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*Research Article*

# STATISTICAL CONVERGENT FUNCTIONS VIA IDEALS WITH RESPECT TO THE INTUITIONISTIC FUZZY 2-NORMED SPACES*

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## Abstract

The main objective of this paper is to introduce and study the notion of ideal λ -statistical convergence of a nonnegative real-valued Lebesque measurable function in the interval $(1,\infty)$ with respect to the intuitionistic fuzzy 2-normed $(\mu,\nu)$. We gave some introduction definitions such as statistical convergence, λ-statistical convergence, intuitionistic fuzzy sets, and so on.Than we investigated their relationship, and made some observations about these classes. Further, we prove some inclusion theorems.

***Keywords: Statistical convergence, intuitionistic fuzzy, ideals.***

*Araştırma Makalesi*

## *SEZGİSEL BULANIK 2-NORMLU UZAYLAR ÜZERİNDE IDEALLER İLE İSTATİSTİKSEL YAKINSAK FONKSİYONLAR*

## Öz

Bu makalenin başlıca amacı, sezgisel bulanık 2-normlu uzaylar $(\mu,\nu)$.üzerinde, $(1,\infty)$ aralığında tanımlı, sıfırdan farklı reel değerli Lebesque ölçülebilir, λ-istatistiksel yakınsak fonksiyonları tanıtmaktır. İstatistiksel Yakınsaklık, λ-istatistiksel yakınsaklık, sezgisel bulanık kümeler ve benzer tanımları verdik.Daha sonra, gözlemlenen bazı sınıflandırmalar yaptık ve bu sınıflar arasındaki ilişkileri inceledik. Ayrıca, bazı sonuç teoremleri de ispatlanacaktır.

***Anahtar kelimeler: İstatistiksel yakınsaklık, sezgisel bulanık, ideal.***

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## 1.INTRODUCTION

The concept of statistical convergence has been introduced by Fast (Fast,1951,241-244) in 1951 and than developed extensivel in different directions by Connor (Connor,1988,47-63), Fridy (Fridy,1985,301-313), Šalát (Šalát,1980,139-150) and many others.

A number sequence $t = (t_k)$ is said to be statistically convergent to $C$ if for every $\epsilon > 0$, $\delta\left(\left\{k \in \mathbb{N} : |t_k - C| \geq \epsilon\right\}\right) = 0.$ If $(t_k)$ is statistically convergent to $C$, we write $st - \lim t_k = C$.

Furthermore, Kostyrko et al. (Kostyrko vd,2001,669-685) introduced a very interesting generalization of statistical convergence called as $\mathcal{I}$-convergence. More about this convergence can be found in (Savas and Das, 2011, 826-830). We should mention here that the idea of $\lambda$-statistical convergence was introduced by Mursaleen (Mursaleen, 2000, 111-115).

Following the introduction of fuzzy set theory by Zadeh (Zadeh,1965,338-353), there has been extensive research to find applications and fuzzy analogues of the classical theories. The theory of intuitionistic fuzzy sets was introduced by Atanassov (Atanassov,1986,87-96); it has been extensively used in decision-making problems (Atanassov vd.,2000,115-119). The concept of an intuitionistic fuzzy metric space was introduced by Park (Park,2004,1039-1046). Furthermore, Saadati and Park (Saadati and Park,2006,331-344) gave the notion of an intuitionistic fuzzy normed space. So far, a good number of research works have been done on various types of intuitionistic fuzzy normed space for instances, (see (Mohiuddine and Lohani,2009,1731-1737 ; Savas and Gurdal, 2014,1621-1629 ; Savas,2015,59-63 ; Savas and Gurdal, 2015, 1513-1874))

However, in (Colak,2010,121-129 ; Colak and Bektaş,2011,953-959) a different direction was given to the study of these important summability methods where the notions of statistical convergence of order $\alpha$ and $\lambda$-statistical convergence of order $\alpha$ were introduced and studied. In this note we intend to introduce the concept of $\mathcal{I}_\lambda$-statistical convergence of order $\alpha$ for a nonnegative real-valued Lebesque measurable function in the interval $(1,\infty)$ by using ideal with respect to the intuitionistic fuzzy 2-normed space $(\mu, v)$ and investigate some of its consequences. We now recall some notation and basic definitions used in the paper.

**Definition 1** A binary operation $*:[0,1]\times[0,1]\to[0,1]$ is said to be a continuous t−norm if the following conditions are satisfied
1. * is associative and commutative,
2. * is continuous,
3. $a * 1 = a$ for all $a \in [0, 1]$ ,
4. $a * b \le c * d$ whenever $a \le c$ and $b \le d$ for each $a, b, c, d \in [0, 1]$ .

**Definition 2** A binary operation $\lozenge:[0,1]\times[0,1]\to[0,1]$ is said to be a continuous t-conorm if it satisfies the following conditions:
1. $\lozenge$ is associate and commutative,
2. $\lozenge$ is continuous,
3. $k\lozenge 0 = k$ for all $k\in[0,1]$,
4. $k\lozenge l \le q\lozenge p$ whenever $k \le q$ and $l \le p$ for each $k,l,q,p\in[0,1]$.

Gähler, [Gähler, S., 1965, 1-43], presented the below concept of 2-normed space.

**Definition 3** Let $K$ be a real vector space of dimension $n$, where $2\le n<\infty$. A 2-norm on $K$ is a function $\|\cdot,\cdot\|: K\times K\to\mathbb{R}$ which satisfies,
1. $\|x,y\|=0$ if and only if $x$ and $y$ are linearly dependent;
2. $\|x,y\|=\|y,x\|$;
3. $\|\alpha x,y\|=|\alpha|\|x,y\|$;
4. $\|x,y+z\|\le\|x,y\|+\|x,z\|$.

The pair $(K,\|\cdot,\cdot\|)$ is then called a 2-normed space.

Mursaleen and Lohani (Mursaleen and Lohani ,2009, 224-234) used the idea of 2-normed space to define the intuitionistic fuzzy 2-normed space.

**Definition 4** The five-tuple $(K,\mu,v,*,\lozenge)$ is said to be an intuitionistic fuzzy 2-norm space (for short, IF2NS) if $K$ is a vector space, $*$ is continuous t-norm, $\lozenge$ is continuous t-conorm, and $\mu,v$ are fuzzy sets on $K\times K\times(0,\infty)$ satisfying the following conditions for every $x,y\in K$ and $p,s>0$.
1. $\mu(x,y;p)+v(x,y;p)\le 1$,
2. $\mu(x,y;p)>0$
3. $\mu(x,y;p)=1$ if and only if $x$ and $y$ are linearly dependent,
4. $\mu(\alpha x,y;p)=\mu(x,y;\frac{p}{|\alpha|})$ for each $\alpha\ne 0$,

5. $\mu(x,y;p)*\mu(x,z;s) \leq \mu(x,y+z;p+s)$,
6. $\mu(x,y;.):(0,\infty)\to[0,1]$ is continuous,
7. $\lim_{p\to\infty}\mu(x,y;p)=1$ and $\lim_{p\to 0}\mu(x,y;p)=0$,
8. $\mu(x,y;p)=\mu(y,x;p)$
9. $v(x,y;p)<1$,
10. $v(x,y;p)=0$ if and only if $x$ and $y$ are linearly dependent,
11. $v(\alpha x,y;p)=v(x,y;\frac{p}{|\alpha|})$ for each $\alpha\neq 0$,
12. $v(x,y;p)\Diamond v(x,z;s)\geq v(x,y+z;p+s)$,
13. $v(x,y;.):(0,\infty)\to[0,1]$ is continuous,
14. $\lim_{p\to\infty}v(x,y;p)=0$ and $\lim_{p\to 0}v(x,y;p)=1$,
15. $v(x,y;p)=v(y,x;p)$

In this case $(\mu,v)$ is called an intuitionistic fuzzy 2-normed on $K$, and we denote it by $(\mu,v)_2$.

## 2. $\mathcal{I}_\lambda$ -STATISTICAL CONVERGENCE OF A NONNEGATIVE REAL-VALUED FUNCTION ON IF2NS

Before we can begin, it will be necessary to introduce some definitions and notation.

**Definition 5** A non-empty family $\mathcal{I}\subset 2^{\mathbb{N}}$ is said to be an ideal of $\mathbb{N}$ if the following conditions hold:
1. $R,S\in\mathcal{I}$ imply $R\cup S\in\mathcal{I}$,
2. $R\in\mathcal{I}, S\subset R$ imply $S\in\mathcal{I}$.

**Definition 6** A non-empty family $\mathcal{F}\subset 2^{\mathbb{N}}$ is said to be a filter of $\mathbb{N}$ if the following conditions hold:
1. $\varnothing\notin\mathcal{F}$,
2. $R,S\in\mathcal{F}$ imply $R\cap S\in\mathcal{F}$,
3. $R\in\mathcal{F}, R\subset S$ imply $S\in\mathcal{F}$.

If $\mathcal{I}$ is a proper nontrivial ideal of $\mathbb{N}$ (i.e $\mathbb{N} \notin \mathcal{I}$), then the family of sets $F(\mathcal{I}) = \{M \subset \mathbb{N} : \exists R \in \mathcal{I} : M = \mathbb{N} \setminus R\}$ is a filter of $\mathbb{N}$. It is called the filter associated with the ideal $\mathcal{I}$. A proper ideal $\mathcal{I}$ is said to be admissible if $\{n\} \in \mathcal{I}$ for each $n \in \mathbb{N}$.

**Definition 7** A sequence $(x_n)$ of elements of $\mathbb{R}$ is said to be $\mathcal{I}$-convergent to $C \in \mathbb{R}$ if for each $\epsilon > 0$ the set $A(\epsilon) = \{n \in \mathbb{N} : |x_n - C| \geq \epsilon\} \in \mathcal{I}$.
Throughout by function $x(t)$ we shall mean a nonnegative real-valued Lebesque measurable function in the interval $(1, \infty)$. $\mathbb{N}$ will stand for the set of natural numbers.

Let $\varphi = \varphi_n$ be a non-decreasing sequence of positive numbers tending to $\infty$ such that $\varphi_{n+1} \leq \varphi_n + 1$, $\varphi_1 = 1$. The collection of such a sequence $\varphi$ will be denoted by $\Delta$. The generalized de Valee-Pousin mean is defined by
$t_n(x) = \frac{1}{\varphi_n} \sum_{k \in I_n} x_k$ where $I_n = [n - \varphi_n + 1, n]$.
We are now ready to define our main results.

**Definition 8** Let $(K, \mu, v, *, \Diamond)$ be an intuitionistic fuzzy 2-normed space. Then, a function $x(t)$ is said to be $\mathcal{I}$-statistically convergent of order $\alpha$ to $C \in K$ where $0 < \alpha \leq 1$, with respect to the intuitionistic fuzzy 2-normed space $(\mu, v)$, if for every $\epsilon > 0$, and every $\delta > 0$, $p > 0$, and for non zero $z \in K$.

$$\left\{ n \in \mathbb{N} : \frac{1}{n^\alpha} \left| \left\{ \begin{array}{l} t \leq n : \mu(x(t) - C, z; p) \leq 1 - \epsilon \\ or\ v(x(t) - C, z; p) \geq \epsilon \end{array} \right\} \right| \geq \delta \right\} \in \mathcal{I}.$$

In this case we write $x(t) \xrightarrow{(\mu, v)} C(S^\alpha(\mathcal{I})^{(\mu,v)_2})$.

**Remark 1** For
$\mathcal{I} = \mathcal{I}_{fin} = \{A \subseteq \mathbb{N} : A \textit{ is a finite subset}\}$,
$\mathcal{I}$-statistically convergent of order $\alpha$ with respect to IF2NS for functions coincides with statistical convergence of order $\alpha$ with respect to IF2NS. For an arbitrary ideal $\mathcal{I}$ and for $\alpha = 1$ it coincides with $\mathcal{I}$-statistical convergence with respect to IF2NS (Savas,2015,59-63). When $\mathcal{I} = \mathcal{I}_{fin}$ and $\alpha = 1$ it becomes only statistical convergence with respect to IF2NS, (Savas,2015,59-63).

**Definition 9** Let $(K,\mu,v,*,\Diamond)$ be an intuitionistic fuzzy 2-normed space. Then, a function $x(t)$ is said to be $[V,\varphi](\mathcal{I})$-summable to $C \in K$ of order $\alpha$ to $C \in K$, where $0<\alpha\leq 1$, with respect to the intuitionistic fuzzy 2-normed space $(\mu,v)$, if for every $\epsilon>0$, and $\delta>0, p>0$, and for non zero $z \in K$

$$\left\{ n\in\mathbb{N}: \frac{1}{\varphi_n^\alpha}\left|\int_{n-\varphi_n+1}^{n}\begin{Bmatrix} t\leq n: \mu(x(t)-C,z;p)\leq 1-\epsilon \\ or\ v(x(t)-C,z;p)\geq\epsilon \end{Bmatrix}\right| \geq \delta \right\} \in \mathcal{I}.$$

In this case we write $[V,\varphi]^\alpha(\mathcal{I})^{(\mu,v)_2}-\lim x = C$.

**Definition 10** A function $x(t)$ is said to be $\mathcal{I}_\lambda$-statistically convergent or $S_\varphi^\alpha(\mathcal{I})$ convergent of order $\alpha$ to $C \in K$, where $0<\alpha\leq 1$, with respect to the intuitionistic fuzzy 2-normed space $(\mu,v)$, if for every $\epsilon>0$, and $\delta>0, p>0$, and for non zero $z \in X$

$$\left\{ n\in\mathbb{N}: \frac{1}{\varphi_n^\alpha}\left|\begin{Bmatrix} t\in I_n: \mu(x(t)-C,z;p)\leq 1-\epsilon \\ or\ v(x(t)-C,z;p)\geq\epsilon \end{Bmatrix}\right| \geq \delta \right\} \in \mathcal{I}.$$

In this case we write $S_\varphi^\alpha(\mathcal{I})^{(\mu,v)_2}-\lim x = C$ or $x(t)\to C(S_\varphi^\alpha(\mathcal{I})^{(\mu,v)_2})$.

**Remark 2** For
$\mathcal{I}=\mathcal{I}_{fin}=\{A\subseteq\mathbb{N}: A\ is\ a\ finite\ subset\}$,
$\mathcal{I}_\varphi$-statistically convergent of order $\alpha$ with respect to the intuitionistic fuzzy 2-normed space $(\mu,v)$ coincides with $\varphi$-statistical convergence of order $\alpha$ with respect to the intuitionistic fuzzy 2-normed space. For an arbitrary ideal $\mathcal{I}$ and for $\alpha=1$ it coincides with $\mathcal{I}_\varphi$-statistical convergence with respect to the intuitionistic fuzzy 2-normed space $(\mu,v)$, (Savas,2015,59-63). When $\mathcal{I}=\mathcal{I}_{fin}$ and $\alpha=1$ it becomes only $\varphi$-statistical convergence with respect to the intuitionistic fuzzy 2-normed space $(\mu,v)$, (Savas,2015,59-63). We shall denote by $S^\alpha(\mathcal{I})^{(\mu,v)_2}$, $S_\varphi^\alpha(\mathcal{I})^{(\mu,v)_2}$, and $[V,\lambda]_\varphi^\alpha(\mathcal{I})^{(\mu,v)_2}$ the collections of all $\mathcal{I}$-statistically convergent of order $\alpha$, $S_\varphi^\alpha(\mathcal{I})^{(\mu,v)_2}$-convergent of order $\alpha$ and $[V,\varphi]_\varphi^\alpha(\mathcal{I})^{(\mu,v)_2}$-convergent of order $\alpha$ sequences respectively.

**Theorem 1** Let $(K,\mu,v,*,\lozenge)$ be an intuitionistic fuzzy 2-normed space, $\varphi=(\varphi_n)$ be a sequence in $\Delta$ and let $0<\alpha\le\beta\le 1$. Then
$S_\varphi^\alpha(\mathcal{I})^{(\mu,v)_2}\subset S_\varphi^\beta(\mathcal{I})^{(\mu,v)_2}$.

Proof. Let $0<\alpha\le\beta\le 1$. For given $\epsilon>0$, every $p>0$, and for non zero $z\in X$, we write

$$\frac{\left|\left\{t\in I_n:\mu(x(t)-C,z;p)\le 1-\epsilon \ or\ v(x(t)-C,z;p)\ge\epsilon\right\}\right|}{\varphi_n^\beta}$$

$$\le\frac{\left|\left\{t\in I_n:\mu(x(t)-C,z;p)\le 1-\epsilon \ or\ v(x(t)-C,z;p)\ge\epsilon\right\}\right|}{\varphi_n^\alpha}$$

and so for any $\delta>0$,

$$\left\{n\in\mathbb{N}:\frac{\left|\left\{t\in I_n:\mu(x(t)-C,z;p)\le 1-\epsilon \ or\ v(x(t)-C,z;p)\ge\epsilon\right\}\right|}{\varphi_n^\beta}\ge\delta\right\}$$

$$\subset\left\{n\in\mathbb{N}:\frac{\left|\left\{t\in I_n:\mu(x(t)-C,z;p)\le 1-\epsilon \ or\ v(x(t)-C,z;p)\ge\epsilon\right\}\right|}{\varphi_n^\alpha}\ge\delta\right\}.$$

Hence if the set on the right hand side belongs to the ideal $\mathcal{I}$ then obviously the set on the left hand side also belongs to $\mathcal{I}$. This shows that
$S_\varphi^\alpha(\mathcal{I})^{(\mu,v)_2}\subset S_\varphi^\beta(\mathcal{I})^{(\mu,v)_2}$.

**Corollary 1** If a function is $\mathcal{I}_\varphi$-statistically convergent of order $\alpha$ to $C$ for some $0<\alpha\le 1$, then it is $\mathcal{I}_\varphi$-statistically convergent to $C$ i.e.
$S_\varphi^\alpha(\mathcal{I})^{(\mu,v)_2}\subset S_\varphi(\mathcal{I})^{(\mu,v)_2}$.
Similarly we can show that

**Theorem 2** Let $(K,\mu,v,*,\lozenge)$ be an intuitionistic fuzzy 2-normed space and let $0<\alpha\le\beta\le 1$. Then

1. $S_\varphi^\alpha(\mathcal{I})^{(\mu,v)_2}\subset S_\varphi^\beta(\mathcal{I})^{(\mu,v)_2}$,
2. $[V,\varphi]_\varphi^\alpha(\mathcal{I})^{(\mu,v)_2}\subset[V,\varphi]_\varphi^\beta(\mathcal{I})^{(\mu,v)_2}$,
3. $S^\alpha(\mathcal{I})^{(\mu,v)_2}\subset S(\mathcal{I})^{(\mu,v)_2}$ and $[V,\varphi]^\alpha(\mathcal{I})^{(\mu,v)_2}\subset[V,\varphi](\mathcal{I})^{(\mu,v)_2}$.

**Theorem 3** Let $(K,\mu,v,*,\Diamond)$ be an intuitionistic fuzzy 2-normed space, $\varphi=(\varphi_n)$ be a sequence in $\Delta$. If $x(t)\to L[V,\varphi]_{\varphi}^{\alpha}(\mathcal{I})^{(\mu,v)_2}$, then $x(t)\to C(S_{\varphi}^{\alpha}(\mathcal{I})^{(\mu,v)_2})$.

Proof. This can be proved by using the techniques similar to those used in Theorem 1 of Savas (Savas,2017,1).

**Theorem 4** Let $(K,\mu,v,*,\Diamond)$ be an intuitionistic fuzzy 2-normed space. Then

$S^{\alpha}(\mathcal{I})^{(\mu,v)_2}\subset S_{\varphi}^{\alpha}(\mathcal{I})^{(\mu,v)_2}$ if $\liminf_n \frac{\varphi_n^{\alpha}}{n^{\alpha}}>0.$

Proof. For given $\epsilon>0$, every $p>0$, and for non zero $z\in X$, we write

$$\frac{\left|\left\{t\le n:\mu(x(t)-C,z;p)\le 1-\epsilon \text{ or } v(x(t)-C,z;p)\ge\epsilon\right\}\right|}{n^{\alpha}}$$

$$\ge\frac{\left|\left\{t\in I_n:\mu(x(t)-C,z;p)\le 1-\epsilon \text{ or } v(x(t)-C,z;p)\ge\epsilon\right\}\right|}{n}$$

$$=\frac{\varphi_n^{\alpha}}{n^{\alpha}}\frac{\left|\left\{t\in I_n:\mu(x(t)-C,z;p)\le 1-\epsilon \text{ or } v(x(t)-C,z;p)\ge\epsilon\right\}\right|}{\varphi_n^{\alpha}}.$$

$\inf_{n\to\infty}\frac{\varphi_n^{\alpha}}{n}=\alpha$, then from definition $\left\{n\in\mathbb{N}:\frac{\varphi_n^{\alpha}}{n^{\alpha}}<\frac{\alpha}{2}\right\}$ is finite. For every $\epsilon>0$,

$$\left\{n\in\mathbb{N}:\frac{\left|\left\{t\in I_n:\mu(x(t)-C,z;p)\le 1-\epsilon \text{ or } v(x(t)-C,z;p)\ge\epsilon\right\}\right|}{\varphi_n^{\alpha}}\ge\delta\right\}$$

$$\subset\left\{n\in\mathbb{N}:\frac{\left|\left\{t\in I_n:\mu(x(t)-C,z;p)\le 1-\epsilon \text{ or } v(x(t)-C,z;p)\ge\epsilon\right\}\right|}{n^{\alpha}}\ge\frac{\alpha}{2}\delta\right\}$$

$$\cup\left\{n\in\mathbb{N}:\frac{\varphi_n^{\alpha}}{n^{\alpha}}<\frac{\alpha}{2}\right\}.$$

Since $\mathcal{I}$ is admissible, the set on the right-hand side belongs to $\mathcal{I}$ and this completed the proof.

The following result immediately follows from the above theorem by using the same techniques.

**Theorem 5** Let $(K,\mu,v,*,\Diamond)$ be an intuitionistic fuzzy 2-normed space. If $\varphi\in\Delta$ be such that for a particular $\alpha, 0<\alpha\le 1$, $\lim_n \frac{n-\varphi_n}{n^\alpha}=0$ then $S_\varphi^\alpha(\mathcal{I})^{(\mu,v)_2}\subset S^\alpha(\mathcal{I})^{(\mu,v)_2}$.

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