New indicators simplifying investigations of nonlinear systems with applications to analyses of complex behavior of coupled systems.

Coupled nonlinear systems and complex networks (CNS) arouse huge interest and fascination among many scientists. During the last decades, considerable efforts have been devoted to the study of dynamics of such systems. This interest is justified by a rich catalog of different types of complicated collective behavior, like different types of synchronization, so called chimeras states, hyperchaos, multistability and others, exhibited by such systems, as well as the various resulting applications, observed analogies and features in real phenomena. Currently, beyond searching of a new patterns existing in CNS, investigations are focused on problems, connected with explanations of their elementary and complex properties, searching for necessary and sufficient conditions for the appearance patterns existing in dynamics of such systems, like for instance travelling or breathing chimeras and basics of scenarios of creation of these states.

Due to complex type of final dynamical behavior of CNS, their sensitivity and dependence on initial conditions, as well as parameters mismatches, investigations of such a systems are very tedious and labor-intensive. It became the main motivation for taking up the topic of the presented project. It is proposed to develop new, Complex Systems – oriented Indicators (CSI), effective methods, allowing for investigations of CNS, with emphasis on simple and fast recognition of dynamical state of network's node oscillators and their respective behavior. For the basis of developed CSI, it is proposed to apply multifaceted modification of very simple and efficient method, of estimations Lyapunov exponents. The LEVF (Lyapunov Exponent based on Vector Field) method, allows for simple and 15 – 35 % faster, estimation of LE. Basing on estimated LE spectrum, values of other indicators, like fractal dimension, Kolmogorov-Sinay entropy, system divergence can be found easier, than using commonly applied methods. All these indicators are of crucial significance in investigations of complex systems dynamics. In the project it is proposed to introduce several modifications to LEVF method and combine with the other indicators, taking all their advantages related to analyses of complex systems. The main feature of the proposed approach that, differs from the commonly applied methods is that it allows for fast identification of the tendency of relative behavior of the node oscillators, yet before the system achieves its final state on the attractor. As the proposed approach is based on the method which is 20% faster than commonly applied methods, these features combined together are expected to give the most efficient tools, allowing scanning the system dynamics in the wide ranges of its parameters. Investigations will be conducted with use of programs that will be specially developed to allow solution of the tasks to be pursued in the project.

The main objectives of the research to be conducted in this project

- ✓ Designing efficient and universal tools for simplification of investigations of CNS,
- ✓ Application of the developed tools in investigations of dynamics of different types of CNS focused on explanations of their elementary and complex properties, searching for necessary and sufficient conditions for the appearance patterns existing in dynamics of such systems.

As a final result it is expected obtaining more specialized indicators and tools, allowing for easier and more effective investigations of dynamics of complex systems. Approaches proposed in the project are multifaceted, as they combine different methods of dynamical systems investigations, developing new approaches that will have many features to be examined. It concerns also numerical methods and applied algorithms. The methods of the CNS investigations to be developed in the project are expected to be faster, simpler and more universal approach than methods commonly applied in such systems studies. As obtained methods are expected to be more user – friendly, it can encourage other scientist's attention to CNS issues. Proposed methods introduce also new perspective on the CNS dynamics, thanks to new types of applied indicators. Thus it is expected that proposed approach would not only facilitate CNS investigations, but also could for instance help to analyze unsolved problems, like CNS elementary and complex properties and necessary and sufficient conditions for the appearance of pattern in their dynamics, or basics of scenarios of their creation.

Last but not least, it is also anticipated that the research will unveil interesting side findings in the domain of nonlinear dynamics, which may benefit the project, be applied in further scientific work and trigger new possibilities of development.