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Study of Nonlinear Dynamics of Complex Chaotic Systems: Combined Chaos-Geometric and Neural Networks Algorithms

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Abstract: An advanced numerical approach to modelling nonlinear processes of chaotic systems is presented and based on the combined chaos theory methods, including generalized concept of compact geometric attractors (CGA), and a neural networks (NNW) simulation algorithm. The use of the fundamental data on a phase space evolution of the nonlinear process in time and the neural networks computational simulation can be considered as one of the novel approaches in the construction of global nonlinear prediction models for evolutionary dynamics of the complex chaotic systems. The approach provides an accurate description of the structure of the corresponding strange attractors for significantly chaotic dynamical systems. As the illustrative examples, the approach is applied to analysis, modelling, and construction of prediction model for a few chaotic dynamical systems (geophysical and quantum electronics, laser systems). The corresponding topological and dynamical invariants for the dynamic time series are computed and analysed.

Keywords: complex chaotic system, dynamics, attractors, neural networks

1. Introduction. Universal Chaos-Geometric Approach to Complex System Dynamics

Multiple physical, chemical, biological, technical, and other systems (devices) demonstrate the typical complex chaotic behaviour. In many important applications a typical dynamic of these systems is the world of strong nonlinearity and chaos. In principle, the most conventional direct approach to dynamics treating problem consists in building an explanatory model using an initial data and parameterizing sources and interactions between process properties. Unfortunately, such that kind of approach is realized with difficulties, and its outcomes are insufficiently correct. In this paper we go on our work on development of a novel, effective approach to modelling nonlinear processes in the significantly chaotic systems. This approach should be based on the combined using of a generalized CGA concept, chaos theory methods and NNW algorithms. Combined using information on the phase space evolution of the nonlinear process in time and the NNW simulation techniques can be considered as one of the fundamentally new approaches in the construction of global nonlinear models. Moe over it is waited that such an approach could provide the most effective and accurate description of the structure of the corresponding strange attractors for significantly chaotic dynamic systems.

Figure 1 presents the flowchart of our combined chaos-geometric and NNW computational approach to nonlinear analysis and prediction of dynamics of a complex system (e.g. [1-5]). As usually one should consider some scalar measurements $s(n) = s(t_0 + n\Delta t) = s(n)$, where t_0 is the start time, Δt is the time step, and n is the number of the measurements. The principal tasks are to reconstruct phase space using as well as possible information contained in $s(n)$ as well as to build the corresponding prediction model and define how predictable is a nonlinear dynamic of the studied system. The new element is using the NNW algorithm in forecasting nonlinear dynamics of chaotic systems [4].

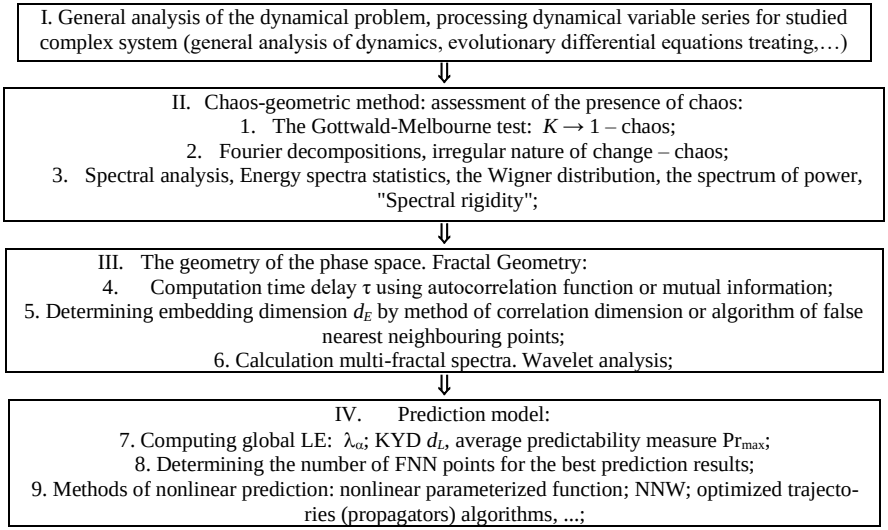

Figure 1. Flowchart of the combined chaos-geometric approach and NNW to nonlinear analysis and prediction of chaotic dynamics of the complex systems (structures, devices)

2. Results and Concluding Remarks

The approach presented is tested by means of numerical analysis, modelling and forecasting nonlinear temporal dynamics for a number of different in nature dynamic systems (quantum electronics systems: semiconductor GaAs/GaAlAs laser device with delayed feedback; atmospheric and hydrologic systems with chemical pollutants). The key topological and dynamical invariants (embedding and correlation dimensions, the Lyapunov's exponents, Kaplan-Yorke dimension, Kolmogorov entropy, average limit of predictability etc) for the corresponding time series are computed and analysed. To conclude, an advanced numerical approach to modelling nonlinear processes of chaotic systems is presented and based on the combined chaos theory methods, CGA concept and NNW simulation algorithms. It is shown that low-dimensional chaos exists in the time series under investigation and quite sufficient predictability is obtained in the forecasting a temporal dynamic of studied systems. The approach can be considered as an effective computational tool for analysis and processing the data of chaotic quantum and laser systems and quantum devices (sensors).

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