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Lacunary strong A_q-convergence sequence spaces defined by a sequence of moduli

AYHAN ESI

Adiyaman University, Science and Art Faculty, Department of Mathematics, 02040, Adiyaman, Turkey. E-mail address: aesi23@hotmail.com.

ABSTRACT

The definition of lacunary strong A-convergence to a modulus is extended to a definition of lacunary strong A_q-convergence with respect to a sequence of moduli. We study some connections between lacunary strong A_q-convergence with respect to a sequence of moduli and lacunary A_q-statistical convergence, where A is a sequence of matrices $An = (aik(n))$ of complex numbers.

Keywords: Lacunary sequence; modulus function; statistical convergence.

INTRODUCTION

By a lacunary sequence $\theta = (k_r)$, where $k_0 = 0$, we shall mean an increasing sequence of non-negative integers with $h_r = k_r$- $k_{r-1} \to \infty$ as $r \to \infty$. The intervals determined by θ will be denoted by $I_r = (k_{r-1}, k_r]$. The space of lacunary strongly convergent sequence space N_θ was defined (Freedman *et al.*, 1978) as follows:

$$N_\theta = \left\{ x = (x_k) : \quad \lim_{r\to\infty} h_r^{-1} \sum_{k\in I_r} |x_k - l| = 0, \ for\ some\ l \right\}.$$

The space N_θ is a BK-space with the norm

$$\|x\|_\theta = \sup_r \left(h_r^{-1} \sum_{k\in I_r} |x_k| \right).$$

N_θ^o denotes the subset of those sequences in N_θ for which $L = 0$. $(N_\theta^0, \|.\|_\theta)$ is

also a BK-space. There is a relation between N_θ and the space $|\sigma_1|$, the space of strongly Cesaro summable sequences, which is defined by

$$|\sigma_1| = \left\{ x = (x_k) : \quad \lim_{n\to\infty} n^{-1} \sum_{k=1}^{n} |x_k - l| = 0, \ \textit{for some } l \right\},$$

and it is well-known that, with the norm

$$\|x\| = \sup_n n^{-1} \sum_{k=1}^{n} |x_k|,$$

$|\sigma_1|$ is a *BK*-space. In the special case, where $\theta = (2^r)$, we have $N_\theta = |\sigma_1|$.

The notion of modulus function was introduced (Nakano, 1953). We recall that a modulus f is a function from $[0,\infty)$ to $[0,\infty)$ such that (i) f(x) = 0 if and only if x = 0, (ii) $f(x+y) \leq f(x) + f(y)$ for all $x,y \geq 0$, (iii) f is increasing, (iv) f is continuous from the right at 0. It follows that f must be continuous on $[0,\infty)$.

Let $F = (f_i)$ be a sequence of moduli such that $\lim_{u\to 0^+} \sup_i f_i(u) = 0$.Throughout this paper the sequence of modulus functions determinated by F will be denoted by $f_i \in F$ for every $i \in N$.

(Connor, 1989; Maddox 1986, 1987; Esi 1995, 1996, 1997; Bilgin 2001; Pehlivan & Fisher 1994, 1995; Kolk 1993; Ruckle 1973) and several authors used modulus functions to construct sequence spaces.

Recently, the concept of lacunary strongly A-convergence was generalized by (Bilgin, 2004) as below:

Let $A = (a_{ik})$ be an infinite matrix of complex numbers such that $Ax = (A_i(x))$ if $A_i(x) = \sum_{k=1}^{\infty} a_{ik} x_k$ converges for each i and $F = (f_i)$ be a sequence of moduli. Then

$$N_\theta(A,F) = \left\{ x : \quad \lim_{r\to\infty} h_r^{-1} \sum_{i\in I_r} f_i(|A_i(x) - l|) = 0, \ \textit{for some } l \right\}$$

and

$$N_\theta^0(A,F) = \left\{ x : \quad \lim_{r\to\infty} h_r^{-1} \sum_{i\in I_r} f_i(|A_i(x)|) = 0 \right\}.$$

The purpose of this paper is to introduce and study a concept of lacunary strongA_q–convergence with respect to a sequence of moduli.

We now introduce the generalizations of lacunary strongly A_q-convergent sequences with respect to a sequence of moduli and investigate some inclusion relations.

Let A denote a sequence of the matrices $A^n = (a_{ik}(n))$ of complex numbers. We write for any sequence$x = (x_k)$, $y_i(n) = A_i^n(x) = \sum_{k=1}^{\infty} a_{ik}(n)x_k$ if it exists for each i and n. We write $A^n(x) = \left(A_i^n(x)\right)_i$, $Ax = (A_n(x))_n$.

The following inequality will be used throughout this paper. Let $p = (p_i)$ be a sequence of positive real numbers with $0 < \inf p_i = H_1 \leq p_i \leq \sup p_i = H_2 < \infty$, and let $D = \max\left(1, 2^{H_2-1}\right)$. Then for $a_k, b_k \in$C, the set of complex numbers, we have (Maddox 1970),

$$|a_k + b_k|^{p_k} \leq D\{|a_k|^{p_k} + |b_k|^{p_k}\} \tag{1}$$

DEFINITION 1. Let F = (f_i) be a sequence of moduli, A denote the sequence of matrices $A^n = (a_{ik}(n))$ of complex numbers and X be locally convex Hausdorff topological linear space whose topology is determined by a set Q of continuous seminorms q and $p = (p_i)$ be a sequence of positive real numbers. $w(X)$ denotes the space of all sequences $x = (x_k)$, where $x_k \in X$. We define the following sequence spaces:

$$N_\theta(A, F, q, p) = \left\{ x \in w(X) : \lim_{r\to\infty} h_r^{-1} \sum_{i\in I_r} \left[f_i\left(q\left(A_i^n(x - le)\right)\right)\right]^{p_i} = 0, \textit{ uniformly in n, for some l} \right\}$$

and

$$N_\theta^0(A, F, q, p) = \left\{ x \in w(X) : \lim_{r\to\infty} h_r^{-1} \sum_{i\in I_r} \left[f_i\left(q\left(A_i^n(x)\right)\right)\right]^{p_i} = 0, \textit{ uniformly in n} \right\},$$

where $e = (1, 1, 1, \ldots)$.

A sequence $x = (x_k)$ is said to be lacunary strong A$_q$-convergent to a number l with respect to sequence of moduli if there is a complex number l such that $x \in N_\theta(A, F, q, p)$. Note that, if we put $f_i = f$ for every $i \in N$ then $N_\theta(A, F, q, p) = N_\theta(A, f, q, p)$. If we get X = C, p_i =constant for every $i \in N$, $A^n = (a_{ik}(n)) = (a_{ik})$ for every $n \in N$ and $q(x) = |x|$, then we obtain $N_\theta(A, F, q, p) = N_\theta(A, F)$ which was defined by Bilgin (Bilgin, 2004). We write $N_\theta(A, F, q, p) = N_\theta(A, q, p)$ for $f_i(x) = x$ for every$i \in N$.

If x is lacunary strong A$_q$-convergent to the value l with respect to sequence of moduli, then we write $x_k \to l[N_\theta(A, F, q, p)]$. If $A = I$, unit matrix, we write

$N_\theta(F,q,p)$ *and* $N_\theta^0(F,q,p)$ for $N_\theta(A,F,q,p)$ and $N_\theta^0(A,F,q,p)$, respectively. Hence $N_\theta(F)$ is the same as the space $N_\theta(X,F)$ of (Pehlivan & Fisher, 1994) for X = C, $q(x) = |x|$, p_i = constant for every $i \in N$ and $A = I$, unit matrix.

PROPOSITION 1. $N_\theta(A,F,q,p)$ *and* $N_\theta^0(A,F,q,p)$ are linear spaces.

Proof. Suppose that $x_k \to l_1$ and $y_k \to l_2$ in $N_\theta(A,F,q,p)$ and $\alpha, \beta \in C$, the set of complex numbers. Then there exist integers T_α and T_β such that $|\alpha| \le T_\alpha$ *and* $|\beta| \le T_\beta$. Therefore, we have,

$$E_{r,n}[F(\alpha x + \beta y - (\alpha l_1 + \beta l_2)e)] \le D(T_\alpha)^{H_2} E_{r,n}[F(x - l_1)e] + D(T_\beta)^{H_2} E_{r,n}[F(y - l_2)e] \quad (2)$$

where $E_{r,n}[F(x)] = h_r^{-1} \sum_{i \in I_r} \left[f_i\left(q\left(A_i^n(x)\right)\right)\right]^{p_i}$. Now it follows (2), $\alpha x + \beta y \to \alpha l_1 + \beta l_2 \in \quad [N_\theta(A,F,q,p)]$.

THE INCLUSION RELATION BETWEEN $N_\theta(A,F,q,p)$ AND $N_\theta(A,q,p)$

THEOREM 1. Let A be a sequence the matrices $A^n = (a_{ik}(n))$ of complex numbers and F = (f_i) be a sequence of moduli. If $x = (x_k)$ lacunary strong A_q-convergent to l then $x = (x_k)$ lacunary strong A_q-convergent to l with respect to sequence of moduli, i.e., $N_\theta(A,q,p) \subseteq N_\theta(A,F,q,p)$.

Proof. Let F = (f_i) be a sequence of moduli and put $\sup_i f_i(1) = T$. Let $x = (x_k) \in N_\theta(A,q,p)$ and $\varepsilon > 0$. We choose $0 < \delta < 1$ such that $f_i(u) < \varepsilon$ for every u with $0 \le u \le \delta$ $(i \in N)$.We can write

$$h_r^{-1} \sum_{i \in I_r} \left[f_i\left(q\left(A_i^n(x - le)\right)\right)\right]^{p_i} = h_r^{-1} \sum_1 \left[f_i\left(q\left(A_i^n(x - le)\right)\right)\right]^{p_i} + h_r^{-1} \sum_2 \left[f_i\left(q\left(A_i^n(x - le)\right)\right)\right]^{p_i},$$

where the first summation is over $q\left(A_i^n(x) - l\right) \le \delta$ and the second over $q\left(A_i^n(x) - l\right) > \delta$. By definition modulus f_i for every i, we have

$$h_r^{-1} \sum_{i \in I_r} \left[f_i\left(q\left(A_i^n(x - le)\right)\right)\right]^{p_i} \le \varepsilon^{H_2} + \left(2T\delta^{-1}\right)^{H_2} h_r^{-1} \sum_{i \in I_r} \left[\left(q\left(A_i^n(x - le)\right)\right)\right]^{p_i}$$

Therefore $x = (x_k) \in N_\theta(A,F,q,p)$.

THEOREM 2. Let A be a sequence the matrices $A^n = (a_{ik}(n))$ of complex numbers, $p = (p_i)$ be a sequence of positive real numbers with $0 < \inf p_i = H_1 \le \sup p_i = H_2 < \infty$ and F = (f_i) be a sequence of moduli. If $\lim_{u \to \infty} \inf_i \frac{f_i(u)}{u} > 0$, then $N_\theta(A,F,q,p) = N_\theta(A,q,p)$.

Proof. If $\lim_{u\to\infty}\inf_i \frac{f_i(u)}{u} > 0$, then there exists a number $\beta > 0$ such that $f_i(u) \geq \beta u$ for all $u \geq 0$ *and* $i \in N$. Let $x = (x_k) \in N_\theta(A, F, q, p)$. Clearly,

$$h_r^{-1} \sum_{i\in I_r} \left[f_i\left(q\left(A_i^n(x - le)\right)\right)\right]^{p_i} \geq \beta h_r^{-1} \sum_{i\in I_r} \left[\left(q\left(A_i^n(x - le)\right)\right)\right]^{p_i}.$$

Therefore, $x = (x_k) \in N_\theta(A, q, p)$. By using Theorem 1, the proof is complete.

We now give an example to show that $N_\theta(A, F, q, p) \neq N_\theta(A, q, p)$ in the case when $\beta = 0$. Consider$A = I$, unit matrix, $q(x) = |x|$, $p_i = 1$ for every $i \in N$ and $f_i(x) = x^{1/i+1}$ $(i \geq 1,\ x > 0)$ in the case $\beta = 0$. Now we define $x_i = h_r$ *if* $i = k_r$ for some $r \geq 1$ and $x_i = 0$ otherwise. Then we have,

$$h_r^{-1} \sum_{i\in I_r} \left[f_i\left(q\left(A_i^n(x) - l\right)\right)\right]^{p_i} = h_r^{-1}(f_{kr}(h_r)) = h_r^{-1} h_r^{\frac{1}{1+k_r}} \to 1 \quad as \quad r \to \infty$$

and so $x = (x_k) \in N_\theta^0(A, F, q, p) \subseteq N_\theta(A, F, q, p)$. But

$$h_r^{-1} \sum_{i\in I_r} \left[\left(q\left(A_i^n(x - le)\right)\right)\right]^{p_i} = h_r^{-1} \sum_{i\in I_r} |x_i| = h_r^{-1} h_r \to 1 \quad as \quad r \to \infty$$

and so $x = (x_k) \notin N_\theta^0(A, q, p) \subseteq N_\theta(A, q, p)$.

THE INCLUSION RELATION BETWEEN $N\theta(A, F, q, p)$ AND $S_\theta(A, q)$.

In this section we introduce natural relationship between lacunary A_q-statistical convergence and lacunary strong A_q-convergence with respect to a sequence of moduli.

The definition of statistical convergence was introduced (Fast, 1951) and studied by several authors (Connor, 1988; Fridy, 1985; Salat, 1980; Schoenberg, 1959). The sequence x is statistically convergent to l if for each $\varepsilon > 0$, $\lim_{r\to\infty} r^{-1}|K(\varepsilon)| = 0$, where $|K(\varepsilon)|$ denotes the number of elements in $K(\varepsilon) = \{i \in N : |x_i - l| \geq \varepsilon\}$. Schoenberg (Schoenberg, 1959) studied statistical convergence as a summability method and listed some of the elementary properties of statistical convergence. Recently, (Fridy & Orhan 1993) and (Bilgin, 2001) introduced the following definitions of lacunary statistical convergence and lacunary A-statistical convergence, respectively, as below:

DEFINITON 2. Let θ be a lacunary sequence. Then a sequence $x = (x_k)$ is said to be lacunary statistically convergent to a number l if for every $\varepsilon > 0$, $\lim_{r\to\infty} h_r^{-1}|K_\theta(\varepsilon)| = 0$, where $|K_\theta(\varepsilon)|$ denotes the number of elements in $K_\theta(\varepsilon) = \{i \in I_r : |x_i - l| \geq \varepsilon\}$. The set of all lacunary statistical convergent sequences is denoted by S_θ.

Let $A = (a_{ik})$ be an infinite matrix of complex numbers. Then a sequence $x = (x_k)$ is said to be lacunary A-statistically convergent to a number l if for every $\varepsilon > 0$, $\lim_{r\to\infty} h_r^{-1}|KA_\theta(\varepsilon)| = 0$, where $|KA_\theta(\varepsilon)|$ denotes the number of elements in $KA_\theta(\varepsilon) = \{i \in I_r : |A_i(x - le)| \geq \varepsilon\}$. The set of all lacunary A-statistical convergent sequences is denoted by $S_\theta(A)$.

DEFINITION 3. Let A be a sequence of the matrices $A^n = (a_{ik}(n))$ of complex numbers and let $p = (p_i)$ be a sequence of positive real numbers with $0 < \inf p_i = H_1 \leq \sup p_i = H_2 < \infty$, Then a sequence $x = (x_k)$ is said to be lacunary A_q-statistically convergent to a number l if for every $\varepsilon > 0$, $\lim_{r\to\infty} h_r^{-1}\left|KA_{\theta,q}(\varepsilon)\right| = 0$, uniformly in n, where $\left|KA_{\theta,q}(\varepsilon)\right|$ denotes the number of elements in $KA_{\theta,q}(\varepsilon) = \left\{i \in I_r : q\left(A_i^n(x - le)\right) \geq \varepsilon,\ n = 1, 2, \ldots\right\}$. The set of all lacunary A_q-statistical convergent sequences is denoted by $S_\theta(A, q)$.

The following theorems give the relations between lacunary A_q-statistical convergence and lacunary strong A_q-convergence with respect to a sequence of moduli.

THEOREM 3. Let $F = (f_i)$ be a sequence of moduli. Then $N_\theta(A, F, q, p) \subseteq S_\theta(A, q)$ if and only if $\lim_{i\to\infty} f_i(u) > 0$, $(u > 0)$.

Proof. Let $\varepsilon > 0$ and $x = (x_k) \in N_\theta(A, F, q, p)$. If $\lim_{i\to\infty} f_i(u) > 0$, then there exists a number $d > 0$ such that $f_i(\varepsilon) > d$ for $u > \varepsilon$ and $i \in N$. Let $I_r^1 = \left\{i \in I_r : q\left(A_i^n(x - le)\right) \geq \varepsilon,\ n = 1, 2, \ldots\right\}$,

$$h_r^{-1} \sum_{i\in I_r} \left[f_i\left(q\left(A_i^n(x - le)\right)\right)\right]^{p_i} \geq h_r^{-1} \sum_{i\in I_r^1} \left[f_i\left(q\left(A_i^n(x - le)\right)\right)\right]^{p_i} \geq h_r^{-1} d^{H_1} \left|KA_{\theta,q}(\varepsilon)\right|.$$

It follows that $x \in S_\theta(A, q)$.

Conversely, suppose that $\lim_{i\to\infty} f_i(u) > 0$ does not hold, then there is a number $t > 0$ such that $\lim_{i\to\infty} f_i(t) = 0$. We can select a lacunary sequence $\theta = (k_r)$ such that $f_i(t) < 2^{-r}$ for any $i > k_r$. Let $A = I$, unit matrix, define the sequence x by putting $x_i = t$ *if* $k_{r-1} < i \leq \frac{k_r + k_{r-1}}{2}$ and $x_i = 0$ *if* $\frac{k_r + k_{r-1}}{2} < i \leq k_r$. We have $x = (x_k) \in N_\theta^0(A, F, q, p) \subseteq N_\theta(A, F, q, p)$ but $x \notin S_\theta(A, q)$.

THEOREM 4. Let $F = (f_i)$ be a sequence of moduli. Then $N_\theta(A, F, q, p) \supseteq S_\theta(A, q)$ if and only if $\sup_u \sup_i f_i(u) < \infty$.

Proof. Let $x \in S_\theta(A, q)$. Suppose that $h(u) = \sup_i f_i(u)$ and $h = \sup_u h(u)$. Let $I_r^2 = \{i \in I_r : \ q(A_i^n(x - le)) < \varepsilon, \ n = 1, 2, ...\}$. Since $f_i(u) \le h$ for all i and $u > 0$, we have for all n,

$$h_r^{-1} \sum_{i \in I_r} [f_i(q(A_i^n(x - le)))]^{p_i} = h_r^{-1} \sum_{i \in I_r^1} [f_i(q(A_i^n(x - le)))]^{p_i} + h_r^{-1} \sum_{i \in I_r^2} [f_i(q(A_i^n(x - le)))]^{p_i}$$
$$\le h^{H_2} h_r^{-1} |KA_{\theta,q}(\varepsilon)| + [h(\varepsilon)]^{H_2}$$

It follows from $\varepsilon \to 0$ that $x \in N_\theta(A, F, q, p)$.

Conversely, suppose that $\sup_u \sup_i f_i(u) = \infty$. Then we have $0 < u_1 < u_2 < ... < u_{r-1} < u_r < ...$, such that $f_{k_r}(u_r) \ge h_r \, for \, r \ge 1$. Let $A = I$, unit matrix, define the sequence x by putting $x_i = u_r \quad if \, i = k_r$ for some $r = 1, 2, ...$ and $x_i = 0$ otherwise. Then, we have $x \in S_\theta(A, q)$ but $x \notin N_\theta^{(A,F,q,p)}$.

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فضاءات متتاليات غورية قوية التقارب ومعرفة بواسطة متتالية من مقاييس

أيهان إزى
قسم الرياضيات – كلية العلوم والآداب – جامعة أديامان – تركيا

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