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# **Recent Advances in Electrical Engineering**

- *Proceedings of the 13<sup>th</sup> International Conference on Instrumentation, Measurement, Circuits and Systems (IMCAS '14)*
- *Proceedings of the 2<sup>nd</sup> International Conference on Power Engineering, Energy and Electrical Drives (PEED '14)*
- *Proceedings of the 13<sup>th</sup> International Conference on Signal Processing (SIP '14)*
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*Istanbul, Turkey, December 15-17, 2014*



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## Plenary Lecture 1

### On Ulam's Type Stability



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#### Abstract:

Quite often (e.g., in applications) we have to do with functions that satisfy some equations only approximately. There arises a natural question what errors we commit when we replace such functions by the exact solutions to those equations. Some tools to evaluate them are provided within the theory of the Ulam (also Hyers-Ulam) type stability.

The issue of Ulam's type stability of (first, functional, but next also difference, differential and integral) equations has been a very popular subject of investigations for the last nearly fifty years (see, e.g., [3, 8, 9, 10]). The main motivation for it was given by S.M. Ulam in 1940. The following definition somehow describes the main ideas of such stability notion for equations in  $n$  variables ( $\mathbb{R}_+$  stands for the set of nonnegative reals).

**Definition 1.** Let  $A$  be a nonempty set,  $(X, d)$  be a metric space,  $\mathcal{C} \subset \mathbb{R}_+^{A^n}$  be nonempty,  $\mathcal{T}$  map  $\mathcal{C}$  into  $\mathbb{R}_+^A$ , and  $\mathcal{F}_1, \mathcal{F}_2$  map a nonempty  $\mathcal{D} \subset X^A$  into  $X^{A^n}$ . We say that the equation

$$\mathcal{F}_1\varphi(x_1, \dots, x_n) = \mathcal{F}_2\varphi(x_1, \dots, x_n) \quad (1)$$

is  $\mathcal{T}$ -stable provided for every  $\varepsilon \in \mathcal{C}$  and  $\varphi_0 \in \mathcal{D}$  with

$$d(\mathcal{F}_1\varphi_0(x_1, \dots, x_n), \mathcal{F}_2\varphi_0(x_1, \dots, x_n)) \leq \varepsilon(x_1, \dots, x_n), \quad x_1, \dots, x_n \in A,$$

there is a solution  $\varphi \in \mathcal{D}$  of equation (1) such that  $d(\varphi(x), \varphi_0(x)) \leq \mathcal{T}\varepsilon(x)$  for  $x \in A$ .

The next two theorems contain examples of some results on stability of the additive Cauchy equation (see [3]) and of a linear difference equation of higher order (see [7]).

**Theorem 1.** Let  $E_1$  and  $E_2$  be two normed spaces,  $c \geq 0$  and  $p \neq 1$  be fixed real numbers. Let  $f : E_1 \rightarrow E_2$  be such that

$$\|f(x+y) - f(x) - f(y)\| \leq c(\|x\|^p + \|y\|^p), \quad x, y \in E_1 \setminus \{0\}.$$

If  $p < 0$ , then  $f$  is additive (i.e.,  $f(x+y) = f(x) + f(y)$  for  $x, y \in E_1$ ). If  $p \geq 0$  and  $E_2$  is complete, then there is a unique additive  $T : E_1 \rightarrow E_2$  with

$$\|f(x) - T(x)\| \leq \frac{c\|x\|^p}{|2^{p-1} - 1|}, \quad x \in E_1 \setminus \{0\}.$$

**Theorem 2.** Let  $T$  be either  $\mathbb{N}$  or  $\mathbb{Z}$ ,  $X$  be a Banach space over  $F \in \{\mathbb{R}, \mathbb{C}\}$ ,  $(b_n)_{n \in T}$  be a sequence in  $X$ ,  $a_1, \dots, a_m \in F$ ,  $\delta > 0$  and  $r_1, \dots, r_m \in \mathbb{C}$  be the roots of the characteristic equation of the difference equation

$$x_{n+m} = a_1x_{n+m-1} + \dots + a_mx_n + b_n, \quad n \in T. \quad (2)$$

Suppose that  $|r_i| \neq 1$  for  $i = 1, \dots, m$  and  $(y_n)_{n \in T}$  is a sequence in  $X$  with

$$\|y_{n+m} - a_1 y_{n+m-1} - \dots - a_m y_n - b_n\| \leq \delta, \quad n \in T.$$

Then there exists a sequence  $(x_n)_{n \in T}$  in  $X$  such that (2) holds and

$$\|y_n - x_n\| \leq \frac{\delta}{|1 - |r_1|| \cdot \dots \cdot |1 - |r_m||}, \quad n \in T.$$

The lecture contains some basic motivations, definitions and results connected with the notion of the Ulam (but also the Hyers-Ulam) type stability. A general method will also be presented for investigations of that stability, e.g., of the following linear (difference, differential, functional) equations of higher orders:

$$b_m \varphi(n+m) + b_{m-1} \varphi(n+m-1) + \dots + b_1 \varphi(n+1) + b_0 \varphi(n) = G(n),$$

$$b_m \varphi^{(m)}(z) + b_{m-1} \varphi^{(m-1)}(z) + \dots + b_1 \varphi'(z) + b_0 \varphi(z) = G(z),$$

$$b_m \varphi(f^m(z)) + b_{m-1} \varphi(f^{m-1}(z)) + \dots + b_1 \varphi(f(z)) + b_0 \varphi(z) = G(z).$$

It works for analogous integral equations, as well. In many cases, functions satisfying such equations approximately generate the exact solutions to them (see, e.g., [2]). That method can be described in the terms of fixed points in suitable function spaces (for related results see, e.g., [1, 5, 6]). Some examples of simple applications of it are provided.

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1991 – PhD in Mathematics

2000 – Habilitation in Mathematics

Major research interests: functional equations and inequalities with their applications, Ulam's type stability (e.g., of difference, differential, functional, integral and operator equations), real and functional analysis, fixed point theory.

Author of over 100 papers that are already printed or accepted for publication.

Chairman of the Scientific Committee of the series of conferences: International Conference on Functional Equations and Inequalities (ICFEI) (<http://uatacz.up.krakow.pl/icfei/15ICFEI/>)

Chairman of the Organizing Committees of 10th (2005), 11th (2006), 12th (2008), 13th (2009), 14th (2011), 15th (2013), and 16th (2015) ICFEIs (<http://uatacz.up.krakow.pl/icfei/15ICFEI/prev.php>)

Chairman of the Scientific and Organizing Committees of the conference: Conference on Ulam's Type Stability, Ustron (Poland), June 2-6, 2014 (<http://cuts.up.krakow.pl/>)

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Lead Editor of Banach Center Publications volume 99 (2013) titled: *Recent Developments in Functional Equations and Inequalities. Selected Topics*

Lead Guest Editor of *Abstract and Applied Analysis* annual special issues: *Ulam's Type Stability*

(<http://www.hindawi.com/journals/aaa/type.stability/>) in the years 2012, 2013

Lead Guest Editor of Journal of Function Spaces (formerly: Journal of Function Spaces and Applications)  
special issue: Ulam's Type Stability and Fixed Points Methods

(<http://www.hindawi.com/journals/jfs/si/329604/cfp/>)

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