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Selected Topics in Nonlinear Dynamics and Theoretical Electrical Engineering

Springer

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Preface

The last decade has witnessed a tremendous attention devoted to both modeling and simulation of nonlinear dynamical systems. This high interest is due to the growing awareness that nonlinear dynamics is inherent in a vast class of systems, phenomena and events: natural biological systems, physical systems, engineering systems, etc. A study of the relevant state-of-the-art reveals various scientific contributions based on both modeling, simulation and control of nonlinear dynamical systems. Various interesting and striking states of these systems are of particular interest: periodic, quasi-periodic, stable, unstable, deterministic, stochastic, synchronized, torus and chaotic dynamics, etc. A good understanding and mastering of these states does lead to various potential interesting applications.

Model approximation appears to be a very common modeling technique in engineering since accurate models are generally very complex and tough to solve either analytically or even numerically. Further, it is well known that numerical simulation is prone to accumulation of round-off errors during computation, which could result into non-realistic outcomes especially in case of extremely stiff systems. Numerical simulation is also eventually very time-consuming and simulation convergence of is not well tractable systematically. Thus, some trade-off between the potential analysis techniques appears necessary. Approximate models are easily solvable either analytically or numerically although the results obtained are of less accuracy. Accurate modeling while mastering related computational concerns is indeed a serious challenge for modern computational engineering.

This book is a collection of recent advanced contributions in the field of nonlinear dynamics and synchronization, with special applications in the area of theoretical electrical engineering. The book contains twenty-one chapters grouped in five parts.

The first part consisting of five chapters does focus on theoretical issues related to chaos and synchronization and their potential applications in mechanics, transportation, communication and security. The second part having six chapters handles dynamic systems modeling and simulation with special applications to real physical systems and phenomena. The third part consisting of four chapters discusses some fundamentals of electromagnetics (EM) and addresses the modeling and simulation in some real physical electromagnetic scenarios. The fourth part of three chapters

does mainly address stability concerns. Finally, the last part having three chapters assembles some sample applications in the area of optimization, data mining, pattern recognition and image processing.

In the following the contents of twenty-one chapters of this books is respectively briefly presented.

The first chapter, **Synchronization of two nonidentical clocks: What Huygens was able to observe?**, by Krzysztof Czolczynski, Przemysław Perlikowski, Andrzej Stefanski, and Tomasz Kapitaniak, addresses the synchronization of two nonidentical clocks. An in-depth analytical study is carried out to demonstrate the occurrence of both almost complete (in-phase) and almost anti-phase synchronizations. These types of synchronization are defined in terms of the phase shift. Evidence is provided to explain the phenomenon of almost anti-phase synchronization of two pendulum clocks that Huygens was unable to observe experimentally in the XVIIth century.

The second chapter, **On the synchronization of 1D and 2D multi-scroll chaotic oscillators**, by J.M. Muñoz-Pacheco, E. Zambrano-Serrano, O.G. Félix-Beltrán, E. Tlelo-Cuautle, L.C. Gómez-Pavón, R. Trejo-Guerra, A. Luis-Ramos, C. Sánchez-López, investigates synchronization issues in 1D and 2D multi-scroll chaotic oscillators. The applicability of these issues in communication and security systems is demonstrated. The 1D and 2D multi-scroll chaotic oscillators are simulated using the analog computing paradigm. A chaotic synchronization scheme for multi-directional multi-scroll chaos generators is introduced and the Hamiltonian theory is used to derive synchronization criteria. Finally, two schemes are set-up to transmit encrypted binary and analog signals by applying chaotic switching technique and additive chaotic masking, respectively. Both schemes are also implemented using analog computing. This computing paradigm is simulated/emulated on

The third chapter, **Nonlinear filtering of chaos for real-time applications**, by V. Kontorovich and Z. Lovtchikova investigates the nonlinear filtering of chaotic signals in presence of additive white Gaussian noise (AWGN). Specifically, nonlinear filtering and chaotic phenomena are investigated with concrete applications in electrical engineering, basically in communications, control, etc. It is demonstrated that both nonlinear and chaotic filtering are processes leading to various potential applications including those which are related to real-time regime conditions. Examples of these applications include chaos-based communications systems synchronization, real-time control of chaos, radio-frequency interference filtering and mitigation, and chaotic system identification, just to name a few.

The fourth chapter, **Time-of-flight estimation using synchronized chaotic systems**, by Christian F. Wallinger and Markus Brandner develops a theoretical ranging concept based on time-of-flight (ToF) estimation. It is demonstrated that the concept involving chaotic signal leads to various potential metrological applications. A series of performance criteria for these applications are defined as fundamental parameters of the delay estimation process. An experimental demonstration is described showing the applicability of synchronized chaotic systems in a ToF measurement system. Many time-delays are evaluated analytically and experimentally and a comparison is performed to validate the concepts developed.

The fifth chapter, **Binary synchronization of complex dynamics in cellular automata and its applications in compressed sensing and cryptography**, by Radu Dogaru and Ioana Dogaru applies a concept involving cellular automata to both modeling and synchronization of complex dynamics. A specific focus is devoted to the binary synchronization of the transmitted bit stream. It is demonstrated that the decoding of this stream is possible only when the structure of the cellular automata (encryption key) is known. Finally, some applications of the concept developed are considered in cryptography, spread spectrum communications, and compressed sensing. Finally, an implementation of the concept on FPGA is presented.

The sixth chapter, **Fast switching behavior in nonlinear electronic circuits: a geometric approach**, by Tina Thiessen, Sören Plönnigs and Wolfgang Mathis develops a geometric concept to detect some striking and unexpected behavior of a specific class of nonlinear electronic circuits. An example of this behavior is the fast switching behavior of circuits which is characterized by the jumps in their state space. An analytical study is developed and appropriate criteria are derived for the occurrence of jump conditions. The approach developed in this work is essential as it allows a separation between the transient states of the electronic circuits and their permanent states. Finally, it is demonstrated that the geometric concept developed can easily be adapted to a system of equations based on MNA, allowing an implementation on circuit simulators such as SPICE. Numerical simulations are considered to validate the analytical results developed.

The seventh chapter, **Dynamics of Liénard optoelectronic oscillators**, by Bruno Romeira, José Figueiredo, Charles N. Ironside and Julien Javaloyes investigates the behavior a nonlinear optoelectronic oscillators (OEO) of Liénard types. It is demonstrated that the effects due to negative differential resistance across the tunnel diode leads to oscillations within the system. The concept developed in this chapter is validated by some recent experimental results presented by the relevant state-of-the-art. A specific focus is devoted to both electrical and optical systems, likely to exhibit complex dynamics ranging from self-sustained relaxation oscillations, to injection locking and chaotic dynamics. Potential applications of the concept in this chapter are found in the development of secure communication systems and highly stabilized OEO devices for microwave-photonic systems.

The eighth chapter, **Application of coupled dynamical systems for communities detection in complex networks**, by Nikolai Nefedov, models the stable communities' detection and links predictions processes in complex networks by coupled ordinary differential equations. The dynamics of the local states is described by the well-known Kuramoto model. The method is based on the dynamical formulation of modularity using a random walk and then is extended to coupled dynamical systems to detect communities at different hierarchical levels. Both attractive and repulsive coupling are considered and their effects on the dynamics of the global network are analyzed. As proof of concepts of the approach developed in the chapter, practical datasets recorded during the Nokia mobile-data collection campaign are considered and the concept developed is applied to derive the potential structures of the social community and to perform link predictions or recommendations.

The ninth chapter, **Infinite networks of hubs, spirals, and zig-zag patterns in self-sustained oscillations of a tunnel diode and of an erbium-doped fiber-ring laser**, by Ricardo E. Francke, Thorsten Pöschel, and Jason A.C. Gallas, investigates the dynamics of a nonlinear circuit containing diodes as analog devices. Some strange and oscillating patterns are depicted analytically which cannot be explicitly observed experimentally due to their appearance in a compressed form. To overcome this problem a circuit using a tunnel diode is designed. This circuit is likely to display two large spiral cascades over a wide range of parameter settings. It is demonstrated that such a display can be easily observed experimentally.

The tenth chapter, **Study of the dynamics of atmospheric pollution and its association with environmental parameters**, by Siwek Krzysztof, Osowski Stanislaw, and Swiderski Bartosz investigates the dynamic processes of creation of atmospheric pollution due to SO2, NO2 and ozone propagation. The interdependence between the pollution and the environmental atmospheric parameters (e.g. temperature, wing, humidity, insolation, etc) is investigated. It is demonstrated that the interdependence is nonlinear and could lead to chaotic dynamics. Finally, the results of these studies are exploited in the development of prediction models of the concentration of particular pollutants.

The eleventh chapter, System dynamics modeling of intelligent transportation systems – Human and social requirements for the construction of dynamic hypotheses, by Oana Mitrea, structures the knowledge and requirements for the (system dynamics) modeling of distributed actions in the intelligent transportation systems from the perspective of the sociology of technology. This chapter concentrates on the potential of the theory of the distributiveness of actions in heterogeneous constellations (sociology of technology) to enhance the formulation of dynamic hypotheses for system dynamics modeling of ITS. It is demonstrated that the performance of ITS systems depend not only on the interactivity between the vehicle-human systems and the environment, but also on the impact of socio-political and other contextual factors from a broader socio-technical constellation.

The twelfth chapter, **Fundamentals of electrodynamics**, by Branko Miškovic, develops some fundamental basics of the electromagnetics (EM) theory. Some lights are shed on important basic aspects of the EM theory which were not clearly explained by the relevant literature. This is achieved considering three classes of EM quantities namely, electric charges, currents, and kinetic magnetic fields. A new mathematical expression of the general kinetic central law is derived using the concept developed in this chapter. Further, the secondary field transformations are also completed. The relativistic postulates and respective kinematical transformations, based on the incomplete field transformations, are finally disqualified. On the other hand, Einstein's equation and Lorentz' mass function are explained and validated. The circular spatial axes are also explained and validated by the wave cosmic process, which determines by itself gravitational attraction, with unique and uniform lapse of time, in agreement with the Galilean view.

The thirteenth chapter, **Advanced adaptive algorithms in 2D finite elements method of higher order of accuracy**, by Pavel Karban, Ivo Doležel, František Mach, and Bohuš Ulrych develops a new method for automatic adaptivity in

finite element methods of higher order of accuracy. The main attention is devoted to hp-adaptivity techniques that exhibit the highest level of flexibility and exponential convergence of results. The technologies are implemented in the adaptive FEM codes and finally both Agros2D and Hermes2D based on a higher-order finite element method are illustrated by three typical examples.

The fourteenth chapter, **SPICE model for fast time domain simulation of power transformers, exploiting the ferromagnetic hysteresis and eddy-currents**, by Lucian Mandache, Dumitru Topan, Mihai Iordache, and Ioana Gabriela Sirbu, considers both modeling and simulation (using SPICE) of power transformers. Specific states are depicted, namely saturation regime, static hysteresis and eddy currents. The principle of magnetic circuit modeling is based on analog lumped equivalent circuits and the SPICE implementation uses the principle of modularity. It is demonstrated that the method developed in this chapter allows simulation of normal operation modes, as well as critical transients and faulty conditions. A case study is presented to prove the feasibility, usefulness and accuracy of the proposed modeling and simulation approach, where the SPICE results are validated by experimental ones.

The fifteenth chapter, **Hard-coupled modeling of induction shrink fit of gas-turbine active wheel**, by Václav Kotlan, Pavel Karban, Bohuš Ulrych, Ivo Doležel, and Pavel Kus, develops a hard-coupled model of induction heating of a ferromagnetic disk. The mathematical model is derived from three coupled partial differential equations (for the distribution of electromagnetic field, temperature field and field of thermo-elastic displacements) whose coefficients are temperature-dependent functions. The finite element method is implemented into the Hermes and Agros codes and numerical solutions are obtained. The methodology is illustrated by a typical example, i.e., heating of an active wheel of a high-speed gas turbine that is to be hot-pressed on a shaft with the aim of obtaining a shrink fit allowing transferring the given torque at the nominal revolutions. Finally the parameters of the heating process in transverse and longitudinal magnetic fields are evaluated and discussed.

The sixteenth chapter, **Stability analysis and limit cycles of high order sigma-delta modulators**, by Valeri Mladenov, considers the stability analysis of limit cycle oscillations in a one bit high order sigma-delta modulators. An approach is developed and applied to sigma-delta modulators as a general analysis framework. The approach developed is based on a parallel decomposition of the modulator and a direct nonlinear systems analysis. In this representation, the general N-th order modulator is transformed into a decomposition of low order, generally complex modulators, which interact only through the quantizer function.

The seventeenth chapter, **Stability analysis of vector equalization based on recurrent neural networks**, by Mohamad Mostafa, Werner G. Teich, and Jürgen Lindner, focuses on an application of RNNs in communications engineering, namely the vector equalization. The importance of this procedure arises from the fact that there is no need for training. The parameters of the RNN to act as vector equalizer can be obtained by investigating the stability properties of these networks and by choosing a suitable activation function, which is the core of this work. Both global and local stability of the discrete-time and continuous-time RNN in the context of a

vector equalizer are analyzed and the impact of the stability conditions on the equalization process is depicted. It is shown that the global stability is interesting if the weight matrix is not symmetric. Finally, it is demonstrated that a vector equalizer based on RNNs with increasing slope of the activation function during the iteration process can be interpreted as a scheme with a transition from global stability to local stability.

The eighteenth chapter, **Stability of linear circuits with interval data: a case study**, by Zygmunt A. Garczarczyk analyses the stability of a linear lumped electric circuit with interval data that model uncertainties of their element parameters (passive element values R, L, C and controlled source coefficients k). An approach is developed based on the checking of the stability of a symmetric interval matrix associated with the state matrix and on some interval analysis results. The method is demonstrated to be appropriate for the stability analysis. It's depicted from both numerical and experiment investigations that the procedure works effectively for some interval state matrix.

The nineteenth chapter, **Data reconciliation and bias estimation in on-line optimization**, by Moufid Mansour, develops techniques for bias estimation (BE) and data reconciliation (DR) for the detection, estimation and elimination of biases and random errors. It is demonstrated that these techniques can be successfully employed within an online Integrated System Optimization and Parameter Estimation (ISOPE) scheme for the determination of the process optimum, despite the existence of model-reality differences and measurement errors. The performance of the resulting scheme is demonstrated by applying it to the optimization of a two tank CSTR system. The robustness of the optimization scheme is confirmed when applying this scheme to particular process data with multiple biases and noise. Finally, it is demonstrated that the BE and DR techniques are suitable for performing robust online optimization event in cases of noisy and/or errors data.

The twentieth chapter, **Image edge detection and orientation selection with coupled nonlinear excitable elements**, by Atsushi Nomura, Yoshiki Mizukami, Koichi Okada and Makoto Ichikawa, develops an algorithm for edge detection and orientation selection with a grid system consisting of coupled nonlinear excitable elements. The model uses the well-known Fitz-Hugh-Nagumo coupled equations. Two types of coupling are considered i.e. strong inhibitory coupling and strong nonlinearity induced stationary pulses. Using this latter type of coupling the algorithm for edge detection is developed based on a technique where the grid system self-organizes a pulse pattern at edges in an initial condition. This algorithm is further experimentally applied (with a great success) to artificial binary and real images. Finally a benchmarking is performed by comparing the results provided by the algorithm developed in this wok with some results proposed by the relevant literature.

The chapter twenty-first, **Consecutive repeating state cycles determined periodic points in a Turing Machine**, by Michael Stephen Fiske studies the Turing machine with new methods motivated by the notion of recurrence in classical dynamical systems theory. The state cycle of a Turing machine is introduced. It is proven that each consecutive repeating state cycle in a Turing machine determines a unique periodic configuration (point) and vice versa. This characterization is a

periodic point theorem for Turing machines. Using the notion of a prime directed edge and a mathematical operation called edge pattern substitution, a search (or optimization) procedure finds consecutive repeating state cycles. Both periodic and aperiodic states are depicted and these states alternate together when monitoring a control parameter.

Klagenfurt, The Guest Editors
August 2012

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