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MODELING OF THE INTERACTION FOR A LIVING NEURAL NETWORK BY ARTIFICIAL INTELLIGENCE TECHNOLOGIES

Abstract: A new model of the interaction of neurons in a living neural network is considered, which explicitly takes into account the phenomenon of time-delayed interaction within a group of interconnected neurons known in neurophysiology. This model can be used to build control systems in robotics with artificial intelligence. It is shown that similar author's simulation-model examples of a living neural network can be constructed, for example, in the form of chains of a sufficiently large number of groups of interacted neurons of the same type.

Keywords: neural network, artificial intelligence, mathematical model of a neural network, control, interaction delay, robotics, modeling, memorization of information in a brain neural network.

Introduction

The research conducted by the author, in particular, was stimulated by the needs of our partners – specialists in the treatment of special conditions (in accordance with the cooperation of V. M. Glushkov Institute of Cybernetics National Academy of Sciences of Ukraine, Kyiv and with some of Ukrainian clinics, including experts from the Polyclinic for scientists from the National Academy of Sciences of Ukraine (Kiev) and the ATOS clinic, Kiev, [3].) The main profile of ATOS clinic is the diagnosis and treatment of the so-called «special states» of a person – for example drug addiction, alcoholism, gambling and other addictions.

It is sufficiently important for modern neurophysiology to take into account the time lag in the interaction betwing live neurons end limitation for the propagation speed. It is known also that the reaction time of the human body to changes in environmental conditions increases in the case of intoxication. Here it is important to cite the well-known data from experimental neurophysiology, that a nerve impulse propagation speed through thick myelinated fibers (10 to 20 microns in diameter) reaches 70-120 m/s, and for the thinnest unmyelinated fibers - less than 2 m/s [4].

In particular, the models take into account the sequence of processes of information signal propagation between neighboring neurons by passing such a signal through the synapse of an excited neuron to neighboring neurons through the corresponding dendrites of these neurons. In [5], [6], it was proposed to replace in theoretical neurophysiology the synaptic hypothesis formerly traditional among neurophysiologists (according to which memory formation occurs in the form of changes in the strength of interneuronal synaptic connections) by the new hypothesis which is proposed by Arshavsky Yu.I. in [5].

Description of the problem

It is known from neurophysiology [4], [5] that in the process of information memorizing, information signals are transmitted between two neighboring neurons, which proceeds in three basic stages. So, at the first stage, the informational neuroimpulse from the axon of the first neuron penetrates to one of the dendrites of the neighboring neuron through the zone of its synapse. At the second stage, the neuropulse penetrates through the liquid interneuronal medium by the process of diffusion into glutamate molecules. At the third stage, the specific process of glutamate binding to glutamatergic receptors on the dendritic spines of the second neuron is realized and this linkage is fixed with the participation of specific genes.

Modeling the operation of a human neural network is an important task for the use of the developed models, in particular, in the development of android robots with artificial intelligence.

About the concept of the author's mathematical model to describe the basic functions of the living brain.

An important element of the author's conception of modeling the dynamics of the interaction of neurons of a living neural network is taking into account the delay of the interaction of neurons in a neural network. At the same time, the author of this paper for the first time in [1], [2] proposed for describing these processes the mathematical apparatus of differential equations with a retarded argument (DERA) for the general case (that is, an arbitrary finite number of neurons). In the mentioned works, the activity in time of the corresponding processes was modeled in sufficient detail in the transmission of the informational neuroimpulse within groups of 2 and 3 neurons.

In the proposed paper, the author cites the result of your modeling similar processes of information signal propagation inside the quartet of neurons (4 neurons interconnected through axons and dendrites).

Based on [1], [2], the corresponding system of dynamic equations of interaction for the group of four neurons takes the form:

$$\begin{aligned}
&\frac{d^2x_1(t)}{dt^2}+h_1\frac{dx_1(t)}{dt}+\omega_1^2x_1(t)=g_{12}x_2(t-\Delta_{12})+g_{13}x_3(t-\Delta_{13})+g_{14}x_4(t-\Delta_{14}) \ ;\\
&\frac{d^2x_2(t)}{dt^2}+h_2\frac{dx_2(t)}{dt}+\omega_2^2x_2(t)=g_{21}x_1(t-\Delta_{21})+g_{23}x_3(t-\Delta_{23})+g_{24}x_2(t-\Delta_{24}) \ ;\\
&\frac{d^2x_3(t)}{dt^2}+h_3\frac{dx_3(t)}{dt}+\omega_3^2x_2(t)=g_{31}x_1(t-\Delta_{31})+g_{32}x_2(t-\Delta_{32})+g_{34}x_3(t-\Delta_{34}) \ ;\\
&\frac{d^2x_4(t)}{dt^2}+h_4\frac{dx_4(t)}{dt}+\omega_4^2x_4(t)=g_{41}x_1(t-\Delta_{31})+g_{42}x_2(t-\Delta_{32})+g_{43}x_3(t-\Delta_{43}) \ ;
\end{aligned} \quad (1)$$

where $xj(t)$ – is the intensity of excitation of the j-th neuron at the moment of time t. For this case, the quartet of neurons j takes the values 1, 2, 3, 4. Parameters ωi and hi respectively, are the "own" excitation frequency and intensity of neuron activity dissipation; $0<\Delta ij$ – is the magnitude of the delay during the interaction transmission from the i-th neuron to the j-th neuron; gij – is the intensity of the influence of the i-th neuron on the j-th neuron.

From the known biochemical models for the process of transferring and memorization of an operatively received information piece into a neural network, the author finds it appropriate to build the adequate mathematical model for the new information recording process initially for some local neurons group (for example, $N = 3$ or 4), which directly receives information about of the environment current state.

According to what was said, below, we consider the modelling process of functions of the information signal perception by a living neural network for $N = 4$ neurons.

The presented model (1) describes the dependence of the excitation dynamics in a group of neurons on the *totality* of their basic biochemical parameters: the specific frequency (ωi) of neuron oscillations; the magnitude (hi) of the damping in time of these oscillations (that is, the intensity of dissipation of such oscillations); the intensity of the j-th neuron impact on the i-th neuron. The dependence of the excitation conductivity intensity for the neural network from the indicated biochemical characteristics is obtained from the result of experimental studies [4]; namely numerical values of the parameters ωi, hi, gij, Δij can be calculated with experimental methods of neurophysiology.

Below, this solution of the initial problem for the system of equations (1) is studied by the DERA-theory methods [5], [6], [7] with initial conditions on the initial interval as follows:

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$$x_i(t) = q_i(t); \quad \frac{dx_i(t)}{dt} = b_i(t) \text{ for } t \in \left[0, \max_{i,j} \Delta_{ij}\right], \tag{2}$$

where *qi*(*t*) and *bi*(*t*) are given initial functions, *i*, *j* = 1, 2, 3, 4; $i \neq j$, and *xi* (*t*) is the intensity of the *i*-th neuron "informational excitation".

According to the well-known theorems from [7], [8], [9], we achieved the solution of the initial problem (1), (2) as the following decomposition (here *i* 2 = -1):

$$x_j(t) = \sum_{k=1}^{Q} A_{jk} \exp[\sigma_k + i\tau_k], \; j = 1, ..., N, \tag{3}$$

where the values of the coefficient *Ajk* are taken from the initial conditions of the calculation in a particular numerical experiment; *Q* is a large enough integer, the choice of which depends on the required accuracy of approximation by a finite series of the desired numerical solution *xi*(*t*).

In formula (4), eight parameters σ*k* and τ*k*, where *k* = 1, ..., 4 are calculated as solutions of some special algebraic equation, obtained from the requirement that the determinant of the corresponding system of algebraic equations to be equal zero for the system of equations (1):

$$W_4(s) \equiv \begin{vmatrix} \left(s^2 + sh_1 + \omega_1^2\right); & -g_{12}\exp(-s\Delta_{12}); & -g_{13}\exp(-s\Delta_{13}); & -g_{14}\exp(-s\Delta_{14}); \\ -g_{21}\exp(-s\Delta_{21}); & \left(s^2 + sh_2 + \omega_2^2\right); & -g_{23}\exp(-s\Delta_{23}); & -g_{24}\exp(-s\Delta_{24}); \\ -g_{31}\exp(-s\Delta_{31}); & -g_{32}\exp(-s\Delta_{32}); & \left(s^2 + sh_3 + \omega_3^2\right); & -g_{34}\exp(-s\Delta_{34}); \\ -g_{41}\exp(-s\Delta_{41}); & -g_{42}\exp(-s\Delta_{23}); & -g_{43}\exp(-s\Delta_{14}); & \left(s^2 + sh_2 + \omega_2^2\right); \end{vmatrix} = 0$$

where

$$s = \sigma + i\,\tau. \tag{5}$$

This solution has the form as follows

$$S_k = \sigma_k + i\tau_k, \text{ where } k = 1, 2, ...,$$

ensuring the fulfillment of conditions for each pair (σ*k*, τ*k*) to the next:

$$\mathrm{Re}\, W_4(\sigma_k + i\tau_k) = 0, \tag{6.a}$$

$$\mathrm{Im}\, W_4(\sigma_k + i\tau_k) = 0. \tag{6.b}$$

As a result, we obtain the set of the system (6.a), (6.b) solutions as a countable set as a sequence of complex numbers of the form

$$S_k = \sigma_k + i\tau_k, \text{ where } \quad k = 1, 2, ... \tag{7}$$

The result is formulated as the following lemma:

Lemma. For the model of four interacting neurons (*N* = 4), the desired values of the discrete set of complex roots {σ*j* + *i*τ*j*} are obtained as solutions of a system of two algebraic equations (6a) and (6b), that is, respectively, the equality of the real and imaginary parts of the determinant to zero (4) the original system of linear DERA equations (1). In this case, for the original system (1), the following substitution is used:

$$x_j(t) = A_j e^{st},\ j = 1,2,3,4. \tag{8}$$

in the left part of the original system of four equations (1), then from the requirement that the corresponding determinant $W4$ of the system of homogeneous linear equations for the constants $A1$, $A2$, $A3$, $A4$ be equal to zero, the solutions of the system of two equations (6a), (6b) are calculated for the desired pairs of numbers (σ, τ).

Summary

In this paper, we consider an example (1) of the propagation of information signals in the central neural network for some information frequency important for the body with the corresponding "attenuation parameter" σ information signal for a system of four interacting neurons connected by axons and dendrites. Obviously, the same approach and calculation method can be used for the case of $N \geq 5$ neurons using the DERA apparatus [7], [8], [9]. The author carried out numerical calculations of equations of this type for the case when N = 2 [1] and N = 3 [2], confirming the effectiveness of the proposed mathematical model of the functioning of the neural network of the living brain. By the same method, numerical calculations can be performed for any finite number of neurons.

From the point of view of the author, what has been said seems relevant when creating robots with artificial intelligence (AI) of new generations, largely copying some of the principles of nature. For example, for practical purposes of its survival, the body goes through the available possible variants of the "input-output" logic, and this process takes some time due to the rate of biochemical processes in the brain. This determines the presence and magnitude of the delay in the interaction between the neurons of the living brain.

When creating AI devices, the same IF-TO logic is taken into account, and therefore in this case there is a lag in the interaction between artificial neurons of artificial intelligence, and the adequacy of the implementation of the IF-TO logic process in robotics is determined by the level of development of the corresponding AI technologies.

In conclusion, the author notes that his proposed concept of a mathematical model of the basic functions of a living brain can be implemented in a number of practical issues of using AI technologies.

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