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HIGH-PERFORMANCE MODELING, IDENTIFICATION AND ANALYSIS OF HETEROGENEOUS ABNORMAL NEUROLOGICAL MOVEMENT'S PARAMETERS BASED ON COGNITIVE NEURO FEEDBACK-INFLUENCES

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The technique is based on a hybrid model of the neuro-system (Brain cortex nodes and tremor-object), which describes on the basis of wave signal propagation the state and behavior of tremor-objects T, namely the segmental de-scription of 3D elements of trajectories of anormal neurological movements of the studied tremor-objects (limb of the hand) taking into account the matrix of cogni-tive influences of groups of cortex neuro-nodes. The rapid analytical solution of the model as a vector function that describes the 3D elements of the trajectories at each movements segment are constructed using the hybrid integral Fourier's transformations and hybrid spectral function. The main element of the solution is the adaptive infuences matrix that determines the state parameters of the action of certain groups of brain neuro- cortex. Models and methods of multivariable identification are being developed to investigate their neuro-

feedback, which suggest high-speed parallel computations on multicore computers. This model-ing technology consider as a scientific basis for designing inelidgence information systems of the quality medical diagnostic i of critical neurological diseases.

Key words: Computer simulation, Software system, High-performance compu-ting, Tremor diseases, Modeling of objects and processes, Multi-parameter iden-tification.

Introduction. The widespread introduction of modern information technologies into medicine makes it possible to significantly improve the quality of diagnosis of various diseases by providing additional information on the occurrence of the pathological process. One of the most common disorders of the human motor sphere is tremor, which has different etiology and pathogenesis, and its timely diagnosis is one of the current interdisciplinary problems of modern neurology, neurophysiology and neurosurgery. Upper limb tremor is considered to be the most common disorder of motor function in patients. According to the World Health Organization in Ukraine, on average 6% of people aged 65 and over, as well as 3.8% of those under 40, suffer from a variety of pathological tremors. Difficulties in diagnosing this type of disorder are due to the existence of different types of tremors, as well as their same manifestations in differ-ent functional lesions of the nervous system. Using a systematic approach based on the classification of tremor, identifying the causes and description of its neurophysio-logical characteristics can improve the quality of the diagnostic process and prescribe effective treatment.

The method of analysis proposed for the diagnosis of neurological conditions of T-objects is focused primarily on the determination of parameters of abnormal movements of patients with tremor-signs, caused by the negative effects of a certain number of neuronal nodes of the cerebral cortex.[1-3]

The basis of the technique is a hybrid model of the neuro-system (nodes of the head and spinal cord tremor-object), which describes the propagation of the wave signal of the state and behavior of T-objects (people with symptoms of tremor), namely, a segmental description of the 3D elements of the trajectories of the ANM (Abnormal neurological movements) of the T-object under study (limb of the hand), taking into account the matrix of cognitive influences of the neuro-nodal Brain cor-tex groups, which involves the construction of a hybrid spectral function of the sys-tem, taking into account all the ANM segments. In order to decompose complex ANM motions into simpler elements, the number of partitions can be chosen arbitrari-ly, depending on the complexity of the ANM images. The mathematical model as-sumes quantitative characteristics of tremor. In this technique of analyzing spiral test data, an extremely important and up-to-date result is the ability to obtain frequency response, using hybrid Fourier transform and digital signal processing techniques on hybrid spectral functions and spectral values.

Hardware tools for the analysis of abnormal movements of T-objects. The basis for the implementation of the hardware solution is the method of continuous continuous determination of the position of the electronic pen with respect to any control coordinate [3]. To perform empirical studies, a touch pen set (Wacom Cintiq 12WX digitizer) with a sampling rate of 133 Hz and an accuracy of ± 0.25 mm was used.. The pattern looks like an Archimedes spiral with several turns for or against a clockwise arrow, with an inter loop of 9 mm. This template is based on an interactive screen tablet with mozhlyvis-bye performance figure patient using an electronic pen [5] Digitising tablets have been increasingly used to automate the quantification of hand drawn spirals and writing capabilities (Fig. 1).

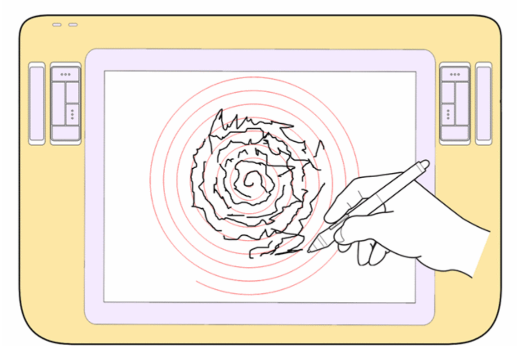


Fig. 1. How to Use Software to Play Archimedes Spiral Template on Wacom Cintiq Graphic Tablet

Series of spiral drawings of patients with essential tremor were visually rated by a board of experts. In these studies, several parameters were used to characterize the tremor. The most frequently used parameter is the Fast Fourier Transform (FFT) of the pen-tip velocity. [3-5]

The e-pen is used to identify handwriting of information (numbers, text information, pattern drawings) or to record and digitize arbitrary movements of the limb. We have proposed a graphical digital pen device with a built-in 3D micro-accelerometer for diagnostic testing.

The microcontroller reads and processes information from a three-axis acceleration sensor (micro-accelerometer). According to the proposed formulas, the instantaneous coordinates of the accelerometer position in space are determined [5-6]. In parallel flow information is received about moving the electronic pen on the plane of the graphic tablet. If system find zero of the pressure of the pen on the sensitive surface of the tablet (indicating the separation of the pen from the surface), the necessary information about moving the pen is obtained from the micro accelerometer – to determine the instant coordinates of the MEMES position [7] of the accelerometer in space, which ensures that the tremor-trajectory data of the trajectory is complete and accurate. The digitized pen position value is transmitted via a WIFI-transmitter to the diagnosing PC. This improves the reliability of the T-object ANR motion detection system (by interacting with the sensitive element of the tablet with an electronic pen and the MEMS accelerometer built into it). Data about moving a pen as a 3D model of an ANR T-object is formed in a PCs window. This makes it possible to decompose complex 3D movements into 3 projections and further analyze each of them and selecting the most decisive for identifying and comprehensively evaluating ANR parameters [5].

Formulation and method of solving the direct inhomogeneous boundary value problem of ANM-analysis based on cognitive feedbacks. According to the program of experimental research of ANM T-objects for obtaining qualitative problem statement and construction of mathematical model of ANM uses data from one of the determining projections of motion in a spiral, which is easily transformed into a Cartesian graph (relative to the z-axis). The given trajectory of motion is connected by cognitive feedbacks with a certain set of neurons of cortex, that send signals to control this oscillatory neurological movement and determine the overall dynamics of the ANM of the investigated T-object (Fig. 2). The sensor system is used as a special helmet to measure the signals for the duration of the movement., that communicates with the patient's appropriate neural nodes of the patient throughout the duration of the movement of the e-pen, which records the behavior of the T-object (limb) (Fig. 2). Trends in Electroencephalograph (EEG) signals recorded by helmet sensors, are stored in the appropriate non-MYSQL database (MongoDB).

In order to decompose the complex ANM path, a scheme of its multicomponent decomposition of segments of the trajectory of a path is used to further formulate the mathematical model. (Fig. 2).

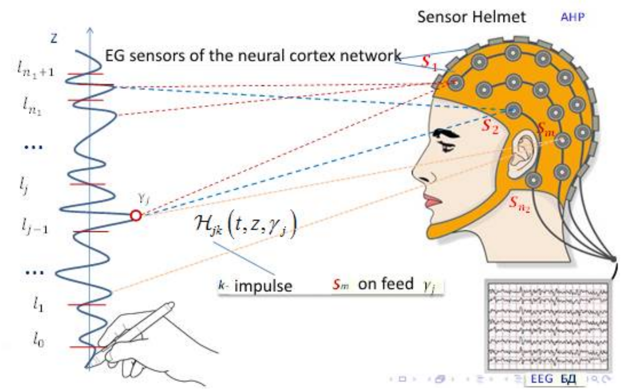


Fig. 2. KGM-T-Object Neuro-Nodes Interaction System. Component decomposition of a complex ANM path into an arbitrary finite number (n1) of simple motion elements

Accordingly, the trend distributions of the EEG signals of neuroswitches that control oscillatory neurological movement and, in general, determine the dynamics of the ANM for each j-th segment of the route are correlated., $j=\overline{1,n_1+1}$, where *n1*- the number of breaking points of the ANM-route. The partitioning can be set arbitrarily automatically, with any number of segments whose lengths may also vary depending on the level of detail of the sections of motion and the choice of acceptable basis functions and on the basis of their acceptable dependences of their approximation [5, 9]. One of the criteria for determining the lengths of the elements of a partition may be the amplitude characteristics of the individual trends of the oscillatory ANR motions, etc. [4].

Mathematical formulation of the decomposition problem. Based on the stated physical assumptions of this subject area of neurological analysis, the direct inhomogeneous initial boundary value problem of determining the parameters of the ANM of a T-object can be described as a system of equations [5, 8]

$$\frac{\partial^2 u_j(t,z)}{\partial t^2} = b_j^2 \frac{\partial^2 u_j}{\partial z^2} + S_j^*(t,z),\ \ z \in \left(l_{j-1}, l_j\right), j=\overline{1,n_1+1} \qquad (1)$$

with homogeneous initial conditions

$$u_j\left(t,z\right)\Big|_{t=0}=0,\qquad \frac{\partial u_j}{\partial t}\Big|_{t=0}=0\qquad ,j=\overline{1,n_1+1},\tag{2}$$

homogeneous boundary conditions and system interface conditions:

$$\frac{\partial}{\partial z}u_1\left(t,z\right)_{z=0}=0,\quad \frac{\partial}{\partial z}u_n\left(t,z\right)_{z=l}=0,\tag{3}$$

$$\left[u_j\left(t,z\right)-u_j\left(t,z\right)\right]\Big|_{z=l_j}=0,$$

$$\left(b_{\mathrm{j}}^2\frac{\partial}{\partial z}u_k\left(t,z\right)-b_{\mathrm{j+1}}^2\frac{\partial}{\partial z}u_{j+1}\left(t,z\right)\right)\Bigg|_{z=l_j}=0,\ j=\overline{1,n_1}\tag{4}$$

in a multi-component area: $D_{n_1}^{+}=\left\{\left(t,z\right):t\in(0;\mathrm{T}),z\in I_{n_1}=\bigcup_{j=1}^{n_1+1}\left(l_{j-1},l_j\right);\ l_0=0,\ l_{n_1+1}\equiv l<\infty\right\}$.

Here (1) is a system of wave equations describing the ANM-trajectory of tremor at each j-th segment of the trajectory $j=\overline{1,n_1+1}$ depending on the resultant action of the set of signals $S_j^*\left(t,z\right),$ coming from EEG sensors to determine the plurality of neurons of brain cortex, that control the behavior of the T-object under investigation, $b_{\mathrm{j}},\ j=\overline{1,n_1+1}$ - components of the phase velocity of propagation of ANM waves, which are the amplitude characteristics of wave tremor motion;

$S_j^*\left(\tau,\xi\right)=\sum_{i=1}^{n_2}\alpha_{ji}S_i\left(\tau,\xi\right),\ \left[\alpha_{ji}\right],\ j=\overline{1,n_1},\ i=\overline{1,n_2}$ - an adaptive matrix that determines the relationships and feedback effects of specific cortex neurosimples on individual small segments of the ANM path. The element of the matrix α_{ji} is the weighting factor (0 to 1) that determines the integral influence of the i-th neuronode S_i to the j-th segment of the movement (are determined by data mining machine learning methods (data mining). The interface conditions (3), (4) ensure the continuity and integrity of the solution of the problem for the entire multicomponent domain of its definition.

Identification of the amplitude components of the ANM. Inverse homogeneous boundary-value problem taking into account cognitive feedback effects of cortex neuro-nodes. Choice of residual functionality:. The amplitude components of the phase velocity of the wave propagation ANM $b_k,\ k=\overline{1,n_1+1}$ boundary value problems (1) - (4) are unknown functions from time. However, on the surfaces of areas $\gamma_k\subset\Omega_k,\ k=\overline{1,n_1+1}$ inhomogeneous environment known traces of solutions (trajectories of the ANM): $u_k\left(t,z\right)\Big|_{\gamma_k}=U_{l_k}\left(t,z\right)\Big|_{\gamma_k}$ (5)

Thus, problem (1) - (5), which is to find functions, is obtained $b_k,\ k=\overline{1,n_1+1}\in D,$ where $D=\left\{v\left(t,z\right):\ v\big|_{\Omega_{k_T}}\in C\left(\Omega_{k_T}\right),\ v>0,\ k=\overline{1,n_1+1}\right\}$.

Incomplete Functionality, which determines the magnitude of the deviation of the desired solution from the traces of the solution obtained empirically on surfaces γ_k, write in the form: $J\left(b_k\right)=\dfrac{1}{2}\displaystyle\int_0^T\sum_{k=1}^{n+1}\left\|u_{s_k}\left(\tau,z,b_k\right)-U_k^*\right\|^2_{L_2(\gamma_k)}\sigma_k\,d\tau$ (6)

where $\left\|\varphi\right\|^2_{L_2(\gamma_k)}=\int_{\gamma_k}\varphi^2d\gamma_k$ – square of norm. In this case $\left\|\varphi\right\|_{L_2(\gamma_k)}=\left|\varphi\left(t,z\right)\right|_{z=\gamma_k}$.

The problem of functional identification of the amplitude parameters of the ANM. Problem (1) - (4), taking into account the necessity of presenting its solution in the form of re-realization of the procedure of functional identification of the amplitude components of the phase propagation wave AHP $b_k^2,\ k=\overline{1,n_1+1}$ as a function of time and conditions, which are known traces of the solution for each of them quite thin k-segment, $k=\overline{1,n_1+1}$, is reformatted to direct boundary value problem (7) - (9) as a system of homogeneous initial boundary value problems for consecutive thin segments of the ANM: $\dfrac{\partial^2}{\partial t^2}u_k\left(t,z\right)=b_k^2\dfrac{\partial^2}{\partial z^2}u_k+S_k^*\left(t,z\right)$ (7)

with initial conditions: $u_k(t,z)\big|_{t=0} = 0, \qquad \left.\frac{\partial u_k}{\partial t}\right|_{t=0} = 0,\ k = \overline{1, n_1 + 1}$ (8)

The boundary conditions in each of the thin segments of the ANM by Z:

$$u_{k-1}(t,z)\big|_{z=l_{k-1}} = U_{L_{l_{k-1}}}, \qquad u_k(t,z)\big|_{z=l_k} = U_{l_k},\ k = \overline{1, n_1 + 1} \quad (9)$$

The choice of functional-residuals. We believe that the components of the phase velocity of the wave propagation are ANM b, $k = \overline{1, n_1 + 1}$ boundary-value problems (7) - (9) are unknown functions from time to time. At known values of the position of the pen $u_k(t,z)$ at the observation points on the segments ANM $\gamma_k \subset \Omega_k,\ k = \overline{1, n_1 + 1}$, $u_k(t,z)\big|_{\gamma_k} = U_{l_k}(t,z)\big|_{\gamma_k}$ (10)

The initial boundary value problem (7) - (9) can be considered for each point z for each thin k1-th segment of the ANR heresy and consists in finding solutions of functions $b_k \in D$, де $D = \left\{ \nu(t,z):\ \nu\big|_{\Omega_{k_1 T}} \in C\left(\Omega_{k_{1T}}\right),\ \nu > 0,\ k = \overline{1, n_1 + 1} \right\}$.

The functional-residual deviation of the solution from its traces by,

according to [8] is written in the form: $J_k(b_{kk}) = \frac{1}{2}\int_0^T \left(\left\| u_k(t,z,b_k) - U_k^* \right\|^2 \right) dt$ (11)

Formulas for gradient components and regularization expressions. We obtain analytic expressions for the components of the residual functional functionals:

$$\nabla J_{\tilde{b}_k} = \int_0^T \int_{l_{k-1}}^{l_k} \phi_k(t,z) \frac{\partial^2}{\partial z^2} u_k(t,z) dz dt. \quad (12)$$

For the functional identification problem, according to [11-12], we obtain the following formulas for the residual functional gradient components

$$\nabla J_{\tilde{b}_k}(t) = \int_{l_{k-1}}^{l_k} \phi_k(t,z) \frac{\partial^2}{\partial z^2} u_k(t,z) dz, \quad (13)$$

$$\phi_k(t,z)=\frac{2}{\Delta h}\sum_{m=0}^{\infty}\frac{1-\operatorname{ch}\left(b_k\beta_m(T-t)\right)}{\left(b_k\beta_m\right)^2}\sin\beta_m\gamma_k\sin\beta_m\left(z-l_{k-1}\right)\left(U_k^*-u_{k_k}^n\right),\ k=\overline{1,n_1+1}$$

$$u_k(t,z)=\frac{2}{\Delta h}\sum_{m=0}^{\infty}\frac{1-\cos\left(b_k\beta_m t\right)}{\beta_m}\sin\beta_m\left(z-l_{k-1}\right)\left(S_k^*\frac{1}{\left(b_k\beta_m\right)^2}\left((-1)^m-1\right)+U_{l_{l_{k-1}}}\left(1-(-1)^m\frac{U_{l_{l_k}}}{U_{l_{l_{k-1}}}}\right)\right)$$

$$\frac{\partial^2}{\partial z^2}u_k(t,z)=-\frac{2}{\Delta h}\sum_{m=0}^{\infty}\beta_m\left(1-\cos\left(b_k\beta_m t\right)\right)\sin\beta_m\left(z-l_{k-1}\right)\left(S_k^*\frac{1}{\left(b_k\beta_m\right)^2}\left((-1)^m-1\right)+U_{l_{l_{k-1}}}\left(1-(-1)^m\frac{U_{l_{l_k}}}{U_{l_{l_{k-1}}}}\right)\right)$$

Regulatory expressions for $n+1$-th step of determining the identifying functional dependency. According to [5, 8], using the method of minimal errors to determine the dependence of the identification of the amplitude components of the phase velocity of propagation of the ANM $\tilde{b}_k^{n+1}$ from time to time for everyone k-th of the ANM-element $k=\overline{1,n_1+1}$, we will get:

$$\tilde{b}_k^{n+1}(t)=\tilde{b}_k^n(t)-\nabla J_{b_k}^n(t)\frac{\left\|u_k^n\left(t,\gamma_k,\tilde{b}_k^n\right)-U_k^*\right\|^2}{\left\|\nabla J_{b_k}^n(t)\right\|_{\gamma_k}^2},\ t\in(0,T),\ k=\overline{1,n_1} \qquad (14)$$

Spatial visualization of the results of digital analysis of the T-object ANM trajectory. Fig. 3 presents the results of digital analysis of abnormal neurologically highly oscillatory movements performed by the limb of an electronic pen on an electronic tablet bypassing the test pattern (Archimedes spirals) with the patient's hand strongly expressed signs of tremor (T-object). As can be seen from Fig.3, such motions are highly heterogeneous, which also contain multiple sections with abnormal motions with high amplitude and frequency characteristics.

For a larger and clearer visualization, a graph depicting the amplitude of fluctuation of the ANM T-object in Fig. 4 is shown in time-space format, where the trajectories of abnormal oscillatory movements of time-dependent and strongly variable small intervals are clearly visible. Such sections of ANM motions can be studied in more detail, breaking them into separate segments on the studied time interval, establishing the

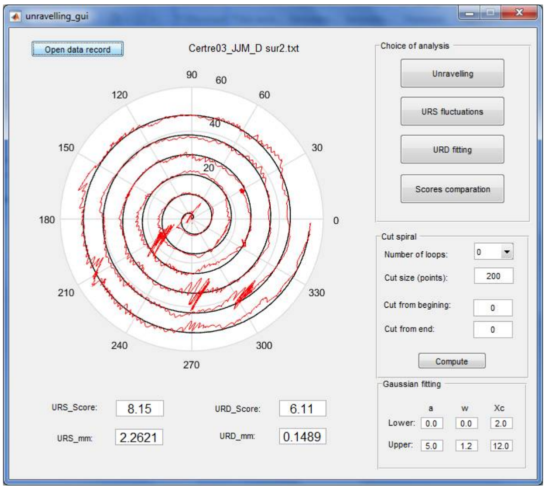
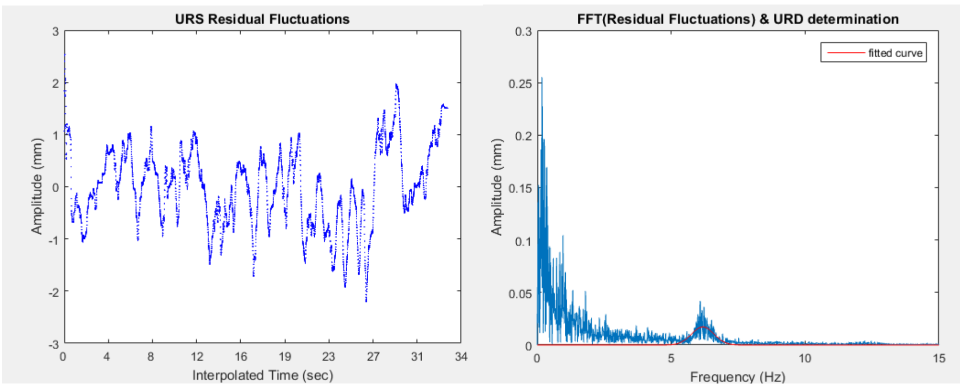


Fig. 3. Results of digital analysis of highly oscillating ANR movements performed by the limb of an electronic pen on an tablet by the Archimedes spiral circumference with signs of tremor.

dependences of their real amplitude and frequency characteristics on the integral temporal distributions of the cognitive signals of the cortex-nodes.



A) B)

Fig. 4. Amplitude (A) and frequency (B) characteristics of highly oscillating ANR movements performed by the limb of an electronic pen on an tablet.

A useful and effective way of analyzing the results obtained is the ability to perform cyclic calculations based on the proportional reduction of the analyzed data sets. In other words, estimates are obtained and compared for each iteration of the limitation of the analyzed data. The results, presented in terms of frequency and amplitude characteristics of the curve, form the basis of the patient's assessment of the computer-assisted diagnosis. Important elements of development are algorithms of mathematical transformations for obtaining values of parameters of the modeled system, possibility of visual representation of the obtained results, necessity of dynamic setting of system parameters. All this allows for greater visibility of the results and promotes the targeted use of technology. A good solution and a positive element of this development is the implementation in the form of a separate module, a library with the ability to constantly update methods and maintain the relevance of research. Implementing the software in this way helps to increase the adaptability and usability of the various systems during the follow-up.[14] The mathematical methods, namely their calculation algorithms, are implemented as a set of classes with methods that model behavior. Software modules, classes, and their interactions are implemented as a single module library, which will allow flexible use of the method of analysis of input data in various applications and programs [fig.5].

Using a built-in 3D micro-accelerometer module in the digital pen of the graphic tablet provides the condition of maintaining the existing satisfactory accuracy of measurements with the additional possibility of controlling the separation of the pen from the surface (Z axis). [5, 14].

```
static void twoDfft(double[][] inputData, double[][] realOut,
double[][] imagOut, double[][] amplitudeOut){
    int height = inputData.length;
    int width = inputData[0].length;
// Two outer loops iterate on output data.
    for (int yWave = 0; yWave < height; yWave++) {
      for (int xWave = 0; xWave < width; xWave++) {
// Two inner loops iterate on input data.
        for (int ySpace = 0; ySpace < height; ySpace++){
            for (int xSpace = 0; xSpace < width; xSpace++) { //
Compute real, imag, and ampltude.
     realOut[yWave][xWave] += (inputData[ySpace][xSpace] *
 Math.cos(2 * Math.PI * ((1.0 * xWave * xSpace / width) + (1.0 *
 yWave * ySpace / height)))) / Math.sqrt(width * height);
     imagOut[yWave][xWave] -= (inputData[ySpace][xSpace] *
 Math.sin(2 * Math.PI * ((1.0 * xWave * xSpace / width) + (1.0 *
 yWave * ySpace / height)))) / Math.sqrt(width * height);
     amplitudeOut[yWave][xWave] = Math.sqrt(realOut[yWave][xWave *
 realOut[yWave][xWave] + imagOut[yWave][xWave] *
 imagOut[yWave][xWave]);}
return imagOut[yWave][xWave];}
```

Fig.5 Excerpt from an example of a computer program from Mudryk I. Mykhalyk D.:Java] [14]

Conclusions. A hybrid model of neuro feedback system is developed, which describes the state and behavior of tremor T-objects based on wave propagation - posthumous description of 3D elements of trajectories of ANM motions through matrices of cognitive influence of groups of neuro-nodes. High-speed analytical solutions of this model's feedback class were obtained based on efficient linearization schemes, the Fourier hybrid integral transform method. The ANM hydride spectral function, systems of orthogonal basis functions and the spectral values of hybrid transformation of feedback model construction are constructed. The results improve the quality and accuracy of the identification and recognition of relationships and interactions; significantly optimize computability through parallelization, reduce the number of computational elements; real-time printing with increasing data requirements, development of independent, dynamic platform-based architectural software for feedback research.

The numerical experiments result based on high-speed parallel computations on multicore computers. Was performed modeling and software development in Java Netbeans 11 using the parallel programing library Framework for Java lang Fork/Join and Stream [15]. Parallel computing software blocks are implemented using algorithms. Presented numerical experiments results, based on high-speed parallel computations on multicore computers. The implementation of the proposed parallelization algorithm allowed to reduce the duration of calculations by 6-8 times.

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