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Some operators on intuitionistic fuzzy sets of root type

R. Srinivasan, N. Palaniappan

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Abstract. In this paper, we define some operators on intuitionistic fuzzy sets of root type and establish their properties.

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Corresponding Author: R. Srinivasan (srinivasanmaths@yahoo.com)

1. Introduction

Fuzzy sets were introduced by Lofti A. Zadeh in 1965 as a generalization of classical (Crisp) sets. Further the Fuzzy Sets are generalized by Krassimir T. Atanassov in which he has taken non-membership values also into consideration and he introduced IFS and its extension IFSST. Following the definition of IFS, the authors introduced the IFSRT In this paper, we define some Operators and establish their properties of newly defined IFSRT.

2. Preliminaries

In this section, we give some definition of various types of IFS.

Definition 2.1 ([1]). Let X be a non empty set. An IFS A in X is defined as an object of the form.

$$A = \{\langle x, \mu_A(x), \nu_A(x)\rangle : x \in X\} \tag{2.1}$$

where the functions

$$\mu_A : X \to [0,1] \quad \text{and} \quad \nu_A : X \to [0,1]$$

denote the membership and non-membership function of A respectively and
$0 \leq \mu_A(x) + \nu_A(x) \leq 1$ for each $x \in X$

Remark. An ordinary fuzzy set can also be generalized as

$$\{\langle x, \mu_A(x), 1-\mu_A(x)\rangle : x \in X\}.$$

Definition 2.2 ([2]). Let X be a non empty set. An intuitionistic fuzzy set of second type (IFSST) A in X is defined as an object of the form

$$A = \{\langle x, \mu_A(x), \nu_A(x)\rangle : x \in X\}$$

where the functions

$$\mu_A : X \to [0,1] \quad \text{and} \quad \nu_A : X \to [0,1]$$

denote the degree of membership and degree of non membership functions of A respectively, and $0 \leq [\mu_A(x)]^2 + [\nu_A(x)]^2 \leq 1$ for each $x \in X$.

Remark. It is obvious that for all real numbers $a, b \in [0,1]$ if $0 \leq a+b \leq 1$ then $0 \leq a^2 + b^2 \leq 1$.

Definition 2.3 ([3]). Let X be a non-empty set. An Intuitionistic Fuzzy Set of Root Type (IFSRT) A in X is defined as an object of the form $A = \{\langle x, \mu_A(x), \nu_A(x)\rangle : x \in X\}$ where the functions $\mu_A : X \to [0,1]$ and $\nu_A : X \to [0,1]$ denote the degree of membership and degree of non membership functions of A respectively, and

$$0 \leq \tfrac{1}{2}\sqrt{\mu_A(x)} + \tfrac{1}{2}\sqrt{\nu_A(x)} \leq 1$$

for each $x \in X$.

Remark. It is trivial that for all real numbers $\alpha, \beta \in [0,1]$ if $0 \leq \alpha + \beta \leq 1$ then $0 \leq \frac{1}{2}\sqrt{a} + \frac{1}{2}\sqrt{\beta} \leq 1$.

Definition 2.4 ([3]). Let X be a non-empty set. Let A and B be two IFSRTs such that

$$A = \{\langle x, \mu_A(x), \nu_A(x)\rangle : x \in X\} \quad (2.2)$$

$$B = \{\langle x, \mu_B(x), \nu_B(x)\rangle : x \in X\} \quad (2.3)$$

Define the following relations and operations on A and B

(i) $A \subset B$ if and only if $\mu_A(x) \leq \mu_B(x)$ and $\nu_A(x) \geq \nu_B(x)$, $\quad \forall\, x \in X$

(ii) $A \supset B$ if and only if $\mu_A(x) \geq \mu_B(x)$ and $\nu_A(x) \leq \nu_B(x)$, $\quad \forall\, x \in X$

(iii) $A = B$ if and only if $\mu_A(x) = \mu_B(x)$ and $\nu_A(x) = \nu_B(x)$, $\quad \forall\, x \in X$

(iv) $A \cup B = \{\langle x, \max(\mu_A(x), \mu_B(x)), \min(\nu_A(x), \gamma_B(x))\rangle : x \in X\}$

(v) $A \cap B = \{\langle x, \min(\mu_A(x), \mu_B(x)), \max(\nu_A(x), \gamma_B(x))\rangle : x \in X\}$

(vi) $A + B = \Big\{\Big\langle x, \sqrt{\mu_A(x)} + \sqrt{\mu_B(x)} - \sqrt{\mu_A(x)}\sqrt{\mu_B(x)}, \sqrt{\nu_A(x)}\sqrt{\nu_B(x)} \Big\rangle : x \in X\Big\}$

(vii) The complement of A is defined by

$$\overline{A} = \{\langle x, \nu_A(x), \mu_A(x)\rangle : x \in X\}$$

Definition 2.5 ([3]). The degree of non-determinacy (uncertainty) of an element $x \in X$ to the IFSRT A is defined by

$$\pi_A(x) = \left(1 - \sqrt{\mu_A(x)} - \sqrt{\nu_A(x)}\right)^2$$

Definition 2.6 ([4])**.** For every IFSRT A, we define the following operators.
The Necessity measure on A.

$$\Box A = \left\{ \left\langle x, \mu_A(x), \left(1 - \sqrt{\mu_A(x)}\,\right)^2 \right\rangle : x \in X \right\}.$$

The Possibility measure on A

$$\Diamond A = \left\{ \left\langle x, \left(1 - \sqrt{\nu_A(x)}\,\right)^2, \nu_A(x) \right\rangle : x \in X \right\}.$$

Definition 2.7 ([5])**.** Let X be a non empty finite set. For every IFSRT $A = \{\langle x, \mu_A(x), \nu_A(x)\rangle : x \in X\}$, we define the following two operators.

$$C(A) = \{\langle x, K, L\rangle : x \in X\},$$

where

$$\begin{aligned} K &= \max_{y \in X} \mu_A(y) \\ L &= \min_{y \in X} \nu_A(y) \text{ and} \end{aligned}$$

$$I(A) = \{\langle x, k, l\rangle : x \in X\}$$

where

$$\begin{aligned} k &= \min_{y \in X} \mu_A(y) \\ l &= \max_{y \in X} \nu_A(y) \end{aligned}$$

We call $C(A)$ and $I(A)$, respectively, as closure and interior of A over the universe X. It is obvious that both $C(A)$ and $I(A)$ are IFSRTs.

Example 2.8. Let $X = \{a, b, c\}$ and let the IFSRT A be

$$A = \{\langle a, 0.2, 0.3\rangle, \langle b, 0.4, 0.4\rangle, \langle c, 0.6, 0.2\rangle\}.$$

Then $C(A) = \{\langle x, 0.6, 0.2\rangle : x \in X\}$, and $I(A) = \{\langle x, 0.2, 0.4\rangle : x \in X\}$ are IFSRTs.

3. The operators D_α and $F_{\alpha,\beta}$

Define the operators D_α and $F_{\alpha,\beta}$ for $\alpha, \beta \in [0,1]$, $\alpha + \beta \le 1$. The later operator will be an extension of the former. Let $\alpha \in [0,1]$ be a fixed number.

Definition 3.1. Given an IFSRT A, an operator D_α is defined by

$$D_\alpha(A) = \left\{ \left\langle x, \left(\sqrt{\mu_A(x)} + \alpha\sqrt{\pi_A(x)}\right)^2, \left(\sqrt{\nu_A(x)} + (1-\alpha)\sqrt{\pi_A(x)}\right)^2 \right\rangle : x \in X \right\}$$

Clearly, $D_\alpha(A)$ is an IFSRT.

Proposition 3.2. *For every IFSRT A and for every $\alpha, \beta \in [0,1]$, we have*

(i) *If $\alpha \le \beta$ then $D_\alpha(A) \subset D_\beta(A)$*
(ii) *$D_0(A) = \Box A$ and*
(iii) *$D_1(A) = \Diamond A$.*

Proof. Let $A = \{\langle x, \mu_A(x), \nu_A(x)\rangle : x \in X\}$ be an IFSRT. Then

$$D_\alpha(A) = \left\{\left\langle x, \left(\sqrt{\mu_A(x)} + \alpha\sqrt{\pi_A(x)}\right)^2, \left(\sqrt{\nu_A(x)} + (1-\alpha)\sqrt{\pi_A(x)}\right)^2\right\rangle : x \in X\right\}$$

and

$$D_\beta(A) = \left\{\left\langle x, \left(\sqrt{\mu_A(x)} + \beta\sqrt{\pi_A(x)}\right)^2, \left(\sqrt{\nu_A(x)} + (1-\beta)\sqrt{\pi_A(x)}\right)^2\right\rangle : x \in X\right\}.$$

Now

$$\begin{aligned}\left(\sqrt{\mu_A(x)} + \alpha\sqrt{\pi_A(x)}\right)^2 &= \mu_A(x) + \alpha^2\pi_A(x) + 2\alpha\sqrt{\mu_A(x)}\sqrt{\pi_A(x)} \\ &\leq \mu_A(x) + \beta^2\pi_A(x) + 2\beta\sqrt{\mu_A(x)}\sqrt{\pi_A(x)} \\ &= \left(\sqrt{\mu_A(x)} + \beta\sqrt{\pi_A(x)}\right)^2\end{aligned}$$

since $\alpha < \beta$ implies $\alpha^2 < \beta^2$ and $(1-\alpha)^2 > (1-\beta)^2$. Also

$$\begin{aligned}&\left(\sqrt{\nu_A(x)} + (1-\beta)\sqrt{\pi_A(x)}\right)^2 = \nu_A(x) + (1-\beta)^2\pi_A(x) + 2\sqrt{\nu_A(x)}(1-\beta)\sqrt{\pi_A(x)} \\ &\leq \nu_A(x) + (1-\alpha)^2\pi_A(x) + 2\sqrt{\nu_A(x)}(1-\alpha)\sqrt{\pi_A(x)} \\ &= \left(\sqrt{\nu_A(x)} + (1-\alpha)\sqrt{\pi_A(x)}\right)^2\end{aligned}$$

since $\alpha < \beta$ implies $1-\alpha > 1-\beta$ which inturn implies $(1-\alpha)^2 > (1-\beta)^2$
It follows that $D_\alpha(A) \subset D_\beta(A)$, which proves (i)

(ii) Now

$$\begin{aligned}D_0(A) &= \left\{\left\langle x, \left(\sqrt{\mu_A(x)} + 0\right)^2, \left(\sqrt{\nu_A(x)} + \sqrt{\pi_A(x)}\right)^2\right\rangle : x \in X\right\} \\ &= \left\{\left\langle x, \mu_A(x), \left(1 - \sqrt{\mu_A(x)}\right)^2\right\rangle : x \in X\right\} = \Box A,\end{aligned}$$

since $\sqrt{\pi_A(x)} = 1 - \sqrt{\mu_A(x)} - \sqrt{\nu_A(x)}$, which proves (ii). Next

$$\begin{aligned}D_1(A) &= \left\{\left\langle x, \left(\sqrt{\mu_A(x)} + \sqrt{\pi_A(x)}\right)^2, \left(\sqrt{\nu_A(x)}\right)^2\right\rangle : x \in X\right\} \\ &= \left\{\left\langle x, \left(1 - \sqrt{\nu_A(x)}\right)^2, \nu_A(x)\right\rangle : x \in X\right\} = \Diamond A,\end{aligned}$$

since $\sqrt{\pi_A(x)} = 1 - \sqrt{\mu_A(x)} - \sqrt{\nu_A(x)}$, which proves (iii) □

Remark: The operator D_α is an extension of the operators □ and ◇

Definition 3.3. The operator $F_{\alpha,\beta}$ for an IFSRT A is defined by

$$F_{\alpha,\beta}(A) = \left\{\left\langle x, \left(\sqrt{\mu_A(x)} + \alpha\sqrt{\pi_A(x)}\right)^2, \left(\sqrt{\nu_A(x)} + \beta\sqrt{\pi_A(x)}\right)^2\right\rangle : x \in X\right\}$$

Theorem 3.4. *For every IFSRT A and for every $\alpha, \beta, \gamma \in [0,1]$ such that $\alpha+\beta \leq 1$, then*

(i) *$F_{\alpha,\beta}(A)$ is an IFSRT*
(ii) *If $0 \leq \gamma \leq \alpha$ then $F_{\gamma,\beta}(A) \subset F_{\alpha,\beta}(A)$*

(iii) *If* $0 \leq \gamma \leq \beta$ *then* $F_{\alpha,\beta}(A) \subset F_{\alpha,\gamma}(A)$
(iv) $D_\alpha(A) = F_{\alpha,1-\alpha}(A)$
(v) $\Box A = F_{0,1}(A)$
(vi) $\Diamond A = F_{1,0}(A)$
(vii) $\overline{F_{\alpha,\beta}(\overline{A})} = F_{\beta,\alpha}(A)$

Proof. (i) Now

$$\frac{\sqrt{\mu_A(x)}+a\sqrt{\pi_A(x)}}{2} + \frac{\sqrt{\nu_A(x)}+\beta\sqrt{\pi_A(x)}}{2} = \frac{\sqrt{\mu_A(x)}}{2} + \frac{\sqrt{\nu_A(x)}}{2} + \frac{\sqrt{\pi_A(x)}}{2}(\alpha+\beta)$$
$$\leq \frac{\sqrt{\mu_A(x)}}{2} + \frac{\sqrt{\nu_A(x)}}{2} + \frac{1-\sqrt{\mu_A(x)}-\sqrt{\nu_A(x)}}{2} \leq \frac{1}{2} < 1.$$

Hence $F_{\alpha,\beta}(A)$ is an IFSRT.

(ii) We have

$$F_{\gamma,\beta}(A) = \left\{\left\langle x, \left(\sqrt{\mu_A(x)} + \gamma\sqrt{\pi_A(x)}\right)^2, \left(\sqrt{\nu_A(x)} + \beta\sqrt{\pi_A(x)}\right)^2\right\rangle : x \in X\right\}$$
$$F_{\alpha,\beta}(A) = \left\{\left\langle x, \left(\sqrt{\mu_A(x)} + \alpha\sqrt{\pi_A(x)}\right)^2, \left(\sqrt{\nu_A(x)} + \beta\sqrt{\pi_A(x)}\right)^2\right\rangle : x \in X\right\}.$$

Now,

$$\begin{aligned}\left(\sqrt{\mu_A(x)} + \gamma\sqrt{\pi_A(x)}\right)^2 &= \mu_A(x) + \gamma^2\pi_A(x) + 2\gamma\sqrt{\mu_A(x)}\sqrt{\pi_A(x)} \\ &\leq \mu_A(x) + \alpha^2\pi_A(x) + 2\alpha\sqrt{\mu_A(x)}\sqrt{\pi_A(x)} \\ &= \left(\sqrt{\mu_A(x)} + \alpha\sqrt{\pi_A(x)}\right)^2, \text{since } \ \gamma \leq \alpha.\end{aligned}$$

Hence by definition 2.4 (i) it follows that $F_{\gamma,\beta}(A) \subset F_{\alpha,\beta}(A)$. The proof of (iii) is similar

(iv) Now

$$F_{\alpha,1-\alpha} = \left\{\left\langle x, \left(\sqrt{\mu_A(x)} + \alpha\sqrt{\pi_A(x)}\right)^2, \left(\sqrt{\nu_A(x)} + (1-\alpha)\sqrt{\pi_A(x)}\right)^2\right\rangle : x \in X\right\}$$
$$= D_\alpha(A).$$

Remark: If $\alpha + \beta = 1$ then $F_{\alpha,\beta}$ coincides with D_α

(v) We have
$$\begin{aligned} F_{0,1}(A) &= \left\{\left\langle x, \left(\sqrt{\mu_A(x)}\right)^2, \left(\sqrt{\nu_A(x)} + \sqrt{\pi_A(x)}\right)^2\right\rangle : x \in X\right\} \\ &= \left\{\left\langle x, \mu_A(x), \left(1 - \sqrt{\mu_A(x)}\right)^2\right\rangle : x \in X\right\} \\ &= \Box A, \ \text{ since } \sqrt{\pi_A(x)} = 1 - \sqrt{\mu_A(x)} - \sqrt{\nu_A(x)}. \end{aligned}$$

(vi)
$$\begin{aligned} F_{1,0}(A) &= \left\{\left\langle x, \left(\sqrt{\mu_A(x)} + \sqrt{\pi_A(x)}\right)^2, \left(\sqrt{\nu_A(x)}\right)^2\right\rangle : x \in X\right\} \\ &= \left\{\left\langle x, \left(1 - \sqrt{\nu_A(x)}\right)^2, \nu_A(x)\right\rangle : x \in X\right\} \\ &= \Diamond A, \ \text{ since} \sqrt{\pi_A(x)} = 1 - \sqrt{\mu_A(x)} - \sqrt{\nu_A(x)}. \end{aligned}$$

(vii)

$$F_{\alpha,\beta}(\overline{A}) = \left\{\left\langle x, \left(\sqrt{\nu_A(x)} + \alpha\sqrt{\pi_A(x)}\right)^2, \left(\sqrt{\mu_A(x)} + \beta\sqrt{\pi_A(x)}\right)^2\right\rangle : x \in X\right\}$$
$$\overline{F_{\alpha,\beta}(\overline{A})} = \left\{\left\langle x, \left(\sqrt{\mu_A(x)} + \beta\sqrt{\pi_A(x)}\right)^2, \left(\sqrt{\nu_A(x)} + \alpha\sqrt{\pi_A(x)}\right)^2\right\rangle : x \in X\right\}$$
$$\overline{F_{\alpha,\beta}(\overline{A})} = F_{\beta,\alpha}(A).$$
□

4. The Operator $G_{\alpha,\beta}$

Definition 4.1. Let $\alpha, \beta \in [0,1]$. Given an IFSRT A, we define the operator

$$G_{\alpha,\beta}(A) = \left\{\left\langle x, \alpha^2\mu_A(x), \beta^2\nu_A(x)\right\rangle : x \in X\right\}$$

Obviously, $G_{1,1}(A) = A \quad G_{0,0}(A) = \overline{U}$, where $\overline{U} = \{\langle x, 0, 0\rangle : x \in X\}$.

Theorem 4.2. *For every IFSRT A, and for every three real numbers $\alpha, \beta, \gamma \in [0,1]$*

(i) $G_{\alpha,\beta}(A)$ *is an IFSRT*
(ii) *If $\alpha \leq \gamma$ then $G_{\alpha,\beta}(A) \subset G_{\gamma,\beta}(A)$*
(iii) *If $\beta \leq \gamma$ then $G_{\alpha,\beta}(A) \supset G_{\alpha,\gamma}(A)$*
(iv) *If $\delta \in [0,1]$ then. $G_{\alpha,\beta}(G_{\gamma,\delta}(A)) = G_{\alpha\gamma,\beta\delta}(A) = G_{\gamma,\delta}(G_{\alpha,\beta}(A))$*
(v) $G_{\alpha,\beta}(C(A)) = C(G_{\alpha,\beta}(A))$
(vi) $G_{\alpha,\beta}(I(A)) = I(G_{\alpha,\beta}(A))$
(vii) $\overline{G_{\alpha,\beta}(\overline{A})} = G_{\beta,\alpha}(A)$

Proof. (i) Now $G_{\alpha,\beta}(A) = \left\{\left\langle x, \alpha^2\mu_A(x), \beta^2\nu_A(x)\right\rangle : x \in X\right\}$. Clearly $G_{\alpha,\beta}(A)$ is an IFSRT.

(ii) We have

$$G_{\alpha,\beta}(A) = \left\{\left\langle x, \alpha^2\mu_A(x), \beta^2\nu_A(x)\right\rangle : x \in X\right\}$$

and

$$G_{\gamma,\beta}(A) = \left\{\left\langle x, \gamma^2\mu_A(x), \beta^2\nu_A(x)\right\rangle : x \in X\right\}.$$

Since $\alpha \leq \gamma$ then $\alpha^2 \leq \gamma^2$, we have $\alpha^2\mu_A(x) \leq \gamma^2\mu_A(x)$. Hence $G_{\alpha,\beta}(A) \subset G_{\gamma,\beta(A)}$.

(iii) The proof is similar.

(iv) Now $G_{\gamma,\delta}(A) = \left\{\left\langle x, \gamma^2\mu_A(x), \delta^2\nu_A(x)\right\rangle : x \in X\right\}$,

$$\begin{aligned} G_{\alpha,\beta}(G_{\gamma,\delta}(A)) &= \left\{\left\langle x, \alpha^2\gamma^2\mu_A(x), \beta^2\delta^2\nu_A(x)\right\rangle : x \in X\right\} \\ &= \left\{\left\langle x, (\alpha\gamma)^2\mu_A(x), (\beta\delta)^2\nu_A(x)\right\rangle : x \in X\right\} \\ &= G_{\alpha\gamma,\beta\delta}(A) \qquad (4.1) \\ G_{\gamma,\delta}(G_{\alpha,\beta}(A)) &= \left\{\left\langle x, \gamma^2\alpha^2\mu_A(x), \delta^2\beta^2\nu_A(x)\right\rangle : x \in X\right\} \\ &= \left\{\left\langle x, (\gamma\alpha)^2\mu_A(x), (\delta\beta)^2\nu_A(x)\right\rangle : x \in X\right\} \\ &= \left\{\left\langle x, (\alpha\gamma)^2\mu_A(x), (\beta\delta)^2\nu_A(x)\right\rangle : x \in X\right\} \\ &= G_{\alpha\gamma,\beta\delta}(A) \qquad (4.2) \end{aligned}$$

From (4.1) and (4.2) it follows that

$$G_{\alpha,\beta}(G_{\gamma,\delta}(A)) = G_{\alpha\gamma,\beta\delta}(A) = G_{\gamma,\delta}(G_{\alpha,\beta}(A))$$

(v) $C(A) = \{\langle x, \max_{y\in X} \mu_A(y), \min_{y\in X} \nu_A(y)\rangle : x \in X\}$,

$$\begin{aligned} G_{\alpha,\beta}(C(A)) &= \left\{\left\langle x, \alpha^2 \max_{y\in X} \mu_A(y), \beta^2 \min_{y\in X} \nu_A(y)\right\rangle : x \in X\right\} \\ &= \left\{\left\langle x, \max_{y\in X} \alpha^2 \mu_A(y), \min_{y\in X} \beta^2 \nu_A(y)\right\rangle : x \in X\right\} \\ &= C\left(G_{\alpha,\beta}(A)\right) \end{aligned}$$

(vi)

$$\begin{aligned} I(A) &= \left\{\left\langle x, \min_{y\in X} \mu_A(y), \max_{y\in X} \nu_A(y)\right\rangle : x \in X\right\} \\ G_{\alpha,\beta}(I(A)) &= \left\{\left\langle x, \alpha^2 \min_{y\in X} \mu_A(y), \beta^2 \max_{y\in X} \nu_A(y)\right\rangle : x \in X\right\} \\ &= \left\{\left\langle x, \min_{y\in X} \alpha^2 \mu_A(y), \max_{y\in X} \beta^2 \nu_A(y)\right\rangle : x \in X\right\} \\ &= I\left(G_{\alpha,\beta}(A)\right) \quad \text{since} \quad \alpha, \beta \in [0, 1] \end{aligned}$$

(vii) Let $A = \{\langle x, \mu_A(x), \nu_A(x)\rangle : x \in X\}$ be an IFSRT. Then
$\overline{A} = \{\langle x, \nu_A(x), \mu_A(x)\rangle : x \in X\}$,
$G_{\alpha,\beta}(A) = \left\{\left\langle x, \alpha^2\mu_A(x), \beta^2\nu_A(x)\right\rangle : x \in X\right\}$,
$G_{\alpha,\beta}(\overline{A}) = \left\{\left\langle x, \alpha^2\nu_A(x), \beta^2\mu_A(x)\right\rangle : x \in X\right\}$,
$\overline{G_{\alpha,\beta}(\overline{A})} = \left\{\left\langle x, \beta^2\mu_A(x), \alpha^2\nu_A(x)\right\rangle : x \in X\right\}$,
$\overline{G_{\alpha,\beta}(\overline{A})} = G_{\beta,\alpha}(A)$. □

5. Conclusion

We have made an attempt to establish some operators on IFSRT. It is still open to check whether there exist an IFSRT in case of the operators already defined on an IFS.

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R. SRINIVASAN (srinivasanmaths@yahoo.com)
Department of Mathematics, Islamiah College, Vaniyambadi, India.

N. PALANIAPPAN (palaniappan.nallappan@gmail.com)
Department of Mathematics, Alagappa University, Karaikudi, India.