ALBANBAY NURTAY

RESEARCH OF CHARACTERISTICS OF AUTO OSCILLATORY PROCESSES AND NONLINEAR EFFECTS IN THE MODELS OF NEURAL SYSTEMS

ABSTRACT

dissertation for the degree of Doctor of Philosophy (Ph.D.) in the specialty "6D071900 – Radio Engineering, Electronics and Telecommunications"

The dissertation work is based on research aimed at studying auto oscillatory processes and nonlinear effects in neural systems based on two coupled FitzHugh-Nagumo neurons.

Relevance of the work.

Modern problems of radio engineering, electronics and telecommunications, increasing the efficiency of communication channels and many other problems can be successfully solved using neural networks. In this regard, the study of the dynamics of neuron-like systems plays an important role in science and technology.

In general, speaking about neural networks, it should be noted, firstly, the complexity of their elementary components – nerve cells (neurons), whose mathematical models themselves are multidimensional systems with complex multiscale dynamics, and, secondly, the complexity of the structures formed by neurons with the help of excitable processes that provide non-local connections between nerve cells. The dynamics of neuron models has been studied for a long time without involving stochastic differential equations, due to the complication of the research problem by the introduction of noise. In addition, it was not clear enough how to correctly introduce noise into models of neurons and neural systems. Nevertheless, experimental data showed the need to take into account noise in order to adequately describe neurons in their natural environment. Under the influence of relatively low noise, excitation and relaxation processes occur in such systems, resulting in undamped stochastic oscillations. However, the issues of auto oscillatory processes in neural networks have been little studied even for the simplest models of neurons.

Another key issue is the study of nonlinear effects in neural systems. Due to the emergency diversity of multi-element systems, both in terms of structural structure and functional properties, a number of key issues and problems remain unexplored here. For a qualitative description of the dynamic effects of neural systems, it is necessary, first of all, to obtain and study an adequate model of the neural system. The use of the most accurate models built on the basis of the Hodgkin-Huxley approach is highly limited, since it leads to the complication of the element model due to a large number of variables and parameters that require fine tuning. In this case, even at the level of individual elements, it is not always possible to trace the mechanisms of the emergence of dynamic modes, to assess

the areas of their existence and stability. The main property of the neural system chosen for modeling is the presence of stable oscillatory solutions corresponding to neuron spikes. To solve this problem, it becomes necessary to develop a model that takes into account certain features of the dynamics of real neurons that are essential for describing specific dynamic phenomena. In this regard, ongoing research in this area is relevant and can have many practical applications.

The purpose of the work: Theoretical, numerical and experimental study of nonlinear effects observed in systems consisting of the same and different types of neurons.

Research objectives of the study:

- To develop a mathematical model that describes the impact of external noise on a system consisting of two types of (connected) FitzHugh-Nagumo neurons;
- To develop a statistical model of a nonlinear effect observed under the influence of external noise in a system consisting of two types of FitzHugh-Nagumo neurons and conduct its numerical study;
- To develop an electronic circuitry model that describes the impact of external noise on a system consisting of two types of FitzHugh-Nagumo neurons;
- Implementation and conduct of experimental studies of a circuit model that describes the impact of external noise on a system consisting of two types of FitzHugh-Nagumo neurons;
- Development of a mathematical model of a system built from one type of FitzHugh-Nagumo neurons;
- Theoretical and numerical study of the dynamics of a system built from one type of FitzHugh-Nagumo neurons;
- Development of a circuit model corresponding to a system built from one type of FitzHugh-Nagumo neurons;
- Implementation and conduct of experimental studies of a circuit model of a system built from one type of FitzHugh-Nagumo neurons;
- Processing of experimental data and their comparison with the conclusions of the theory.

The object of study: Nonlinear effects of a system built from FitzHugh-Nagumo connected neurons.

Research methods: Mathematical models of neural systems were studied theoretically, numerical studies were carried out in MatLab. Circuit models are studied in the environment of special programs Multisim and LabVIEW. Physical experimental studies were carried out using analog electronic devices corresponding to circuit models.

The novelty of the study - for the first time:

- It has been established that the number of "bursting" when exposed to external noise on a system consisting of FitzHugh-Nagumo neurons obeys an exponential distribution.
- It has been shown that in a system built from one type of FitzHugh-Nagumo neurons, neurons do not fire at the same time.

- It has been established that the frequency response of signals generated in a system built from one type of FitzHugh-Nagumo neurons depends on the initial conditions.

The main provisions, put on defense:

1. The number of "bursting" when exposed to external noise on a system consisting of FitzHugh-Nagumo neurons obeys an exponential distribution

2. In a system built from one type of FitzHugh-Nagumo neurons, neurons do not fire at the same time.

3. The frequency response of signals generated in a system built from one type of FitzHugh-Nagumo neurons depends on the initial conditions.

The theoretical and practical significance of the work. The study of signal processing modes using a neural system, as well as the dependence on its own indicators and external noise, allows us to determine the main methods for controlling the dynamics of the entire system. The results obtained can be applied in the creation of new radio-electronic and telecommunication devices, in which the ability to generate and process complex signals can play a significant role by studying the characteristics of auto oscillatory processes and nonlinear phenomena in the models of neural systems.

Personal contribution of the author. All of the theoretical, numerical studies results and physical experiment were obtained personally by the applicant. The setting of tasks and discussion of the results were carried out jointly with the supervisors.

Reliability of results. The reliability of the results of research carried out within the framework of the dissertation is determined by the use of modern mathematical methods in the course of work, the reproducibility of experimental results, the consistency of the results of mathematical modeling and experimental research with each other, with theoretical premises and conclusions obtained by other authors, publications in peer-reviewed scientific journals on the subject of this work, discussion of research results at conferences.

Approbation of work. The results obtained in the dissertation work were reported and discussed at: 15th International Conference "Dynamical Systems Theory and Applications" (Łódź, Poland), "Materials VIII International scientific and methodical conference dedicated to the 90th anniversary of Abai Kazakh National Pedagogical University", "Proceedings Satbayev Readings Innovative Solutions to Traditional Problems: Engineering and Technology.

Publications. Based on the materials of the dissertation work, 7 publications were published, including: 2 articles – in peer-reviewed journals with a high impact factor included in the international Scopus database (Chaos, Journal of Computational and Nonlinear Dynamics); 2 articles – in publications recommended by the Committee for Quality Assurance of Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan; 3 – in collections of abstracts of international conferences, including 1 – in a foreign international conference (15th International Conference "Dynamical Systems Theory and Applications" Łódź, Poland).

The structure and scope of the dissertation. The dissertation work consists of an introduction, three sections, a conclusion, 126 titles of the list of sources used and contains two appendices. The total volume of the dissertation work is 86 pages, 48 pictures.