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# SOME CLASS OF ENTIRE DOUBLE SEQUENCE OF INTERVAL NUMBERS

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**ABSTRACT**

*In this paper, the new concept of class of entire sequence space of interval numbers is introduced. The different properties of sequence space like completeness, solidness,AB space,AK property and symmetric are studied.*



***KEYWORDS:***

*Banach space;*
*AB space;*
*AK property;*
*Sequence algebra.*

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## 1. INTRODUCTION

Interval arithmetic was first suggested by Dwyer [5] in 1951. Development of interval arithmetic as a formal system and evidence of its value as a computational device was provided by Moore [10] in 1959 and Moore and Yang [11] 1962. Furthermore, Moore and others [12] have developed applications to differential equations.

Chiao in [8] introduced sequence of interval numbers and defined usual convergence of sequences of interval number. Sengönül and Eryilmax [13] in 2010 introduced and studied bounded and convergent sequence space of interval numbers and showed that these spaces are complete metric space. Recently Esi [1],[2],[3] and [7] introduced some new type sequence spaces of interval numbers.

A set consisting of a closed interval of real numbers x such that a$\leq$x$\leq$b is called an interval number. A real interval can also be considered as a set. Thus we can investigate some properties of interval numbers, for instance arithmetic properties or analysis properties. We denote the set of all real valued closed intervals by $I\Re$. Any elements of $I\Re$ is called closed interval and denoted by $\bar{x}$. That is $\bar{x} = \{x \in \Re : a \leq x \leq b\}$. An interval number $\bar{x}$ is a closed subset of real numbers. Let $x_l$ *and* $x_r$ be be respectively first and last points of the interval number $\bar{x}$.

For $\bar{x}_1, \bar{x}_2 \in I\Re$, we define $\bar{x}_1 = \bar{x}_2$ if and only if $x_{1l} = x_{2l}$ *and* $x_{1r} = x_{2r}$

$$\bar{x}_1 + \bar{x}_2 = \{x \in \Re : x_{1l} + x_{2l} \leq x \leq x_{1r} + x_{2r})\}$$

$$\bar{x}_1 \times \bar{x}_2 = \{x \in \Re : \min(x_{1l}x_{2l}, x_{1l}x_{2r}, x_{1r}x_{2l}, x_{1r}x_{2r}) \leq x \leq \max(x_{1l}x_{2l}, x_{1l}x_{2r}, x_{1r}x_{2l}, x_{1r}x_{2r})\}$$

The set of all interval numbers $I\Re$ is a complete metric space defined by

$$d(\bar{x}_1, \bar{x}_2) = \max\{|\bar{x}_{1l} - \bar{x}_{2l}|, |\bar{x}_{1r} - \bar{x}_{2r}|\}$$

In the special case $\bar{x}_1 = [a,a]$ and $\bar{x}_2 = [b,b]$, we obtain usual metric of $\Re$.

Let us define transformation $f : N \times N \to \Re$, $k,l \to f(k,l) = \bar{x}_{k,l}$, then $\bar{x} = (\bar{x}_{k,l})$ is called double sequence of interval numbers. $\bar{x}_{k,l}$ is called $k,l^{th}$ term of sequence $\bar{x} = (\bar{x}_{k,l})$. We denote by $\omega^2(IR)$ the set of all double sequence of interval numbers.

A sequence $\bar{x} = (\bar{x}_{k,l})$ of double sequence interval numbers is said to be convergent in the Pringsheim's sense or P-convergent to the interval number $\bar{x}_0$ if for each $\varepsilon > 0$ there exists a positive integer $k_0$ such that $d(\bar{x}_{k,l}, \bar{x}_0) < \varepsilon$ for all $k,l \geq k_0$.

A sequence $\bar{x} = (\bar{x}_{k,l})$ of double sequence of interval numbers is said to be double interval fundamental sequence if for every $\varepsilon > 0$ there exists $k_0 \in$ N such that $d(\bar{x}_{k,l}, \bar{x}_{m,n}) < \varepsilon$ whenever $m,n,k,l > k_0$.

Let $p = (p_{k,l})$ be a double sequence of positive real numbers.

An interval double sequence space $E^2(IR)$ is said to be solid if $\bar{y} = (\bar{y}_{k,l}) \in E^2(IR)$ whenever $|\bar{y}_{k,l}| \leq |\bar{x}_{k,l}|$ for all $k,l \in$ N and $\bar{x} = (\bar{x}_{k,l}) \in E^2(IR)$.

An interval double sequence space $E^2(IR)$ is said to be monotone if $E^2(IR)$ contains the canonical pre-image of all its step spaces.

A interval double sequence space $E^2(IR)$ is said to be sequence algebra if

$\bar{x}\otimes\bar{y}=(\bar{x}_{k,l}\otimes\bar{y}_{k,l})\in E^2(IR)$, whenever $\bar{x}=(\bar{x}_{k,l})\in E^2(IR)$, $\bar{y}=(\bar{y}_{k,l})\in E^2(IR)$ .

Let us denote the space of all entire functions of interval numbers by $\Gamma^2(IR)$. For each fixed $k,l$ we define the metric

$$\rho(\bar{x}_{k,l},\bar{y}_{k,l})=\max\{\left|x_{k,l}{}^f-y_{k,l}{}^f\right|^{1/p_{k,l}},\left|x_{k,l}{}^r-y_{k,l}{}^r\right|^{1/p_{k,l}}\}=[d(\bar{x}_{k,l},\bar{y}_{k,l})]^{1/p_{k,l}}$$

We define $\Gamma^2(IR)$ by $\Gamma^2(IR)=\{\bar{x}=(\bar{x}_{k,l})\in\omega^2(IR):\lim_{k,l\to\infty}\rho(\bar{x}_{k,l},\bar{0})=0\}$

Throughout this paper, let $\lambda=(\lambda_{k,l})$ be a fixed double sequence of positive real numbers such that $\frac{\lambda_{k+1,l+1}}{\lambda_{k,l}}\to 1$ as $k,l\to\infty$ and $\lambda_{k,l}\neq 1$ for all k,l. The space $G^2_{\lambda^2}(IR)$ is defined by

$$G^2_{\lambda^2}(IR)=\{\bar{x}=(\bar{x}_{k,l}):\sum_{k,l=1}^{\infty}\lambda_{k,l}{}^2 d(\bar{x}_{k,l},\bar{0})^2<\infty\}$$

**Example:** Let $\lambda=(\lambda_{k,l})=(kl),k,l\in N$ and $\bar{x}=(\bar{x}_{k,l})=([\frac{1}{(kl)^4},\frac{1}{(kl)^2}])$

Then $\sum_{k,l=1}^{\infty}\lambda_{k,l}{}^2 d(\bar{x}_{k,l},\bar{0})^2=\sum_{k,l=1}^{\infty}\lambda_{k,l}{}^2\left[\max\left(\left|\frac{1}{(kl)^4}\right|,\left|\frac{1}{(lk)^2}\right|\right)\right]^2$

$$=\sum_{k,l=1}^{\infty}(kl)^2\frac{1}{(kl)^4}=\sum_{k,l=1}^{\infty}\frac{1}{(kl)^2}<\infty$$. Hence $(\bar{x}_{k,l})$ is in $G^2_{\lambda^2}(IR)$

## 2. MAIN RESULTS:

**Theorem 2.1.** The sequence space $G^2_{\lambda^2}(IR)$ is a complete metric space with respect to the metric defined by $\bar{d}(\bar{x},\bar{y})=\sum_{k,l=1}^{\infty}\lambda_{k,l}{}^2 d(\bar{x}_{k,l},\bar{y}_{k,l})^2$

(2.1)

**Proof:** Let $(\bar{x}^n)$ be a Cauchy sequence in $G^2_{\lambda^2}(IR)$. Then for a given $\varepsilon>0$ there exists $n_0$ $\in$ N such that

$\bar{d}(\bar{x}^n,\bar{x}^m)<\varepsilon$ for all n,m $\geq n_0$

then $\sum_{k,l=1}^{\infty} \lambda_{k,l}{}^2 d(\bar{x}_{k,l}{}^n, \bar{x}_{k,l}{}^m)^2 < \varepsilon$ for all n,m $\geq$ $n_0$

(2.2)

$$d(\bar{x}_{k,l}{}^n, \bar{x}_{k,l}{}^m)^2 \lambda_{k,l}{}^2 < \varepsilon \text{ for all n,m} \geq n_0$$

$$d(\bar{x}_{k,l}{}^n, \bar{x}_{k,l}{}^m)^2 < \varepsilon \big/ \lambda_{k,l}{}^2 \text{ for all n,m} \geq n_0 \text{ and for all } k,l \in \mathrm{N}$$

$$d(\bar{x}_{k,l}{}^n, \bar{x}_{k,l}{}^m) < \left( \frac{\varepsilon}{\lambda_{k,l}{}^2} \right)^{1/2} < \varepsilon \text{ for all n,m} \geq n_0 \text{ and for all } k,l \in \mathrm{N}$$

This means that $(\bar{x}_{k,l}{}^n)$ is a Cauchy double sequence in $I\Re$. Since $I\Re$ is a Banach space , $(\bar{x}_{k,l}{}^n)$ is convergent. Now , let $\lim_n \bar{x}_{k,l}{}^n = \bar{x}_{k,l}$ for each $k,l \in \mathrm{N}$

Taking limit as m $\to \infty$ in (2.2) we have $\sum_{k,l=1}^{\infty} \lambda_{k,l}{}^2 d(\bar{x}_{k,l}{}^n, \bar{x})^2 < \varepsilon$ for all n $\geq$ $n_0$.

$\bar{d}(\bar{x}^n, \bar{x}) < \varepsilon$ for all n $\geq$ $n_0$. Now for all n $\geq$ $n_0$, $\bar{d}(\bar{x}, 0) \leq \bar{d}(\bar{x}^n, \bar{x}) + \bar{d}(\bar{x}^n, 0) < \varepsilon + \infty = \infty$

Thus $\bar{x} = (\bar{x}_{k,l}) \in G^2_{\lambda^2}(IR)$ and so $G^2_{\lambda^2}(IR)$ is complete. This completes the proof.

**Theorem 2.2.** $G^2_{\lambda^2}(IR)$ is a subset of $\Gamma^2(IR)$.

**Proof:** Let $\bar{x} = (\bar{x}_{k,l}) \in G^2_{\lambda^2}(IR)$ , then $\sum_{k,l=1}^{\infty} \lambda_{k,l}{}^2 d(\bar{x}_{k,l}, \bar{0})^2 < \infty$

(2.3)

where $\frac{\lambda_{k+1,l+1}}{\lambda_{k,l}} \to 1$ as $k,l \to \infty$ and $\lambda_k, l \neq 1$ for all $k,l$

(2.4)

We claim that $[d(\bar{x}_{k,l}, \bar{0})]^{1/p_{k.l}}$ converges to zero as $k,l \to \infty$.

From Equation (2.3)

$$\lambda_{k,l}{}^2 d(\bar{x}_{k,l}, \bar{0})^2 < \varepsilon^{2p_{k.l}} \text{ for all } k \in N$$

$$\Rightarrow d(\bar{x}_{k,l}, \bar{0})^2 < \varepsilon^{2p_{k.l}} \big/ \lambda_{k,l}{}^2$$

$$\Rightarrow d(\bar{x}_{k,l}, \bar{0}) < \varepsilon^{p_{k.l}} \big/ \lambda_{k,l}$$

$$\Rightarrow [d(\bar{x}_{k,l}, \bar{0})]^{1/p_{k.l}} < \varepsilon \big/ \lambda_{k,l}{}^{1/p_{k.l}} < \varepsilon_1 \quad \text{from (2.4)}$$

Hence $[d(\bar{x}_{k,l}, \bar{0})]^{1/p_{k.l}} \to 0$ as $k,l \to \infty$ and so $\bar{x} \in \Gamma^2(IR)$. Consequently , $G^2_{\lambda^2}(IR)$ is a subset of $\Gamma^2(IR)$.

**Remark.** $G^2_{\lambda^2}(IR)$ is a Banach space with norm

$$\|\bar{x}\|_{G^i_{\lambda^2}} = \{\sum_{k,l=1}^{\infty} \lambda_{k,l}{}^2 [d(\bar{x}_{k,l}, \bar{0})]^2\}^{1/2}$$

**Theorem 2.3.** If $G^2_{\lambda^2}(IR)$ and $G^2_{\mu^2}(IR)$ are two double sequences of interval numbers, then $G^2_{\lambda^2}(IR) = G^2_{\mu^2}(IR)$ if and only if $k_1 \le \frac{\lambda_{k,l}}{\mu_{k,l}} \le k_2$, where $k_1$ *and* $k_2$ are constants.

**Proof:** The sufficiency of the condition $k_1 \le \frac{\lambda_{k,l}}{\mu_{k,l}} \le k_2$

(2.5)

If $\lambda_{k,l} \le k_2 \mu_{k,l}$ then $\lambda_{k,l}{}^2 d(\bar{x}_{k,l}, \bar{0})]^2 \le k_2{}^2 \mu_{k,l}{}^2 d(\bar{x}_{k,l}, \bar{0})]^2$.

If $(\bar{x}_{k,l}) \in G^2_{\mu^2}(IR)$, $\sum_{k,l=1}^{\infty} \mu_{k,l}{}^2 d(\bar{x}_{k,l}, \bar{0})^2 < \infty$

Therefore $\sum_{k,l=1}^{\infty} \lambda_{k,l}{}^2 d(\bar{x}_{k,l}, \bar{0})^2 \le \sum_{k,l=1}^{\infty} k_2{}^2 \mu_{k,l}{}^2 d(\bar{x}_{k,l}, \bar{0})^2 < \infty$. This implies that

$(\bar{x}_{k,l}) \in G^2_{\lambda^2}(IR)$.

Hence $G^2_{\mu^2}(IR) \subset G^2_{\lambda^2}(IR)$ (2.6)

Similarly, if $k_1 \mu_{k,l} \le \lambda_{k,l}$ then $G^2_{\lambda^2}(IR) \subset G^2_{\mu^2}(IR)$ (2.7)

From (2.6) and (2.7), $G^2_{\lambda^2}(IR) = G^2_{\mu^2}(IR)$

To prove the necessity of the condition, let us suppose that the condition is not satisfied . First consider the right hand side inequality of (2.3). Let $\frac{\lambda_{k,l}}{\mu_{k,l}} \to \infty \; as \; k,l \to \infty$.

Then it has a subsequence $\frac{\lambda_{k_n,l_n}}{\mu_{k_n,l_n}} \to \infty \; \frac{\lambda_{k_n}}{\mu_{k_n}} \to \infty \; as \; k_n, l_n \to \infty$ in such a manner that

$\frac{\lambda_{k_n,l_n}}{\mu_{k_n,l_n}} > n$ for the values n=1,2,..... and $k_1 < k_2 < .....$, $l_1 < l_2 < .....$

Now we shall define a sequence $(\bar{x}_{k,l})$ as follows

$$\bar{x}_{k,l} = \begin{cases} [0, \frac{1}{n \; \mu_{k,l}}] when \; k = k_n, l = l_n \\ [0,0] \; when \; k \ne k_n, l \ne l_n \end{cases}$$

Then $\sum_{k,l=1}^{\infty} \mu_{k,l}{}^2 d(\bar{x}_{k,l},\bar{0})^2 = \sum_{n=1}^{\infty} \mu_{k_n,l_n}{}^2 d(\bar{x}_{k_n,l_n},\bar{0})^2$

$$= \sum_{n=1}^{\infty} \frac{\mu_{k_n,l_n}{}^2}{n^2 \mu_{k_n,l_n}{}^2} = \sum_{n=1}^{\infty} \frac{1}{n^2} < \infty$$

Therefore $(\bar{x}_{k,l}) \in G^2_{\mu^2}(IR)$ (2.8)

But $\sum_{k,l=1}^{\infty} \lambda_{k,l}{}^2 d(\bar{x}_{k,l},\bar{0})^2 = \sum_{n=1}^{\infty} \lambda_{k_n,l_n}{}^2 d(\bar{x}_{k_n,l_n},\bar{0})^2$

$$> \sum_{n=1}^{\infty} n^2 \mu_{k_n,l_n}{}^2 d(\bar{x}_{k_n,l_n},\bar{0})^2 = \sum_{n=1}^{\infty} \frac{n^2 \mu_{k_n,l_n}}{n^2 \mu_{k_n,l_n}} = \infty$$

Thus $\sum_{k,l=1}^{\infty} \lambda_{k,l}{}^2 d(\bar{x}_{k,l},\bar{0})^2 > \infty$

Therefore $(\bar{x}_{k,l}) \notin G^2_{\lambda^2}(IR)$ (2.9)

From (2.8) and (2.9) contradict (2.6)

Similarly , if the left hand side inequality of (2.5) is not satisfied, then we can contradict (2.7) by constructing a sequence of the above type.

Hence the condition $k_1 \le \frac{\lambda_{k,l}}{\mu_{k,l}} \le k_2$ is necessary and sufficient in order that

$G^2_{\lambda^2}(IR) = G^2_{\mu^2}(IR)$

**Theorem 2.4.** $G^2_{\lambda^2}(IR)$ is an AK space.

**Proof:** For each $(\bar{x}_{k,l}) \in G^2_{\lambda^2}(IR)$, $\left\|(\bar{x}^{[n]}) - \bar{x}\right\| \to 0 \;\; as \; n \to \infty$. Hence $G^2_{\lambda^2}(IR)$ has AK .

**Theorem 2.5.** $G^2_{\lambda^2}(IR)$ has AB property.

**Proof:** It is enough to show that $G^2_{\lambda^2}(IR)$ has monotone norm. Indeed for n<m and for every $(\bar{x}_{k,l}) \in G^2_{\lambda^2}(IR)$, we have

$$\left\|(\bar{x}^{[n]})\right\|^2 = \sum_{k,l=1}^{n} \lambda_{k,l}{}^2 d(\bar{x}_{k,l},\bar{0})^2 < \sum_{k,l=1}^{m} \lambda_{k,l}{}^2 d(\bar{x}_{k,l},\bar{0})^2 = \left\|(\bar{x}^{[m]})\right\|^2$$

$$\left\|(\bar{x}^{[n]})\right\| < \left\|(\bar{x}^{[m]})\right\|$$

Also $\{\|(\bar{x}^{[n]})\|,\ n=1,2,...\}$ is a monotonically increasing sequence of interval numbers bounded above by $\|\bar{x}\|_{G^2_{\lambda^2}(IR)}$. Hence $\|\bar{x}\|_{G^2_{\lambda^2}(IR)} = \lim_{n\to\infty}\|(\bar{x}^{[n]})\| = \sup_n\{\|(\bar{x}^{[n]})\|, n=1,2,...\}$. Thus $G^2_{\lambda^2}(IR)$ has monotone norm.

**Theorem 2.6.** The space $G^2_{\lambda^2}(IR)$ is solid.

**Proof:** Let $(\bar{x}_{k,l})$ and $(\bar{y}_{k,l})$ be two sequences such that $(\bar{x}_{k,l}) \in G^2_{\lambda^2}(IR)$ and

$$d(\bar{y}_{k,l},\bar{0}) \le d(\bar{x}_{k,l},\bar{0}) \text{ for all } k,l \in N$$

Since $(\bar{x}_{k,l}) \in G^2_{\lambda^2}(IR)$ , we have $\sum_{k,l=1}^{\infty} \lambda_{k,l}{}^2 d(\bar{x}_{k,l},\bar{0})^2 < \infty$

Also we have $\lambda_{k,l}{}^2 d(\bar{y}_{k,l},\bar{0})^2 \le \lambda_{k,l}{}^2 d(\bar{x}_{k,l},\bar{0})^2$

$$\sum_{k,l=1}^{\infty} \lambda_{k,l}{}^2 d(\bar{y}_{k,l},\bar{0})^2 \le \sum_{k,l=1}^{\infty} \lambda_{k,l}{}^2 d(\bar{x}_{k,l},\bar{0})^2 < \infty$$

So $(\bar{y}_{k,l}) \in G^2_{\lambda^2}(IR)$. Therefore $G^2_{\lambda^2}(IR)$ is solid.

**Theorem 2.7.** The space $G^2_{\lambda^2}(IR)$ is symmetric.

**Proof:** Let $(\bar{x}_{k,l})$ be a sequence in $G^2_{\lambda^2}(IR)$. Then $\sum_{k,l=1}^{\infty} \lambda_{k,l}{}^2 d(\bar{x}_{k,l},\bar{0})^2 < \infty$ .For $\varepsilon > 0$ there exists $k,l = k_0(\varepsilon)$ such that $\sum_{k,l=1}^{\infty} \lambda_{k,l}{}^2 d(\bar{x}_{k,l},\bar{0})^2 - \sum_{k,l \le k_0}^{\infty} \lambda_{k,l}{}^2 d(\bar{x}_{k,l},\bar{0})^2 < \varepsilon$. Let $(\bar{y}_{k,l})$ be a rearrangement of $(\bar{x}_{k,l})$ and $k_1$ be such that $\{\bar{x}_{k,l} : k,l \le k_0\} \subseteq \{\bar{y}_{k,l} : k,l \le k_1\}$

Then $\sum_{k,l=1}^{\infty} \lambda_{k,l}{}^2 d(\bar{y}_{k,l},\bar{0})^2 - \sum_{k,l \le k_1}^{\infty} \lambda_{k,l}{}^2 d(\bar{x}_{k,l},\bar{0})^2 < \varepsilon$ and so $\sum_{k,l=1}^{\infty} \lambda_{k,l}{}^2 d(\bar{y}_{k,l},\bar{0})^2 < \infty$

Hence $(\bar{y}_{k,l}) \in G^2_{\lambda^2}(IR)$ and $G^2_{\lambda^2}(IR)$ is symmetric.

**Theorem 2.8.** The space $G^2_{\lambda^2}(IR)$ is sequence algebra.

**Proof:** We consider the space $G^2_{\lambda^2}(IR)$. Let $(\bar{x}_{k,l})$ and $(\bar{y}_{k,l})$ be two sequences in $G^2_{\lambda^2}(IR)$ and $0 < \varepsilon < 1$. Then the result follows from the following inclusion relation.

$$\{k,l \in N : \bar{d}(\bar{x}_k, l \otimes \bar{y}_{k,l},\bar{0})\} \supseteq \{k,l \in N : \bar{d}(\bar{x}_{k,l},\bar{0})\} \cap \{k,l \in N : \bar{d}(\bar{y}_{k,l},\bar{0})\}$$

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