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Opera suspicionată (OS) Suspicious work	Opera autentică (OA) Authentic work

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p.197:15 – p.198:02	p.241:01 – p.242:03
p.231:01 – p.281:00	p.243:01 – p.305:00
p.299:01 – p.332:00	p.306:01 – p.344:00
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colecția tehne 3

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Introduction to Analogical Modeling and Numerical Simulation

With (M_{pdx}) and Taylor Series for Distributed Parameters Processes

Galaxia Gutenberg

Colecție coordonată de Mihaela-Ligia Ungureșan

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LETTER FOR THE READER

Dear reader,

Usually, a scientific book represents a means of communication between the author and the reader, whereby the author introduces the reader to a specific field in the area of knowledge by presenting a range of concepts and approaches, of instruments and methods, of expertise and certainties structured in various ways, and – intentionally or unintentionally – raising questions to the reader, for which the book does not necessarily bring an answer.

After going through a book, the reader has a benefit if he retains the spirit of the book, if he manages to build on it a reference point and to progress on the gradient of knowledge on the basis of the readings.

Which is the field in the area of knowledge addressed in this book? According to the title, the field it considers has two entrances, one for those coming from the world of processes with distributed parameters, the other for those coming from the domain of modeling and simulation techniques. Through these entrances one gains access to a category of numerical methods that allow for the numerical solution of differential equations with partial derivates, used in various applied fields as models for the processes with distributed parameters.

The book presents the theoretical foundations of the methods that have as a starting point the developments in Taylor series, the characteristics of the methods. It also develops examples and discusses practical applications.

The readers who are familiar with the processes with distributed parameters, who are, in my view, much closer to the real world –

multidimensional, non-homogeneous, non-isotropic – being used to the fact that multidimensional signals are propagated in distinct ways in different directions, know how difficult it is to estimate the way in which the phenomena occur in processes with distributed parameters and how hard it is to work with models based on differentiated equations with partial derivates. Therefore, they may be interested to use the first entrance and deepen their knowledge of the calculation method based on the principle of iterative local linearization presented in the first part of the book and to study the M_{pdx} *method (the matrix of partial derivates of the state vector) which constitutes the subject of the main part of this book.*

Readers having as a background the field of modeling and simulation techniques and who are interested in the processes with distributed parameters may find in the methods presented by the authors extremely advantageous alternatives for the numerical solution of the equations provided by the models with distributed parameters. Irrespective of the applicative justification, those interested in evaluations and estimates based on mathematical models will find in this book, methods comparable to the methods of numerical integration known in the literature, which, in addition, allow for increasing the accuracy of calculations.

The large domain of application of the numerical modeling and simulation methods, which represent the focus of this book, render it interesting for multiple categories of researchers: engineers, physicist, biologists, chemical engineers, computer science engineers, having different levels of knowledge, from students to experienced specialists.

The multiple well structured examples allow the reader to develop his own application models and calculation formulas, which it can then implement by using usual computing software for engineers.

For those interested in applications in the field of automatic process control, the expression „process with distributed parameters" from the book's title requires a supplementary specification. For them „process" represents, in principle, the controlled part in an automatic system. In the general scientific terminology, which is used in the title, the process may also represent the entire automatic system. As a consequence, the methods presented in this book can be applied also for studying through simulation the control systems of plants with distributed parameters.

After having discussed with Professor Coloşi – the first author – about this new book, which is a remarkable work with a complex character, I realized that I had the chance, across time and during the many years we know each other, to witness the birth of the ideas comprised in this book. These ideas reflect restless research efforts in fields such as energetic, chemistry, electrotechnique, which were finalized under his coordination and got materialized in numerous articles, doctoral theses, dissertations and graduation theses, as well as in participations at conferences and published books.

I am convinced that you as a reader, after going through this book, will be also convinced of its value and utility.

Prof. dr. eng. Toma-Leonida Dragomir,
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30.08.2009

or polynomial variants, used in technique. With these solutions we were able to establish the initial conditions and the final conditions. Also we were able to establish the performances of numerical integration, using the indicator called "cumulative relative error in percent" (crep), which in most examples was between the limits ($10^{-6} \div 10^{-2}$) %, a fact that certifies the accuracy of the method and the programs.

Chapter 12: „Conclusions" presents the importance of study the analogical modeling and numerical simulation through ($\mathbf{M}_{pdx}$) and Taylor Series.

Appendix AI, AII and AIII helps the reader to understand all material presented in Chapters 1 - 12.

The entire paper has been elaborated by Tiberiu Coloşi. This paper could not be published without the very qualified and collegiate support of all authors.

Some examples and programs have been elaborated and included, in many years, in the projects and diploma papers of the students of the Faculty of Automation and Computer Science within the Technical University of Cluj-Napoca.

Prof. Tiberiu Coloşi expresses his thanks and gratitude to Alexander von Humboldt Foundation in Bonn-Germany, for the given material support as well as to Prof. Eng. Rolf Unbehauen, PhD. from the Institut für Allgemeine und Theoretische Elektrotechnik der Universitat Erlangen-Nürnberg-Germany for the professional support and the collegiate atmosphere he enjoyed in this university collective, during twenty months.

THE AUTHORS

IInd PART

PROCESSES WITH DISTRIBUTED PARAMETERS

Chapter 4

LINEAR PROCESSES WITH DISTRIBUTED PARAMETERS

4.1. Introduction

It is known that the usual analytical modeling of linear processes with distributed parameters can be expressed using equations or systems of equations with linear partial derivatives, homogeneous (without a free component) or non homogeneous (with free component). The category of equations with linear partial derivatives (pde), to which this chapter refers to, is presented in the following examples:

$$a_{00}y + a_{10}\frac{\partial y}{\partial t} + a_{01}\frac{\partial y}{\partial p} = \varphi(t,p) \quad (4.1)$$

$$a_{000}y + a_{100}\frac{\partial y}{\partial t} + a_{010}\frac{\partial y}{\partial p} + a_{001}\frac{\partial y}{\partial q} = \varphi(t,p,q) \quad (4.2)$$

$$a_{00}y + a_{10} + \frac{\partial y}{\partial t} + a_{01}\frac{\partial y}{\partial p} + a_{20}\frac{\partial^2 y}{\partial t^2} + a_{11}\frac{\partial^2 y}{\partial t \partial p} + a_{02}\frac{\partial^2 y}{\partial p^2} = \varphi(t,p) \quad (4.3)$$

$$a_{000}y + a_{200}\frac{\partial^2 y}{\partial t^2} + a_{020}\frac{\partial^2 y}{\partial p^2} + a_{002}\frac{\partial^2 y}{\partial q^2} = \varphi(t,p,q) \quad (4.4)$$

$$a_{000}y + a_{100}\frac{\partial y}{\partial t} + a_{010}\frac{\partial y}{\partial p} + a_{001}\frac{\partial y}{\partial q} + a_{200}\frac{\partial^2 y}{\partial t^2} + a_{110}\frac{\partial^2 y}{\partial t \partial p} +$$
$$+ a_{020}\frac{\partial^2 y}{\partial p^2} + a_{011}\frac{\partial^2 y}{\partial p \partial q} + a_{002}\frac{\partial^2 y}{\partial q^2} + a_{101}\frac{\partial^2 y}{\partial t \partial q} = \varphi(t,p,q) \quad (4.4')$$

$$a_{0000}y + a_{1000}\frac{\partial y}{\partial t} + a_{0100}\frac{\partial y}{\partial p} + a_{0010}\frac{\partial y}{\partial q} + a_{0001}\frac{\partial y}{\partial r} + a_{2000}\frac{\partial^2 y}{\partial t^2} +$$
$$+ a_{1100}\frac{\partial^2 y}{\partial t \partial p} + a_{0200}\frac{\partial^2 y}{\partial p^2} + a_{0110}\frac{\partial^2 y}{\partial p \partial q} + a_{0020}\frac{\partial^2 y}{\partial q^2} + a_{0011}\frac{\partial^2 y}{\partial q \partial r} + \quad (4.4")$$
$$+ a_{0002}\frac{\partial^2 y}{\partial r^2} + a_{1001}\frac{\partial^2 y}{\partial t \partial r} + a_{0101}\frac{\partial^2 y}{\partial p \partial r} + a_{1010}\frac{\partial^2 y}{\partial t \partial q} = \varphi(t, p, q, r)$$

$$a_{00}y + a_{30}\frac{\partial^3 y}{\partial t^3} + a_{03}\frac{\partial^3 y}{\partial p^3} = \varphi(t, p) \quad (4.5)$$

$$a_{000}y + a_{300}\frac{\partial^3 y}{\partial t^3} + a_{030}\frac{\partial^3 y}{\partial p^3} + a_{003}\frac{\partial^3 y}{\partial q^3} = \varphi(t, p, q) \quad (4.6)$$

$$a_{00}y + a_{40} + \frac{\partial^4 y}{\partial t^4} + a_{04}\frac{\partial^4 y}{\partial p^4} = \varphi(t, p) \quad (4.7)$$

$$a_{000}y + a_{400}\frac{\partial^4 y}{\partial t^4} + a_{040}\frac{\partial^4 y}{\partial p^4} + a_{004}\frac{\partial^4 y}{\partial q^4} = \varphi(t, p, q) \quad (4.8)$$

All coefficients (a…) are considered to be constant or variable, and φ(t, p), y(t, p), φ(t, p, q), y(t, p, q), φ(t, p, q, r) and y(t, p, q, r), fulfil the continuity conditions in the Cauchy sense. The independent variables (t), (p), and (q) could represent the time (t), respectively the spatial abscise (p), and (q) defined, for instance, in Cartesian coordinates.

The initial conditions (IC) are considered to be known, and other explanations could be added, from case to case, for boundary conditions (BC) and final conditions (FC).

4.2. State variables, initial conditions and final conditions

Introducing the notations:

$$x_{TP} = \frac{\partial^{T+P} y}{\partial t^T \partial p^P} \quad (4.9)$$

$$x_{TPQ} = \frac{\partial^{T+P+Q} y}{\partial t^T \partial p^P \partial q^Q} \quad \text{or} \quad x_{TPQR} = \frac{\partial^{T+P+Q+R} y}{\partial t^T \partial p^P \partial q^Q \partial r^R} \tag{4.10}$$

(for T = 0, 1, 2, …; P = 0, 1, 2, …; Q = 0, 1, 2, …; R = 0,1, 2, …) the ten pde, that is (4.1), (4.2), …, (4.8) can be rewritten as:

$$a_{00}x_{00} + a_{10}x_{10} + a_{01}x_{01} = \varphi_{00} \tag{4.11}$$

$$a_{000}x_{000} + a_{100}x_{100} + a_{010}x_{010} + a_{001}x_{001} = \varphi_{000} \tag{4.12}$$

$$a_{00}x_{00} + a_{10}x_{10} + a_{01}x_{01} + a_{20}x_{20} + a_{11}x_{11} + a_{02}x_{02} = \varphi_{00} \tag{4.13}$$

$$a_{000}x_{000} + a_{200}x_{200} + a_{020}x_{020} + a_{002}x_{002} = \varphi_{000} \tag{4.14}$$

$$\begin{aligned} &a_{000}x_{000} + a_{100}x_{100} + a_{010}x_{010} + a_{001}x_{001} + a_{200}x_{200} + a_{110}x_{110} + \\ &+ a_{020}x_{020} + a_{011}x_{011} + a_{002}x_{002} + a_{101}x_{101} = \varphi_{000} \end{aligned} \tag{4.14'}$$

$$\begin{aligned} &a_{0000}x_{0000} + a_{1000}x_{1000} + a_{0100}x_{0100} + a_{0010}x_{0010} + a_{0001}x_{0001} + \\ &+ a_{2000}x_{2000} + a_{1100}x_{1100} + a_{0200}x_{0200} + a_{0110}x_{0110} + a_{0020}x_{0020} + \\ &+ a_{0011}x_{0011} + a_{0002}x_{0002} + a_{1001}x_{1001} + a_{0101}x_{0101} + a_{1010}x_{1010} = \varphi_{0000} \end{aligned} \tag{4.14''}$$

$$a_{00}x_{00} + a_{30}x_{30} + a_{03}x_{03} = \varphi_{00} \tag{4.15}$$

$$a_{000}x_{000} + a_{300}x_{300} + a_{030}x_{030} + a_{003}x_{003} = \varphi_{000} \tag{4.16}$$

$$a_{00}x_{00} + a_{40}x_{40} + a_{04}x_{04} = \varphi_{00} \tag{4.17}$$

$$a_{000}x_{000} + a_{400}x_{400} + a_{040}x_{040} + a_{004}x_{004} = \varphi_{000} \tag{4.18}$$

In the hypothesis of integration with respect to time (t), the elements of the state vector (**x**), which correspond to the pde (1), (2), …(8) are presented in Table 4.1.

The notation (n, υ) in line 2, Table 4.1, underlines by n = I, II, III and IV the order of pde, and by υ = 2, 3 and 4 the number of variables, respectively 2 for (t, p), 3 for (t, p, q) and 4 for (t, p, q, r).

The state vector is presented in Table 4.2 for the initial conditions ($\mathbf{x}_{IC}$) and for some possible boundary conditions ($\mathbf{x}_{BC}$), respectively the final conditions ($\mathbf{x}_{FC}$), where (0) and (f) underline the initial and final values.

Table 4.1

pde	4.1	4.2	4.3	4.4	4.4’	4.4”	4.5	4.6	4.7	4.8
Notation	I·2	I·3	II·2	II·3	II·3	II·4	III·2	III·3	IV·2	IV·3
x STATE VECTOR	x_{00}	x_{000}	x_{00} x_{10}	x_{000} x_{100}	x_{000} x_{100}	x_{0000} x_{1000}	x_{00} x_{10} x_{20}	x_{000} x_{100} x_{200}	x_{00} x_{10} x_{20} x_{30}	x_{000} x_{100} x_{200} x_{300}

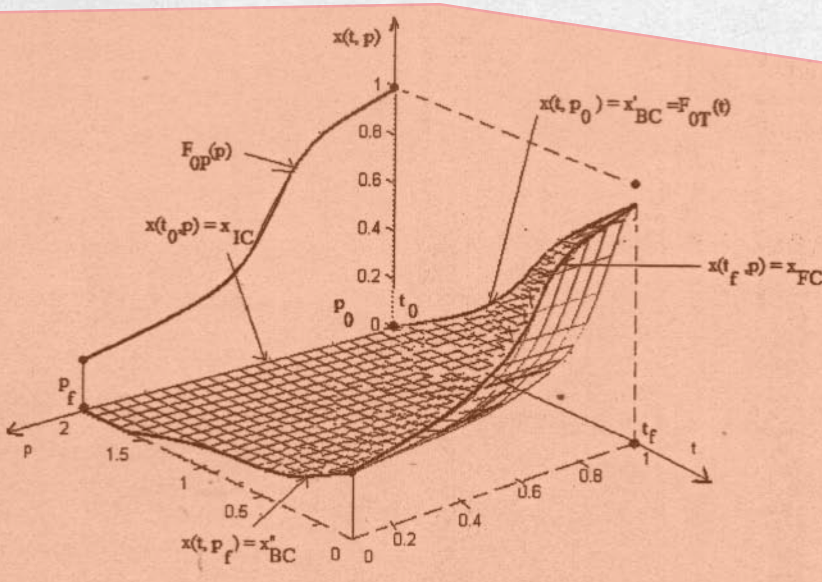

Fig. 4.1: The evolutions of $F_{0T}(t)$ and $F_{0P}(p)$

In order to exemplify the first line from Table 4.2 it is considered: $x(t, p) = F_{0T}(t) \cdot F_{0P}(p)$, where the exponentials $F_{0T}(t)$ and $F_{0P}(p)$ present increasing, respectively decreasing evolutions, as in figure 4.1. It can be noticed that: