The problem is posed of the stationary regimes of biological systems (BS) and the automatic (computerized) structural identification of BS with a simple or hierarchical structure. When the BS are in the stationary regime one of the methods for automatic identification of multilevel BS is considered in detail. In the specific case of two-cluster compartmental BS functioning in a quasilinear mode, a solution is presented for the problem of the structural and parametric identification of a BS.

Compartmental approach of the BS’s stationary regimes

In studying of real dynamical system of human organism, or their biophysical analogs, the problem arises of identifying some special regimes of such systems and their mathematical models describing the behavior of such biological structures. We study the respiratory neuron networks (RNS) and the cordial regulations system (CRS) as some of fundamental object. It is known that such systems have some special regimes for example a stationary rhythm generation when the frequency of breathing (or a heart rhythm) does not change some long time. There is some special regime when the rhythm generation is absent. It is a stationary regime too.

In such a ease we have some state of dynamic equilibrium, then a classical behavior approach using a “black box” model can be applied. Here, a standard signal $U=U(t)$ is applied to the input of the system (this signal taking the form of a rectangular pulse) or a set of sinusoids at fixed frequencies. Then the mathematical model-analog of such biological systems is constructed as a function of the output signal $y=y(t)$. It is assumed in this case that in the given stationary state the variables of the RNS (or CRS) can either be treated as constants, or may have small variations about a mean level. In the latter case, we may talk about a definite noise, since the real RNS (or CRS) is subjected to a constant disturbance from intero- and extero- receptors. But when our work is carried out with isolated preparations, it is impossible to exclude noise and real biological variations.

The problem of constructing mathematical models of the biological systems under investigation has both theoretical and applied aspects. In most cases the construction of such mathematical models based on differential equations (DE), is done phenomenologically, with subsequent identification of its parameters [4]. The problem of the structural identification of the mathematical models is, then, often not solved. Such problem is related to those of determining the order of the differential equation (presenting the behavior of biological system), and also the problem of choosing optimal ranges of the dynamic variables [1,2,3].

We consider below the measuring complex of the new technical direction. We mean here, the creation of measuring systems carrying out intellectual functions in studying structures which themselves maintain the intellectual activity of the human organism. For such purpose the method of minimal realization (MMR) was considered in detail by us [1,2,3]. It is very convenient for parametric and structural identification of mathematical models of such biological system (BS).

A further development of MMR is in the identification of linear approximation matrices for detailing the structure of the BS being studied and particularly for the neuron networks system. Now the method of minimal realization provides not only structural and parameter identification of the BS’s model but also determines the lowest order $m$ of the model, optimum length $t$ and amplitude $U$ for the stimulus that influence to the output of BS. The problem of BS’s identification is based on existence of stationary regimes (SR) and the possibility of compartmental approximation of such a systems.

The last condition wants the pool’s (block’s) organization of BS. We shall describe a BS by an oriented graph, where such pools presented by the vertices and the ties are presented by the paths. We call the BS irreducible of any pair of vertices is connected by a path. Other wise, we call the BS reducible. The reducible case presents the hierarchical BS [2,3] and irreducible one presents the catenary systems [1]. Then the vector $x$ presents the state of each $i$-th compartment (pool). For excitatory systems (neuron networks, muscles) the components $x_i$ of vector $x$ present the activity of
each neuron pool for example. Its activity depends from every neighborhood pools (presenting by \( \sum_{j=1}^{m} a_{ij} p_j(y) x_j \)). Then the compartmental model of BS is as follows:

\[
\dot{x} = \sum_{j=1}^{m} p_j(y) x_j - bx + ud_i ,
\]

where \( b \) is a damping coefficient, \( ud_i \) present the input drive (ID) from other structures and the integral output of BS \( y = \sum_{i=1}^{m} c_i x_i \) presents the influence of the connectedness between the pools.

In the vector-matrix form the model (1) is as follows:

\[
\dot{x} = APx - bx + ud ,
\]

where \( d, x \in \mathbb{R}^m \) and \( b, u \) are scaling factors, \( P=P(y) \) - matrix presenting the influencers of feedbacks.

In many cases, BS has a complex hierarchical structure. For the whole complex multilevel structure of the system it is necessary to have a general identification algorithm. Procedures for the identification of such model based on the existence of some hypothetical isolated clusters of the BS. The problem of the organization of intercluster connections, and the elucidation of whether each identified cluster belong to a particular \( j \)-th level of the hierarchy of BS is one of the main problem. For such hierarchical BS we can present their general form (the model of the hierarchic BS) in the form of a differential equation:

\[
\dot{x} = Ax - bx + ud
\]

where \( x \in \mathbb{R}^m, m = m_1 + m_2 + \ldots + m_n, R^m = R^{m_1} \oplus R^{m_2} \oplus \ldots \oplus R^{m_n} \) and matrix \( A \) takes the block-triangular form:

\[
A =\begin{bmatrix}
A_{11} & 0 & \ldots & 0 \\
A_{21} & A_{22} & \ldots & 0 \\
\vdots & \vdots & \ddots & \vdots \\
A_{n1} & \cdots & \cdots & A_{nn}
\end{bmatrix}
\]

So we shall suppose that the BS under examination is in a quasilinear state and it is considered that the contribution of feedback’s a small and may be neglected (matrix \( P(y)=I \), see(2)). If complex feedback’s occur in the BS, then it becomes nonlinear and matrix \( A \) depends on \( y \), i.e., \( A=A(y) \). The identification of such systems will be ambiguous, but the methods developed below may, under particular conditions, be also be applied to such systems.

For cooperative biological systems, matrix \( A \) must have nonnegative components (\( A_{ij} \geq 0 \)). Every \( A_{ij} \) present the intercluster or extracluster connectedness and the structural identification problem with BS reduces to the identification of matrices \( A_{ij} \), entering in matrix \( A \), the identification of the number of hierarchic levels, and positions of each cluster in the multilevel hierarchic structure of the BS.

So if we have two-level (two cluster) BS the model takes the following general form:

\[
\begin{align*}
\dot{x}_1 &= A_{11} x_1 - b_1 x_1 + u_1 d_1 \\
\dot{x}_2 &= A_{21} x_1 + A_{22} x_2 - b_2 x_2 + u_2 d_2 \\
y_1 &= C^T_1 x_1; y_2 = C^T_2 x_2
\end{align*}
\]
where vector $x_1 \in \mathbb{R}^{m_1}$ describes the behavior of the elements (compartments) of the upper (first) level, and vector $x_2 \in \mathbb{R}^{m_2}$ the behavior of compartments of the lower (second) level cluster vectors $d_1 \in \mathbb{R}^{m_1}$ and $d_2 \in \mathbb{R}^{m_2}$ define the inputs to each cluster, respectively. Finally, $y_1$ and $y_2$ present the outputs of the first- and second-level clusters, respectively. Than the matrix $A$ has the form:

$$
\begin{bmatrix}
A_{11} & 0 \\
A_{21} & A_{22}
\end{bmatrix}
$$

(6)

**Experimental investigation of BS's stationary regimes**

For first we must be sure that the linear behavior of the BS takes place for every cluster. It is clear that we can't use the method of minimal realization if the BS has not a linear property. We can identify the linear behavior of BS if we analyze the empirical relationships between the effect at the input of every cluster of the BS and the deviation of the outgoing variable obtained at the output. Its take place if we increase the amplitude $U$ of input signal in $k$ time and after that the output signal increase its amplitude in same $k$ time. For example see Fig.1. After hyperventilation of animal (cat) we stimulated the inspiratory place of the reticula formation located in reticula nucleus gigantocellularis (RNG) [3].

Amplitude $U$ of impulses

$$
\begin{array}{ccc}
U=6v & U=12v & U=18v \\
\text{IAPhr} & \text{IAPhr} & \text{IAPhr}
\end{array}
$$

Fig.1. The dependence of the integral activity of the phrenic nerve (IAPhr) on the amplitude of impulses $U$ after stimulation of reticula nucleus gigantocellularis (RGC), cat has hyperventilation. The linear property between input and output signal is presented.

It is evident that the amplitude of output (IAPhr) increasing simultaneously with increase of amplitude in output impulse. Such dependence we got when the expiratory place of RNG was stimulated and the activity of 10-th intercostal nerve was registrated.

For example the dependence of the tale reflex discharges (L) from 10-th internal intercostal nerves are presented in our experiments (see Fig.2).

Such dependence we have for the human cordial regulation system. We use the special step-test with computer identification of the output of CRS on the putting effort. It we increase such output in $k$ time the frequency of CRS and cordial pressure increase in $k$ time. According to MMR we construct (with computer using) the mathematical model of each cluster of respiratory neuron networks (especial of expiratory network and inspiratory network) and for CRS. The models of these systems can be discussed.
Fig. 2. The dependence of the late reflex discharges (L) in 10-th internal intercostal nerves (IICn) on the amplitude of electrical impulses of 11-th IICn in the chloralose-anesthetized cats (after hyperventilation). The duration of the impulse 1 msec, amplitude of impulses is changed from $U_1 = 4V$ to $U_4 = 16V$.

a) natural discharge; b) integral activity (the curve of «moving average» of IICn activity) of intercostal nerve after stimulation.

But now we must say that it must be simultaneously used some additional procedure. In the case we should calculate and compare the eigenvalues of matrices $\Lambda$ in every time after the alteration of amplitude of input signal. If we have the invariance of the eigenvalues of the matrices $\Lambda$ rather than the matrices themselves in every time the BS is not changed and all our procedure described above is correct. It is thus necessary to compare the characteristic polynomials of the matrices obtained for different sets of neurophysiology of cardiology experiments. We create the algorithm and software that provides this procedure in every time after the alteration of amplitude and the cases perenting on Fig. 1 and Fig. 2 proved that idea.

So our software may be use for some BS with a simple or a hierarchical structure but investigator must be sure that the MMR he may apply.

References