd_{\mu}(v_4), sd_{\gamma}(v_4)) = (0.18, 0.30).$$
$$sd_{\mu}(v_5) = |0.25 - 0.09| = 0.16, sd_{\gamma}(v_5) = |0.09 - 0.14| = 0.5$$
$$\Rightarrow sd(v_5) = (sd_{\mu}(v_5), sd_{\gamma}(v_5)) = (0.16, 0.16).$$

The minimum degree of G is $s\delta(G) = [s\delta_{\mu}(G), s\delta_{\gamma}(G)] = [0.04, 0.06]$ and the maximum degree of G is $s\Delta(G) = [s\Delta_{\mu}(G), s\Delta_{\gamma}(G)] = [0.26, 0.66]$.

Definition 3.10. For an intuitionistic fuzzy graph of second type any vertex is said to be positive or negative signed, if $\sigma : V(G) \to \{+1, -1\}$ is positive or negative, where σ is a function associated from $V(G)$ of G on the comparison basis of its membership and non-membership values of V, similar to its edge sign.

In the graph shown in Fig. 3 all the edges get assigned except the diagonal edge because for this edge the membership and corresponding non-membership values are equal.
An intuitionistic fuzzy graph of the second type is said to be positive if all the edges get the positive sign or only an even number of edges have negative sign, basically, the sign of IFGST is determined by the product of the signs of all its edges. Similarly, an IFGST is said to be negative signed if an odd number of its edges are negative.

Lemma 3.11. *An intuitionistic fuzzy signed graph of the second type is a positive signed graph if every even length cycle has all negative signed edges.*

Proof. In the graph shown in Fig. 4 we see that all the edges contain negative sign in the even length cycle, so the product of edge signs is always positive, hence, it is a positive signed graph. □

Corollary 3.12. *An intuitionistic fuzzy signed graph of the second type is a negative signed graph if every odd length cycle in it has all negative signed edges.*

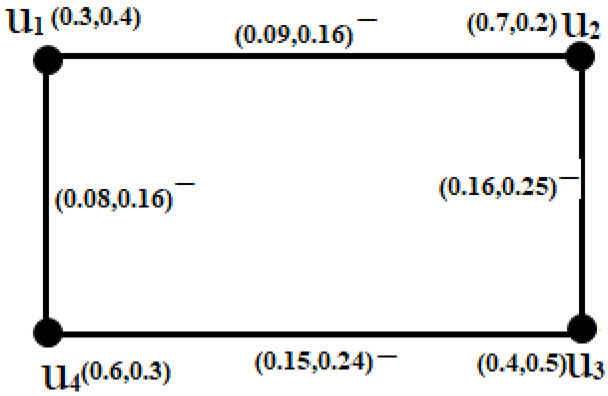

Fig. 4: A positive intutionistic fuzzy signed graph of the second type.

Definition 3.13. An intuitionistic fuzzy signed graph of the second type G is said to be balanced if every cycle of the graph has either an even number of negative signed edges or all positive signed edges. We say that an IFSGST G is completely balanced if $\sum_{j+1}^{n} P_j = \sum_{j+1}^{n} Q_j$ for all the edges of G (see Fig. 5) where, P_j represents the degree of the membership function and Q_j represents the degree of the non-membership function.

Proposition 3.14. *An odd length of an intuitionistic fuzzy signed graph of the second type cycle is balanced if and only if it contains at least one positive edge or an odd number of positive edges.*

Definition 3.15. The *frustration number* is defined as the minimum number of edges that is required to be removed from a graph to make it a balanced graph.
In a crisp graph the frustration number is calculated by just removing the negative signed edges so that each cycle in the graph becomes positive, so, we obtain balanced signed graph but we select those edges arbitrarily, there being no rule to select such edges. But in intuitionistic fuzzy signed graphs of the second type we follow some algorithmic approach to delete such edges. The steps of this algorithm are as follows:

- Collect all the negative signed edges,
- Select the edge having the minimum membership and the maximum non-membership,
- Remove the selected edge and continue the process till we get all positive cycles in the graph.

For any nodes and edges, we represent the membership value by P and the non-membership value by Q and for any two adjacent positive nodes the following proposition holds good:

Proposition 3.16. *An edgee* (P,Q) *joining two positive nodes* $u\,(P_1,Q_1)$ *and* $v\,(P_2,Q_2)$ *is positive signed either if* $P_1 > Q_2$ *or* $P_2 > Q_1$.

Proof. For an edge $e = uv$, we know that $P = \min\{P_1, P_2\}$ and $Q = \max\{Q_1, Q_2\}$ and since the nodes are positive thus, $P_1 > Q_1$ and $P_2 > Q_2$. Thus, in this case for a positive signed edge, the membership value of the edge has to be greater than the non-membership value and it is possible only either if $P_1 > Q_2$ or $P_2 > Q_1$. □

Definition 3.17. The complement of an intuitionistic fuzzy graph of the second type G is $G^c = (V^c, E^c)$, where, $V^c$is the complement of an intuitionistic fuzzy set of the second type of vertices and

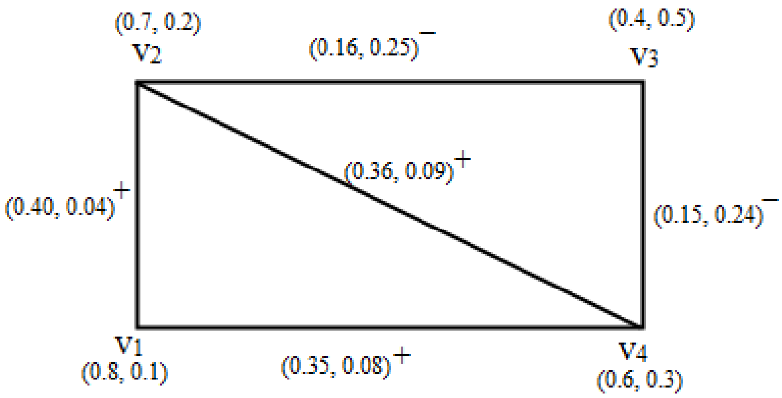

Fig. 5: A completely balanced intuitionistic fuzzy signed graph of the second type.

E^c is the set of edges between those vertices which are nonadjacent in G. Hence the membership of V becomes the non-membership of V^c and the non membership value of V becomes the membership of V^c. So, if $V = (P, Q)$ then $V^c = (Q, P)$. Thus we can easily verify that in the complement of an intuitionistic fuzzy signed graph of the second type each node changes its sign.

Example 3.18. An example of a complement of an intuitionistic fuzzy signed graph of the second type is shown in Fig. 6 below:

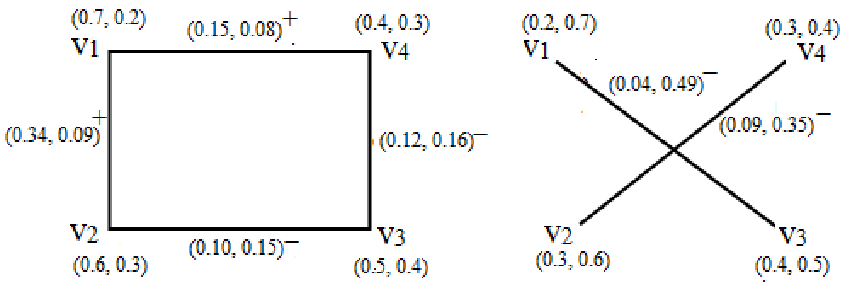

Fig. 6: The switching of an intuitionistic fuzzy signed graph of the second type.

Theorem 3.19. *The complement graph of a balanced IFSGST is always positive if it is of an odd length cycle.*

Proof. We know that the complement of an odd length cycle with n number of nodes is an $(n-3)$-regular graph with n number of nodes. Thus for odd n, $n-3$ is always even, so all the nodes are connected by an even number of edges. Hence for any negative nodes in the complement graph there always exist an even number of negative edges whose product is always positive. Hence the overall product of the signs always remains positive. □

Theorem 3.20. *The complement of an intuitionistic fuzzy signed graph of the second type path graph L_n, where n is odd is a positive signed graph if and only if either all the nodes or at least the end nodes of L_n are negative.*

Proof. As we know that the complement of a path graph have $\frac{n(n-3)}{2}+1$ edges, we may say that the complement of a path graph with n number of nodes is $(n-3)$ -regular with an extra edge between the end nodes. Thus if the path L_n has an odd number of nodes then each node has an even degree except the end nodes of the path L_n, i.e., the sign of the complement graph depends upon that extra edge only which joins the end nodes of L_n, and if the end node of L_n is negative then in its complement graph it becomes positive so the edge associated with it also becomes positive. Hence the overall multiplication of the signs of all edges in complement of L_n always remains positive. □

4 Conclusion

In this paper, we defined the concept of intuitionistic fuzzy signed graph of the second type and established some of their properties. In the future we will extend these concepts to neutrosophic graphs and their properties.

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