On Strong Interval-Valued Intuitionistic Fuzzy Graph

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Abstract

In this paper, the strong interval-valued intuitionistic fuzzy graphs are introduced. Cartesian product, composition and join of two strong interval-valued intuitionistic fuzzy graphs defined. Some propositions involving strong interval-valued intuitionistic fuzzy graphs are stated and proved.

Keywords: Intuitionistic fuzzy graph, Interval valued intuitionistic fuzzy graph, Strong interval valued intuitionistic fuzzy graph.

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1. Introduction

In 1965, Zadeh [9] introduced the concept of fuzzy set as a method of finding uncertainty. In 1986, Atanassov proposed Intuitionistic Fuzzy Set (IFS) [4] which looks more accurately to uncertainty quantification and provides the opportunity to precisely model the problem based on the existing knowledge and observations. After three years Atanassov and Gargov [3] introduced Interval-Valued Intuitionistic Fuzzy set (IVIFS) which is helpful to model the problem precisely.

In 1975, Rosenfeld [7] introduced the concept of fuzzy graphs. Yeh and Bang [8] also introduced fuzzy graphs independently. Fuzzy graphs are useful to represent relationships which deal with uncertainty and it differs greatly from classical graphs. It has numerous applications to problems in computer science, electrical engineering, system analysis, operations research, economics, networking routing, transportation, etc. Interval-Valued Fuzzy Graphs (IVFG) are defined by Akram and Dudec [2] in 2011. Atanassov [5] introduced the concept of intuitionistic fuzzy relations and Intuitionistic Fuzzy Graph (IFG). In fact, interval-valued fuzzy graphs and interval valued intuitionistic fuzzy graphs are two different models that extend theory of fuzzy graph. S.N.Mishra and A.Pal [6] introduced the product of interval valued intuitionistic fuzzy graph. Akram and Bijan Davvaz [1] introduced Strong Intuitionistic Fuzzy Graphs (SIFG). In this paper, The notion of Strong Interval-Valued Intuitionistic Fuzzy Graphs (SIVIFG) are introduced.
2. Preliminaries

Definition 2.1 A fuzzy set $V$ is a mapping $\sigma$ from $V$ to $[0, 1]$. A fuzzy graph $G$ is a pair of functions $G = (\sigma, \mu)$ where $\sigma$ is a fuzzy subset of a non-empty set $V$ and $\mu$ is a symmetric fuzzy relation on $\sigma$, i.e., $\mu(u, v) \leq \sigma(u) \land \sigma(v)$. The underlying crisp graph of $G = (\sigma, \mu)$ is denoted by $G^* = (V, E)$ where $E \subseteq V \times V$.

Let $D[0, 1]$ be the set of all closed subintervals of the interval $[0, 1]$ and element of this set are denoted by uppercase letters. If $M \in D[0, 1]$ then it can be represented as $M = [ML, MU]$, where $ML$ and $MU$ are the lower and upper limits of $M$.

Definition 2.2 An intuitionistic fuzzy graph with underlying set $V$ is defined to be a pair $G = (A, B)$ where

1) the functions $\mu_A : V \to [0, 1]$ and $\gamma_A : V \to [0, 1]$ denote the degree of membership and non-membership of the element $x \in V$ respectively, such that $0 \leq \mu_A(x) + \gamma_A(x) \leq 1$ for all $x \in V$.

2) the functions $\mu_B : E \subseteq V \times V \to [0, 1]$ and $\gamma_B : E \subseteq V \times V \to [0, 1]$ are defined by $\mu_B((x, y)) \leq \min(\mu_A(x), \mu_A(y))$ and $\gamma_B((x, y)) \geq \max(\gamma_A(x), \gamma_A(y))$ such that $0 \leq \mu_B((x, y)) + \gamma_B((x, y)) \leq 1$, $\forall (x, y) \in E$.

Definition 2.3 An intuitionistic fuzzy graph $G = (A, B)$ is called strong intuitionistic fuzzy graph if $\mu_B((x, y)) = \min(\mu_A(x), \mu_A(y))$ and $\gamma_B((x, y)) = \max(\gamma_A(x), \gamma_A(y))$, $\forall (x, y) \in E$.

Definition 2.4 An interval valued intuitionistic fuzzy graph with underlying set $V$ is defined to be a pair $G = (A, B)$ where

1) the functions $M_A : V \to [0, 1]$ and $N_A : V \to [0, 1]$ denote the degree of membership and non-membership of the element $x \in V$, respectively, such that $0 \leq M_A(x) + N_A(x) \leq 1$ for all $x \in V$.

2) the functions $M_B : E \subseteq V \times V \to [0, 1]$ and $N_B : E \subseteq V \times V \to [0, 1]$ are defined by $M_B((x, y)) \leq \min(M_A(x), M_A(y))$ and $N_B((x, y)) \geq \max(N_A(x), N_A(y))$ such that $0 \leq M_B((x, y)) + N_B((x, y)) \leq 1$, $\forall (x, y) \in E$.

Hereafter, we use the notation $xy$ for $(x, y)$ an element of $E$.

3 Strong Interval-Valued Intuitionistic Fuzzy Graph

Definition 3.1 An interval valued intuitionistic fuzzy graph $G = (A, B)$ is called strong interval valued intuitionistic fuzzy graph if $M_B((x, y)) = \min(M_A(x), M_A(y))$ and $N_B((x, y)) = \max(N_A(x), N_A(y))$ such that $V = \{x, y, z\}$, $E = \{xy, yz, zx\}$, $A$ is an interval valued intuitionistic fuzzy set of $V$.
and let B is an interval-valued intuitionistic fuzzy set of $E \subseteq V \times V$. Here

$A = \{ < x, [0.5,0.7], [0.1,0.3] >, < y, [0.6,0.7], [0.1,0.3] >, < z, [0.4,0.6], [0.2,0.4] > \}$,

$B = \{ < xy, [0.3,0.6], [0.2,0.4] >, < yz, [0.3,0.5], [0.2,0.4] >, < xz, [0.3,0.5], [0.2,0.4] > \}$

\[ <x,[0.5,0.7],[0.1,0.3]> <xz,[0.3,0.5],[0.2,0.4]> <z,[0.4,0.6],[0.2,0.4]> \]

\[ <xy,[0.3,0.6],[0.2,0.4]> <yz,[0.3,0.5],[0.2,0.4]> <y,[0.6,0.7],[0.1,0.3]> \]

**Fig-1 Interval-valued intuitionistic fuzzy graph**

**Example 3.2** Figure 2 is an SIVIFG $G = (A,B)$, where $A = \{ < x, [0.5,0.7], [0.1,0.3] >, < y, [0.6,0.7], [0.1,0.3] >, < z, [0.4,0.6], [0.2,0.4] > \}$,

$B = \{ < xy, [0.5,0.7], [0.1,0.3] >, < yz, [0.4,0.6], [0.2,0.4] >, < xz, [0.4,0.6], [0.2,0.4] > \}$

\[ <x,[0.5,0.7],[0.1,0.3]> <xz,[0.4,0.6],[0.2,0.4]> <z,[0.4,0.6],[0.2,0.4]> \]

\[ <xy,[0.5,0.7],[0.1,0.3]> <yz,[0.4,0.6],[0.2,0.4]> <y,[0.6,0.7],[0.1,0.3]> \]

**Fig – 2 Strong interval-valued intuitionistic fuzzy graph**

**Definition 3.2** Let $A_1$ and $A_2$ be interval-valued intuitionistic fuzzy subsets of $V_1$ and $V_2$ respectively. Let $B_1$ and $B_2$ interval-valued intuitionistic fuzzy subsets of $E_1$ and $E_2$ respectively. The **Cartesian product** of two SIVIFGs $G_1$ and $G_2$ is denoted by $G_1 \times G_2 = (A_1 \times A_2, B_1 \times B_2)$ and is defined as follows:

1) \( (M_{A_1 \times A_2})(x_1, x_2) = \min \{ M_{A_1}(x_1), M_{A_2}(x_2) \} \)

\( (M_{A_1 \times A_2})(x_1, x_2) = \min \{ M_{A_1}(x_1), M_{A_2}(x_2) \} \)

\( (N_{A_1 \times A_2})(x_1, x_2) = \max \{ N_{A_1}(x_1), N_{A_2}(x_2) \} \)

\( (N_{A_1 \times A_2})(x_1, x_2) = \max \{ N_{A_1}(x_1), N_{A_2}(x_2) \} \), \quad \forall \ x_1 \in V_1, x_2 \in V_2

2) \( (M_{B_1 \times B_2})(x, y) = \min \{ M_{B_1}(x), M_{B_2}(y) \} \)

\( (M_{B_1 \times B_2})(x, y) = \min \{ M_{B_1}(x), M_{B_2}(y) \} \), \quad \forall \ x \in V_1, y \in V_2
(M_{B_1 U} \times M_{B_2 U})(x,y_1,y_2) = \min \left( M_{A_1 U}(x), M_{A_2 U}(y_1), M_{A_2 U}(y_2) \right), i = 1,2.

Similarly,

\( (M_{A_1 U} \times M_{A_2 U})(x,y_1,y_2) = \min \left( M_{A_1 U}(x), M_{A_1 U}(y_1), M_{A_2 U}(y_2) \right) \)

\( (M_{A_1 U} \times M_{A_2 U})(x,y_1,y_2) = \min \left( M_{A_1 U}(x), M_{A_1 U}(y_1), M_{A_2 U}(y_2) \right) \)

\( (N_{B_1 L} \times N_{B_2 L})(x,y_1,y_2) = \min \left( N_{A_1 L}(x), N_{A_1 L}(y_1), N_{A_2 L}(y_2) \right) \)

\( (N_{A_1 L} \times N_{A_2 L})(x,y_1,y_2) = \min \left( N_{A_1 L}(x), N_{A_1 L}(y_1), N_{A_2 L}(y_2) \right) \)

\( (N_{B_1 L} \times N_{B_2 L})(x,y_1,y_2) = \min \left( N_{A_1 L}(x), N_{A_1 L}(y_1), N_{A_2 L}(y_2) \right) \)

Hence,

\( (M_{B_1 L} \times M_{B_2 L})(x,y_1,y_2) = \min \left( (M_{A_1 L} \times M_{A_2 L})(x,y_1,y_2), (M_{A_1 L} \times M_{A_2 L})(x,y_2) \right) \)

\( (M_{B_1 U} \times M_{B_2 U})(x,y_1,y_2) = \min \left( (M_{A_1 U} \times M_{A_2 U})(x,y_1,y_2), (M_{A_1 U} \times M_{A_2 U})(x,y_2) \right) \)

\( (N_{B_1 L} \times N_{B_2 L})(x,y_1,y_2) = \min \left( (N_{A_1 L} \times N_{A_2 L})(x,y_1,y_2), (N_{A_1 L} \times N_{A_2 L})(x,y_2) \right) \)

Similarly, we can show that

\( (N_{B_1 L} \times N_{B_2 L})(x,y_1,y_2) = \min \left( (N_{A_1 L} \times N_{A_2 L})(x,y_1,y_2), (N_{A_1 L} \times N_{A_2 L})(x,y_2) \right) \)
\[(N_{B_1 \cup N_{B_2}})((x, x_2)(x, y_2)) = \max \left( (N_{A_1 \cup N_{A_2}})(x, x_2), (N_{A_1 \cup N_{A_2}})(x, y_2) \right) \]

Hence, \(G_1 \times G_2\) is not strong interval valued intuitionistic fuzzy graph. This completes the proof.

**Proposition 3.2** If \(G_1 \times G_2\) is strong interval valued intuitionistic fuzzy graph then at least \(G_1\) or \(G_2\) must be strong.

**Proof:** Suppose that \(G_1\) and \(G_2\) are not strong interval valued intuitionistic fuzzy graphs, there exist \(x_i, y_i \in E_i, i = 1, 2\) such that

\[
\begin{align*}
M_{B_i}(x_i, y_i) &< \min(M_{A_i}(x_i), M_{A_i}(y_i)) \\
M_{B_i}(x_i, y_i) &< \min(M_{A_i}(x_i), M_{A_i}(y_i)) \\
N_{B_i}(x_i, y_i) &> \max(N_{A_i}(x_i), N_{A_i}(y_i)) \\
N_{B_i}(x_i, y_i) &> \max(N_{A_i}(x_i), N_{A_i}(y_i))
\end{align*}
\]

Let \(E = \{(x, x_2)(x, y_2) / x_2 \in V_1, x_2, y_2 \in E_2 \} \cup \{(x, z)(y_1, z) / z \in V_2, x_1, y_1 \in E_1\}\)

Consider, \((x, x_2)(x, y_2) \in E\), we have

\[
\begin{align*}
(M_{B_1 \cup B_2})(\{(x, x_2)(x, y_2)\}) = \min(M_{A_1}(x), M_{A_2}(x_2 y_2)) \\
&< \min(M_{A_1}(x), M_{A_2}(x_2), M_{A_2}(y_2))
\end{align*}
\]

Similarly,

\[
\begin{align*}
(M_{B_1 \cup B_2})(\{(x, x_2)(x, y_2)\}) = \min(M_{A_1}(x), M_{A_2}(x_2 y_2)) \\
&< \min(M_{A_1}(x), M_{A_2}(x_2), M_{A_2}(y_2))
\end{align*}
\]

\[
\begin{align*}
(M_{A_1 \cup A_2})(x, x_2) &< \min(M_{A_1 \cup A_2}(x, x_2), M_{A_1 \cup A_2}(x, y_2)) \\
(M_{A_1 \cup A_2})(x, x_2) &< \min(M_{A_1 \cup A_2}(x, x_2), M_{A_1 \cup A_2}(x, y_2))
\end{align*}
\]

Hence,

\[
\begin{align*}
(M_{B_1 \cup B_2})(\{(x, x_2)(x, y_2)\}) &< \min(M_{A_1 \cup A_2}(x, x_2), (M_{A_1 \cup A_2}(x, x_2), M_{A_1 \cup A_2}(x, y_2)) \\
(M_{B_1 \cup B_2})(\{(x, x_2)(x, y_2)\}) &< \min(M_{A_1 \cup A_2}(x, x_2), (M_{A_1 \cup A_2}(x, x_2), M_{A_1 \cup A_2}(x, y_2))
\end{align*}
\]

Similarly, we can show that

\[
\begin{align*}
(N_{B_1 \cup B_2})(\{(x, x_2)(x, y_2)\}) &> \max((N_{A_1 \cup A_2})(x, x_2), (N_{A_1 \cup A_2})(x, x_2)) \\
(N_{B_1 \cup B_2})(\{(x, x_2)(x, y_2)\}) &> \max((N_{A_1 \cup A_2})(x, x_2), (N_{A_1 \cup A_2})(x, x_2))
\end{align*}
\]

Hence, \(G_1 \times G_2\) is not strong interval valued intuitionistic fuzzy graph, which is a contradiction. This completes the proof.

**Remark: 3.1** If \(G_1\) is an SIVIFG and \(G_2\) is not an SIVIFG, then \(G_1 \times G_2\) need not be an SIVIFG.

**Example 3.3** Let \(G_1 = (A_1, B_1)\) be an SIVIFG, where \(A_1 = \{< a, [0.6, 0.7], [0.1, 0.3] >, < b, [0.6, 0.7], [0.1, 0.3] >\}\) and \(B_1 = \{< ab, [0.6, 0.7], [0.1, 0.3] >\}\), \(G_2 = (A_2, B_2)\) is not SIVIFG, where \(A_2 = \{< c, [0.4, 0.6], [0.2, 0.4] >, < d, [0.4, 0.6], [0.2, 0.4] >\}\).
Definition 3.3 Let $A_1$ and $A_2$ be interval-valued intuitionistic fuzzy subsets of $V_1$ and $V_2$ respectively. Let $B_1$ and $B_2$ be such that $A_1 \times A_2$ and $B_1 \times B_2$ are not SIVIFG, where $A_1 = \{(a, c), [0.4, 0.6], [0.1, 0.2]\}$, $A_2 = \{(a, d), [0.4, 0.6], [0.2, 0.4]\}$, and $B_2 = \{(b, c), [0.4, 0.6], [0.2, 0.4]\}$. In this example, $G_1$ is an SIVIFG and $G_2$ is not an SIVIFG, then $G_1 \times G_2$ is an SIVIFG.

Example 3.4 Let $G_1 = (A_1, B_1)$ be an SIVIFG, where $A_1 = \{< a, [0.4, 0.6], [0.2, 0.4] >, b, [0.4, 0.6], [0.2, 0.4] >\}$ and $B_1 = \{< ab, [0.4, 0.6], [0.2, 0.4] >\}$. Suppose $G_2 = (A_2, B_2)$ is not an SIVIFG, where $A_2 = \{< c, [0.6, 0.7], [0.1, 0.3]\}, \{< d, [0.6, 0.7], [0.3, 0.5]\}\}$. Let $B_2 = \{< cd, [0.5, 0.6], [0.2, 0.4]\}$, $G_1 \times G_2 = (A_1 \times A_2, B_1 \times B_2)$ is not an SIVIFG, where $A_2 = \{< (a, c), [0.6, 0.7], [0.1, 0.3]\}, \{< (a, d), [0.6, 0.7], [0.1, 0.3]\}\}$. Let $B_2 = \{< cd, [0.5, 0.6], [0.2, 0.4]\}$, $G_1 \times G_2 = (A_1 \times A_2, B_1 \times B_2)$ is an SIVIFG, where $A_1 \times A_2 = \{< (a, c), [0.4, 0.6], [0.2, 0.4]\}$, $< (b, c), [0.4, 0.6], [0.2, 0.4]\}$, $< ((a, c), (b, c)), [0.4, 0.6], [0.2, 0.4]\}$, and $B_1 \times B_2 = \{< ((a, c), (b, d)), [0.4, 0.6], [0.2, 0.4]\}$. In this example, $G_1$ is an SIVIFG and $G_2$ is an SIVIFG.

Proposition 3.3 Let $G_1$ be a strong interval valued intuitionistic fuzzy graph. Then for any interval valued intuitionistic fuzzy graph $G_2$, $G_1 \times G_2$ is strong interval valued intuitionistic fuzzy graph if and only if

$$M_{A_1 \times A_2}(x, y) = \max \{M_{A_1}(x, y) M_{A_2}(x, y)\},$$

$$N_{A_1 \times A_2}(x, y) = \min \{N_{A_1}(x, y) N_{A_2}(x, y)\},$$

for all $x \in V_1, y \in V_2$.

Definition 3.3 Let $A_1$ and $A_2$ be interval-valued intuitionistic fuzzy subsets of $V_1$ and $V_2$ respectively. Let $B_1$ and $B_2$ be interval valued intuitionistic fuzzy subsets of $E_1$ and $E_2$ respectively. The composition of two strong interval valued intuitionistic fuzzy graphs $G_1$ and $G_2$ is denoted by $G_1 \times G_2 = (A_1 \times A_2, B_1 \times B_2)$.
(\(N_{B_1 \cup B_2}\))(x_1, x_2)(y_1, y_2)) = \max(N_{A_2L}(x_2), N_{A_2U}(y_2), N_{B_1L}(x_1y_1)), \\
(\(N_{B_1 \circ B_2}\))(x_1, x_2)(y_1, y_2)) = \max(N_{A_2L}(x_2), N_{A_2U}(y_2), N_{B_1L}(x_1y_1)), \\
\forall (x_1, x_2)(y_1, y_2) \in E^0 - E \\
Where \(E^0 = E \cup \{(x_1, x_2)(y_1, y_2)|x_1y_1 \in E_1, x_2 \neq y_2 \} \)

The following propositions are stated without their proof.

**Proposition 3.4** If \(G_1\) and \(G_2\) are the strong interval valued intuitionistic fuzzy graph then the composition \(G_1[G_2]\) is a strong interval valued intuitionistic fuzzy graph.

**Proposition 3.5** If \(G_1[G_2]\) is a strong interval valued intuitionistic fuzzy graph then atleast \(G_1\) or \(G_2\) must be strong.

**Example 3.5** Let \(G_1 = (A_1, B_1)\) be an SIVIFG, where \(A_1 = \{< a, [0.6, 0.7], [0.1, 0.3] >, < b, [0.6, 0.7], [0.1, 0.3] >\}\) and \(B_1 = \{< ab, [0.4, 0.6], [0.2, 0.4] >\}\). \(G_2 = (A_2, B_2)\) is not an SIVIFG, where \(A_2 = \{< c, [0.4, 0.6], [0.2, 0.4] >, < d, [0.4, 0.6], [0.2, 0.4] >\}\) and \(B_2 = \{< cd, [0.3, 0.5], [0.3, 0.5] >\}\). \(G_1[G_2]\) is not an SIVIFG, where \(A_1 \circ A_2 = \{< (a, c), [0.4, 0.6], [0.2, 0.4] >, < (a, d), [0.4, 0.6], [0.2, 0.4] >\}\) and \(B_1 \circ B_2 = \{< ((a, c), (a, d)), [0.3, 0.5], [0.3, 0.5] >, < ((a, c), (b, c)), [0.4, 0.6], [0.2, 0.4] >, < ((a, c), (b, d)), [0.4, 0.6], [0.2, 0.4] >, < ((a, d), (b, c)), [0.4, 0.6], [0.2, 0.4] >\}\). In this example, \(G_1\) is an SIVIFG and \(G_2\) is not an SIVIFG, then \(G_1[G_2]\) is not an SIVIFG.

**Example 3.6** Let \(G_1 = (A_1, B_1)\) be an SIVIFG, where \(A_1 = \{< a, [0.4, 0.6], [0.2, 0.4] >, < b, [0.4, 0.6], [0.2, 0.4] >\}\) and \(B_1 = \{< ab, [0.4, 0.6], [0.2, 0.4] >\}\). \(G_2 = (A_2, B_2)\) is a strong interval valued intuitionistic fuzzy graph. Where \(A_1 \circ A_2 = \{< (a, c), [0.4, 0.6], [0.2, 0.4] >, < (a, d), [0.4, 0.6], [0.2, 0.4] >\}\) and \(B_1 \circ B_2 = \{< ((a, c), (a, d)), [0.4, 0.6], [0.2, 0.4] >, < ((a, c), (b, c)), [0.4, 0.6], [0.2, 0.4] >, < ((a, c), (b, d)), [0.4, 0.6], [0.2, 0.4] >, < ((a, d), (b, c)), [0.4, 0.6], [0.2, 0.4] >\}\). In this example, \(G_1\) is an SIVIFG and \(G_2\) is not an SIVIFG, then \(G_1[G_2]\) is an SIVIFG.

**Proposition 3.6** Let \(G_1\) be a strong interval valued intuitionistic fuzzy graph. Then for any interval valued intuitionistic fuzzy graph \(G_2\), \(G_1[G_2]\) is a strong interval valued intuitionistic fuzzy graph if

\[M_{A_1U}(x_1) \leq M_{B_1U}(x_2y_2), N_{A_1U}(x_1) \geq N_{B_1L}(x_2y_2), \forall x_1 \in V_1, x_2y_2 \in E_2\]

**Definition 3.4** Let \(A_1\) and \(A_2\) be interval valued intuitionistic fuzzy subsets of \(V_1\) and \(V_2\) respectively. Let \(B_1\) and \(B_2\) interval valued intuitionistic fuzzy subsets of \(E_1\) and \(E_2\) respectively. The **join** of two strong interval valued intuitionistic fuzzy graphs \(G_1\) and \(G_2\) is denoted by \(G_1 + G_2 = (A_1 + A_2, B_1 + B_2)\) and is defined as follows:

1. \((M_{A_1L} + M_{A_2L})(x) = (M_{A_1L} + M_{A_2L})(x) \) if \(x \in V_1 \cup V_2\)
2. \((M_{A_1U} + M_{A_2U})(x) = (M_{A_1U} + M_{A_2U})(x) \) if \(x \in V_1 \cup V_2\)
3. \((N_{A_1L} + N_{A_2L})(x) = (N_{A_1L} + N_{A_2L})(x) \) if \(x \in V_1 \cup V_2\)

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The join of graphs $G_1^*$ and $G_2^*$ is the simple graph $G_1^* + G_2^* = (V_1 \cup V_2, E_1 \cup E_2 \cup E')$ where $E'$ is the set of all edges joining the nodes of $V_1$ and $V_2$. In this construction it is assumed that $V_1 \cap V_2 = \emptyset$.

**Proposition 3.7** If $G_1$ and $G_2$ are the strong interval valued intuitionistic fuzzy graphs, then $G_1 + G_2$ is a strong interval intuitionistic fuzzy graph.

4 Conclusion
In this paper, Cartesian product, Composition and Join of two SIVIFGs are discussed. Our future plan to extend our research to some other operations on interval valued intuitionistic fuzzy graph.

References