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On Some New Scenario of Almost Boundedness Using Matrices

Reham A. Alahmadi

ABSTRACT: The authors M. F. Rahman and A. B. M. R. Karim have structured and studied the space $r_g^w(t,s)$ and have computed its various properties like completeness, duals and many others as can be seen in [24]. The basic structure of this paper is to further study it and investigate for the characterization with sequences of almost bounded f_∞, almost convergent f and almost sequences converging to zero f_0. Also, we will prove that $\widetilde{F}$ is not solid, where symbol $\widetilde{F}$ represents space having Riesz transform in f.

Key Words: Δ-operator, almost convergence, matrices.

Contents

1. Preliminary and Introduction

Let all sequences be represented by Ω. We call a sequence space as subspace of Ω. Throughout the paper, $\mathbb{N}$, $\mathbb{R}$ and $\mathbb{C}$ acts as set of whole numbers, the set of real numbers and the set of complex numbers, respectively. Let ℓ_∞ acts as the set of all bounded sequences and $\ell(t)$ represents the following:

$$\ell(t) = \left\{ v = (v_j) \in \Omega : \sum_j |v_j|^{t_j} < \infty \right\},$$

for $0 < t_j \leq \mathcal{H} = \sup_j t_j < \infty$ as can be seen in [1], [15], [25], [31].

Consider the spaces $\mathcal{U}$ and $\mathcal{V}$ and let $\mathcal{B} = (b_{nk})$ represent as an infinite matrix. Then, the matrix $\mathcal{B}$ expresses the $\mathcal{B}$-transformation from $\mathcal{U}$ *into* $\mathcal{V}$, if corresponding to all $v = (v_j) \in \mathcal{U}$, $\mathcal{B}v = \{(\mathcal{B}v)_n\}$ exists and belongs to $\mathcal{V}$; where $(\mathcal{B}v)_n = \sum_k b_{nk}v_k$. We represent the symbol without limits as runs from 0 to ∞. The symbol $\mathcal{B} \in (\mathcal{U} : \mathcal{V})$ signifies every matrix from $\mathcal{U}$ to $\mathcal{V}$ *i.e.*, $\mathcal{B} : \mathcal{U} \to \mathcal{V}$. A sequence v is known as $\mathcal{B}$-summable to l if $\mathcal{B}v$ approaches to l and it is known as the $\mathcal{B}$-limit of v as can be seen in [3], [9], [10], [26] and many more as can be seen in text.

Thus, for the space $\mathcal{U}$, the matrix domain $\mathcal{U}_\mathcal{B}$ of $\mathcal{B}$ is

$$\mathcal{U}_\mathcal{B} = \{v = (v_j) \in \Omega : \mathcal{B}v \in \mathcal{U}\}. \tag{1.1}$$

As in [27], let $\mathcal{T}$ represents the shift operator on Ω, which means, $\mathcal{T}v = \{v_n\}_{n=1}^\infty$, $\mathcal{T}^2 v = \{v_n\}_{n=2}^\infty$ and so on. By Banach limit $\mathcal{L}$ on ℓ_∞ represents as a non-negative linear functional so that $\mathcal{L}$ is invariant under the shift operator on ℓ_∞, which means, $\mathcal{L}(\mathcal{T}v) = \mathcal{L}(v)$ for each $v \in \ell_\infty$ and $\mathcal{L}(e) = 1,\ e = (1, 1, 1, ...)$.

According to author in [20], a sequence $v = \{v_n\} \in \ell_\infty$ is almost convergent having $\mathcal{F}$-lim $v = \lambda$ if and only if

$$\lim_{m\to\infty} t_{mn}(v) = \lambda \text{ uniformly in } n \in \mathbb{N},$$

where, $\Psi_{mn}(v) = \frac{1}{m+1} \sum_{j=0}^{m} v_{n+j}$. The work on such have been studied by various authors as in [12], [14], [21], [23], [26]- [29], and many others.

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Also, as in [20], the set f_∞ is defined as

$$f_\infty = \left\{ v \in \ell_\infty : \sup_{mn} |\Psi_{mn}(v)| < \infty \right\}.$$

Define the set

$$f = \left\{ v \in \ell_\infty : \lim_{m\to\infty} \Psi_{mn}(v) = \beta \ \text{ uniformly in } n \in \mathbb{N} \right\},$$

and is called as almost convergent sequences.

Define the sequence $\tau = (\tau_m)$ by

$$\tau_m = \begin{cases} 1, & \text{if m is even,} \\ 0, & \text{if m is odd.} \end{cases}$$

It is clear that τ is almost convergent to $\frac{1}{2}$ but is not convergent.

We call a matrix $\mathcal{B} = (b_{rm})$ to be regular (see, [11], [19], [26], [27],) iff it holds the following:

(*i*) $\lim_{r\to\infty} \sum_{m=0}^{\infty} b_{rm} = 1,$

(*ii*) $\lim_{r\to\infty} b_{rm} = 0, \quad (m = 0, 1, 2, \cdots),$

(*iii*) $\sum_{m=0}^{\infty} |b_{rm}| < \mathcal{D}, \quad (\mathcal{D} > 0, \ r = 0, 1, 2, \cdots).$

As in [11], define sequence of positive numbers by $w = (w_m)$ and denote $W_i = \sum_{m=0}^{i} w_m$ for $i \in \mathbb{N}$. So, $R^w = (r^w_{im})$ of (R, w_i)- mean is given by

$$r^w_{im} = \begin{cases} \frac{w_m}{W_i}, & \text{if } 0 \le m \le i, \\ 0, & \text{if } m > i, \end{cases}$$

and (R, w_i) mean is regular iff $W_i \to \infty$ as $i \to \infty$.

For $0 < t_m \le \mathcal{H} = \sup t_m < \infty$, the author in [23] have defined the space $r^w(g, t)$ as follows:

$$r^w(g,t) = \left\{ v = (v_m) \in \Omega : \sum_m \left| \frac{1}{W_m} \sum_{j=0}^{m} g_j w_j v_j \right|^{t_m} < \infty \right\},$$

where, $g_j \neq 0 \ \forall \ j \in \mathbb{N}$.

Represent $\mathcal{U}^\beta$ the $\beta-$ dual of $\mathcal{U}$ and is the set of every sequence $v = (v_m)$ so that $v\lambda = (v_m \lambda_m) \in cs$ for each $\lambda = (\lambda_m) \in \mathcal{U}$, where cs acts as set of all convergent series.

2. Main Results

Here we will define the space $r^w_g(t, s)$ and compute matrix classes $\big(r^w_g(t,s) : f_\infty\big)$, $\big(r^w_g(t,s) : f\big)$ and $\big(r^w_g(t,s) : f_0\big)$; where f_∞, f and f_0 have been defined as before.

Following AlBaidani [4]-[7], Boss [18], Dowlath et al [8], Hamid et al [13,16], Jalal et al [17,28], Mursaleen et al [22], Rahman et al [24], Sheikh and Ganie [26], Tarray et al [30], and others, the sequence space $r^w_g(t,s)$ is defined as the space whose $R^w_{s,g}$- transform is in $\ell(t)$, that is,

$$r^w_g(t,s) = \left\{ v = (v_m) \in \Omega : \sum_m \left| \frac{1}{W_m^{s+1}} \sum_{j=0}^{m} g_j w_j v_j \right|^{t_m} < \infty \right\}, \tag{2.1}$$

where, $0 < t_m \le \mathcal{H} = \sup t_m < \infty, \ s \ge 0$ and for each $m \in \mathbb{N}$, we have $g_m \neq 0$..

The set given by (2.1) can be redefined by using (1.1) as

$$\left\{ \ell(t) \right\}_{R^w_{s,g}} = \left\{ v \in \Omega : R^w_{s,g} v \in \ell(t) \right\}.$$

Set $\eta=(\eta_m)$ as $R^w_{s,g}$-transform of $v=(v_m)$, which means,

$$\eta_m=\frac{1}{W_m^{s+1}}\sum_{i=0}^{m} g_i w_i v_i. \tag{2.2}$$

Now define the following lemma required for proving the main theorems.

Lemma 2.1 *As in [24], define $\mathcal{D}_1$, $\mathcal{D}_2$ as follows:*

$$\mathcal{D}_1=\Bigg\{b=(b_m)\in\Omega:$$

$$\sup_m\left|\triangle\left(\frac{b_m}{g_m w_m}\right)W_m^{s+1}\right|^{t_m}<\infty \text{ and } \sup_m\left|\frac{b_m}{g_m w_m}W_m^{s+1}\right|^{t_m}<\infty\Bigg\}$$

$$\text{and } \mathcal{D}_2=\bigcup_{C>1}\Bigg\{b=(b_k)\in\Omega:$$

$$\sum_m\left|\triangle\left(\frac{b_m}{g_m w_m}\right)W_m^{s+1}C^{-1}\right|^{t'_m}<\infty \text{ and } \left\{\left(\frac{b_m}{g_m w_m}W_m^{s+1}C^{-1}\right)^{t'_m}\right\}\in\ell_\infty\Bigg\}.$$

Then, for $1<t_m\le\mathcal{H}<\infty$, we have
$\left[r_g^w(t,s)\right]^\beta=\mathcal{D}_1$; $(0<t_m\le 1)$ *and* $\left[r_g^w(t,s)\right]^\beta=\mathcal{D}_2$.

It is important to note for $s=0$, the space $r_g^w(t,s)$ reduces to $r^q(g,t)$ as can be searched in [14].
To get easiness in notations, we set

$$\Psi_{ir}(\mathcal{B}v)=\frac{1}{i+1}\sum_{j=0}^{i}\mathcal{B}_{r+j}(v)=\sum_k b(r,k,i)v_k$$

where,

$$b(r,k,i)=\frac{1}{i+1}\sum_{j=0}^{i}b_{r+j,k};\ (r,k,i\in\mathbb{N}).$$

Also,

$$\widehat{b}(r,k,i)=\triangle\left[\frac{b(r,k,i)}{g_k w_k}\right]W_k^{s+1}$$

where,

$$\triangle\left[\frac{b(r,k,i)}{g_k w_k}\right]W_k^{s+1}=\left[\frac{b(r,k,i)}{g_k w_k}-\frac{b(r,k+1,i)}{g_{k+1}w_{k+1}}\right]W_k^{s+1},$$

where t'_k denotes the Holder conjugate and

$$\triangle\left[\frac{b(r,k,i)}{g_k w_k}\right]=\left[\frac{b(r,k,i)}{g_k w_k}\right]-\left[\frac{b(r,k+1,i)}{g_{k+1}w_{k+1}}\right]$$

and it was further considered in [19], [17] and many more.

Theorem 2.1 *(i) For each $m\in\mathbb{N}$ with $1<t_m\le\mathcal{H}<\infty$. We have $\mathcal{B}\in\left(r_g^w(t,s):f_\infty\right)$ iff we have an integer $\varkappa>1$ so that*

$$\sup_{i,r\in\mathbb{N}}\sum_m\left|\widehat{b}(i,m,r)\varkappa^{-1}\right|^{t'_m}<\infty, \tag{2.3}$$

and

$$\left\{\left(\frac{b_{im}}{g_m w_m} W_m^{s+1} \varkappa^{-1}\right)^{t'_m}\right\} \in \ell_\infty \ \forall\ i \in \mathbb{N}. \tag{2.4}$$

(ii) *If* $\forall\ m \in \mathbb{N}$ *and* $0 \le t_m \le 1$, *Then* $\mathcal{B} \in \left(r_g^w(t,s) : \ell_\infty\right)$ *iff*

$$\sup_{i,m,r \in \mathbb{N}} \left|\widehat{b}(i,m,r)\right|^{t_m} < \infty \tag{2.5}$$

Proof:

Suppose the conditions (2.3) and (2.4) holds and $v \in r_g^w(t,s)$. Then $\{b_{nm}\}_{m\in\mathbb{N}} \in [r_g^w(t,s)]^\beta$, $\forall n \in \mathbb{N}$, the $\mathcal{B}$-transform of v exists. Now using

$$|ab| \le \varkappa\left\{|a\varkappa^{-1}|^{t'} + |b|^p\right\},$$

where $\varkappa > 0$, $a,\ b \in \mathbf{C}$, $t > 1$ along with $t^{-1} + (t')^{-1} = 1$ [2], and we see by utilizing the relation (2.2) that

$$\begin{aligned}
|\Psi_{rj}(\mathcal{B}v)| &= \left|\sum_k b(j,m,r)v_m\right| \\
&= \left|\sum_m \widehat{b}(j,m,r)\eta_m\right| \\
&\le \sum_m \left|\widehat{b}(j,m,r)\eta_m\right| \\
&\le \sum_m \varkappa\left\{\left|\widehat{b}(j,m,r)\varkappa^{-1}\right|^{t'_m} + |\eta_m|^{t_m}\right\}.
\end{aligned}$$

Now, take supremum over r, j on both sides, we see $\mathcal{B}v \in f_\infty$ for every $v \in r_g^w(t,s)$.

Conversely, we suppose $\mathcal{B} \in \left(r_g^w(t,s) : f_\infty\right)$ and $1 < t_m \le \mathcal{H} < \infty\ \forall\ m \in \mathbb{N}$. Therefore, $\mathcal{B}v$ exists for each $v \in r_g^w(t,s)$ and this implies that $\{b_{n,m}\}_{m\in\mathbb{N}} \in [r_g^w(t,s)]^\beta\ \forall n \in \mathbb{N}$, the necessity is obvious for (2.4). But for all r, n , $\sum_j b(n,j,r)v_j$ exists and $v \in r_g^w(t,s)$, so that $\{b(n,k,m)\}_{k\in\mathbb{N}}$ defines the continuous linear functionals $\phi_{rn}(v)$ on $r_g^w(t,s)$ by

$$\phi_{rn}(v) = \sum_j b(n,j,r)v_j;\ (n,j,r \in \mathbb{N}).$$

Since $r_g^w(t,s)$ is complete and $\sup_{n,r}\left|\sum_j b(n,j,r)v_j\right| < \infty$ on $r_g^w(t,s)$, so by Banach–Steinhaus theorem, there exists $\varkappa > 0$ such that

$$\sup_{r,n}|\phi_{rn}(v)| = \sup_{r,n}\sum_j |b(n,j,r)v_j| = \sup_{r,n}\left|\widehat{b}(n,j,r)\eta_j\right| < \infty.$$

So there by giving $\sup_{r,n}\left|\widehat{b}(n,j,r)\varkappa^{-1}\right|^{t'_j} < \infty$, yielding the necessity of (2.3) and completed the proof (i).

The part (ii) can be proved similarly and the proof of theorem is complete. □

Theorem 2.2 *For* $1 < t_m \le \mathcal{H} < \infty$, $\mathcal{B} \in \left(r_g^w(t,s) : f\right)$ *iff* (2.3), (2.4), (2.5) *holds for each* $m \in \mathbb{N}$ *of Theorem 2.2 and there is* (β_m) *sequence of scalars so that*

$$\lim_{r\to\infty} \widehat{b}(n,m,r) = \beta_m,\ uniformly\ in\ n \in \mathbb{N}. \tag{2.6}$$

Proof: Suppose (2.3), (2.4), (2.5) and (2.6) holds good and $v \in r_g^w(t,s)$. Then $\mathcal{B}v$ exists and by (2.6) we see for each $m \in \mathbb{N}$ that

$$|\widehat{b}(l,m,r)\varkappa^{-1}|^{t'_m} \to \left|\beta_m \varkappa^{-1}\right|^{t'_m}$$

as $r \to \infty$, uniformly in l,m yielding with (2.3) that

$$\sum_{j=0}^{m} \left|\beta_j \varkappa^{-1}\right|^{t'_j} = \lim_{r\to\infty} \sum_{j=0}^{m} \left|\widehat{b}(l,j,r)\varkappa^{-1}\right|^{t'_m} \ (uniformly\ in\ l)$$

$$\leq \sup_{l,r\in\mathbb{N}} \sum_{j=0}^{m} \left|\widehat{b}(l,j,r)\varkappa^{-1}\right|^{t'_m} < \infty, \tag{2.7}$$

holds for each $m \in \mathbb{N}$. But given $v \in r_g^w(t,s)$ and as in [25]-Theorem 2.2, $r_g^w(t,s)$ is isomorphic to $\ell(t)$ linearly, so yielding $\sigma \in \ell(t)$. Hence, from (2.7), the series $\sum_m \beta_m \eta_m$ and $\sum_m \widehat{b}(l,m,r)\eta_m$ converges for each r,l and $\sigma \in \ell(t)$. Thus, for a given $\epsilon > 0$, fix $m_0 \in \mathbb{N}$ so that

$$\left(\sum_{m=m_0+1}^{\infty} |\eta_m|^{t_m}\right)^{\frac{1}{t_m}} < \epsilon.$$

Now clearly for some $r_0 \in \mathbb{N}$, we see

$$\left|\sum_{m=0}^{m_0} \left[\widehat{b}(l,m,r) - \beta_m\right]\right| < \epsilon,$$

for every $r \geq m_0$ and uniformly in l. But (2.6) holds, giving

$$\left|\sum_{m_0+1}^{\infty} \left[\widehat{b}(l,m,r) - \beta_m\right]\right|$$

is arbitrary small. Therefore, we see

$$\lim_r \sum_m b(l,m,r)v_m = \lim_r \sum_m \widehat{b}(l,m,r)\eta_m$$
$$= \sum_m \beta_m \eta_m,$$

uniformly in l. Consequently, $\mathcal{B}v \in f$ there by proving sufficiency.

We now let $\mathcal{B} \in \left(r_g^w(t,s) : f\right)$. Then, necessities of (2.3) and (2.4) are immediate from Theorem 2.2 since $f \subset f_\infty$. To establish the necessity of (2.6), we define

$$b_l^m(w) = \begin{cases} (-1)^{l-m}\frac{W_m^{s+1}}{g_l w_l}, & \text{if } m \leq l \leq m+1, \\ 0, & \text{if } 0 \leq l < k \ or \ l > m+1. \end{cases}$$

But for each $v \in r_g^w(t,s)$, $\mathcal{B}v$ exists and is in f, yielding obviously that $\mathcal{B}b^{(m)}(w) = \left\{\triangle\left(\frac{b_{lm}}{g_m w_m}\right) W_m^{s+1}\right\}_{n\in\mathbb{N}} \in f$ for each $m \in \mathbb{N}$, which proves the necessity of (2.6). This concludes the proof. □ □

Note that if we let $\beta_m \to 0$ for each $m \in \mathbb{N}$ if above theorem, we have the following result.

Theorem 2.3 *Let $1 < t_m \leq \mathcal{H} < \infty$ for every $m \in \mathbb{N}$. Then $\mathcal{B} \in \left(r_g^w(t,s) : f_0\right)$ if and only if (2.3), (2.4), (2.5) and (2.6) hold.*□

Corollary 2.1 *If we take $g_m = 1$ for each $m \in \mathbb{N}$, then we get results obtained in [1].*$\square$

Corollary 2.2 *If we take $s = 0$, then we get results obtained in [14].*$\square$

Corollary 2.3 *If we take $g_m = 1$ and $s = 0$ for all $m \in \mathbb{N}$, then we get results obtained in [28].*$\square$

Definition 2.1 *Solid spaces [18]: We call a sequence space $\mathcal{X}$ to be solid if and only if $\ell_\infty \mathcal{X} \subset \mathcal{X}$.*

Definition 2.2 *Define a space $\widetilde{F}$ as the sets of all sequences such that its R-transform is in the space f, that is,*

$$\widetilde{F} = \left\{ \upsilon \in \Omega : \lim_{m\to\infty} \sum_{k=0}^{m} \frac{1}{m+1} \sum_{j=0}^{k} \frac{w_j \upsilon_{j+n}}{W_k^{s+1}} = \beta \quad \textit{uniformly in } n \in \mathbb{N} \right\}.$$

Theorem 2.4 *The space $\widetilde{F}$ is not solid space.*

Proof: To prove the result, choose

$$\varsigma = (\varsigma_j) = \left(\frac{W_0}{w_0}, -\left(\frac{W_0}{w_0} + \frac{W_0}{w_0} \right), \left(\frac{W_1}{w_1} + \frac{W_2}{w_2} \right), \cdots, (-1)^j \left(\frac{W_j}{w_j} + \frac{W_{j+1}}{w_{j+1}} \right), \cdots \right); \; s = 0$$

and

$$\xi = (\xi_j) = \Big(1, -1, 1, \cdots, (-1)^j, \cdots \Big).$$

Then trivially, we see $\varsigma \in f$ and $\xi \in \ell_\infty$. Define $\varsigma\xi = \upsilon$, that is, $(\varsigma\xi)_j = (\upsilon_j)$. Also, it is obvious that

$$(\upsilon_j) = \left(\frac{W_0}{w_0}, \left(\frac{W_0}{w_0} + \frac{W_0}{w_0} \right), \left(\frac{W_1}{w_1} + \frac{W_2}{w_2} \right), \cdots, \left(\frac{W_j}{w_j} + \frac{W_{j+1}}{w_{j+1}} \right), \cdots \right).$$

So, by definition of Riesz matrix, we see that

$$\mathcal{F}_R - \lim \upsilon = \lim_{m\to\infty} \sum_{k=0}^{m} \frac{1}{m+1} \sum_{j=0}^{k} \frac{w_j \upsilon_{j+n}}{W_k} = \infty.$$

Therefore, for spaces ℓ_∞ and $\widetilde{F}$, the multiplication $\ell_\infty \widetilde{F}$ is not a subset of $\widetilde{F}$ and hence we conclude that the space $\widetilde{F}$ is not solid.$\square$ $\square$

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Reham A. Alahmadi,

Department of Basic Science, College of Science and Theoretical Studies,

Saudi Electronic University, Riyadh 11673,

Kingdom of Saudi Arabia.

E-mail address: r.alhmadi@seu.edu.sa