## INVESTIGATION OF THE SYNERGETIC PROPERTY OF BIOMECHANICAL MAMALIA SYSTEM WITH COMPUTING USING

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**Abstract**. The work presents procedure and global theory that provides the identification of synergetic property of animal muscles. It may be in normal states, under drugs influences, under electrical stimulations and different other influences. The procedure is based on identification of matrix $A$ (presents the conductivity between compartments of biological dynamic systems BDS) and its eigenvalues. After that the procedure of $A$ transformation into non-negative matrix $Q \geq 0$ was realized according to specific software. For concrete laboratory animal such procedure was used and the value of synergetic degree was calculated too. The coefficient $\chi$ presents the synergetic property of muscles under different condition. The discussion of biological result was presented too.

### 1. Introduction

There are different approaches for investigation and describing of biomechanical muscles property. According to compartmental-clusters theory the identification of muscles mathematical model are based on analyses of muscles answers to different input perturbation. According to such procedure the behavior of muscles determine the Markov's parameters $y_i$. If we use such parameter we can construct the mathematical model of muscles especially the matrix *A*. The matrix presents the connectedness between blocks of muscles. So the matrix *A* and their eigenvalues present the biomechanical property of muscles and its specific functional condition. Such procedure we can use for synergism identification.

The synergism is a basic property of different biosystem. According to such property the human population and the biosphere at all are existing. But the investigations of the property are based only on some quality property of BDS. The synergetic, cooperative property of BDS can be described according to its famous phenomenological property. Such property provides the absence of inhibition and suppression connectedness between elements (compartments) of BDS. The phenomenological approach is very famous because the synergetic theory of biosystem (was based by I. Prigogine [7, 8]) use such a property (commensalism, mutualism and others).

Now it is known that identification of such property on nature has many problems and does not suitable for simple biological experiments. As role the biologist and ecologist determine such property only according to specific quality procedure without strong mathematical calculation. Today we ascertain that the synergetic theory has many application for different BDS but there is no a common mathematical formalization of such synergetic property. It is absent a formal procedure that provides the identification of synergetic property of BDS and especially of biomechanical mammalian system (muscles and others tissue).

It is evident that physiologist use the word "synergism" when we investigate muscles. One hundred yeas ago the "synergism" was presented as a basic property of muscles that provides the moving of legs and hands, because if we contract one type of muscles (biceps for examples) the other opponent (triceps) muscles must be relaxed.

### 2. Compartmental-cluster's approaching for BDS modeling.

According to compartmental approaches every BDS have compartment's (block's) stricture and connectedness between every compartment may be presented by special coefficient $a_{ij}$. Such coefficients includes on matrix *A*. So the matrix *A* and their eigenvalues present the biomechanical property of muscles and its specific functional condition. The basic model of such BDS has a form:

$$\begin{aligned} dx/dt &= AP(y)x - bx + ud \\ y &= c^T x \end{aligned}, \qquad (1)$$

where $x$, $d \in R^m, A = \{a_{ij}\}_{i,j=1}^m, a_{ij} > 0$ if $i \neq j$, $P = diag\{p_j(y)\}_{j=1}^m, y \in R^1$.

If BDS have a cluster structure the model (1) transform into the formula (2) where matrix *A=A (y)* is a functional matrix. It depends on value y (if may be nonlinear dependence). The common case of BDS model has the form:

$$dx / dt = A(y)x - bx + ud$$
$$y = Cx \tag{2}$$

where $A=A(y)$ – functional matrix, $C$ – matrix $n$ x $n$ dimension, where $n$ is a number of clusters, $y$ - function of output signal.

There are some different method for identification of model (1) and model (2) presenting the dynamical property of muscles. But every of them based on identification of Markov's parameters of BDS. Such parameters we can obtain if special adequate input signal may be created by investigators. For every BDS such perturbation (specific input signal) was done by us with special mechanical perturbation (mechanic pulse with special electronic equipment). If we perturb the muscles (does some pulse tissue) with special equipment the muscles return to its first form and size. Such process we can register as a dependence of value x presenting the reshaping of form and size of muscles on real time $t$.

One of the typical examples of such process we present on fig. 1.

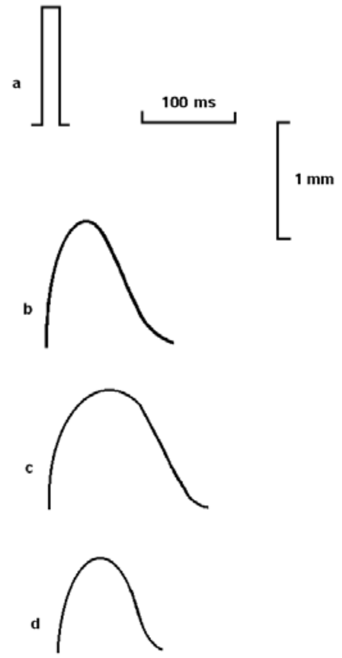


Fig.1. *Diagram of ferromagnetic particle's moving in musculus gastrognemius (animal was anesthe-ties of Nembutal 50 mg/kg, with artificial respiration): a) – pulse perturbation, b) – normal state of muscles, c) – after miorelaxing state, d) – tetanus state by electrical stimulation with frequency* $\nu = 75$ *Hz.*

For procedure of muscles models identification we use the method of minimal realization (MMR). It may be using if the BDS is on stationary regimes and investigators can register the output signal (for fig. 1 it is a value $x$ on $t$) of biosystem as an answer on input signal (mechanical perturbation for fig. 1). For such procedure we create special theory and software.

The software and hardware provides the registration of value $y – y\ (t)$ presenting the dynamic of BDS behavior on input perturbation (Bu). For this case the difference model (DM) of BDS can be constructed according to our software. The DM has a special form of system of equation (equal to system (1)):

$$x(n+1) = Ax(n) + Du$$
$$y(n) = C^T x(n) \tag{3}$$

where $x$ – vector of stage, $A$ – matrix of compartments connectedness, $B$ – vector of input perturbation, $u$ – special scaling factor presenting such perturbation, $c$ – vector of $x_i$ contribution on value of output signal. It is easy to see that model (3) equal to model (1) and (2) but these differential equations may be identificated from system (3) according to special procedure (it was created by us).

So if we obtain $y = y\ (t)$ as a Markov's parameters of BDS output we can construct the model (3) and models (1), (2). The model (3) has a matrix $A$ and its eigenvalues. It may be presenting the dynamic of muscles behavior and its property. One of the main property of BDS is a synergetic property. Let us consider how such property we can investigate according to our theory.

**3. Theory of synergism identification of muscles property according to compartmental-clusters approaching.**

If we have a Markov's parameters of muscles (under specific perturbation) we can obtain DM of our BDS in form (3) and calculate new matrix $A_0$:

$$A_0=A/\lambda(A) \ . \qquad (4)$$

Here $\lambda(A)$ is Perron root of matrix $A$ presenting the model (3). Then Perron root of $A_0$ : $\lambda(A_0)=1$ and $A=\lambda(A)A_0$ . After that we must find new canonic matrix $F$:

$$F = \begin{bmatrix} 010........0 \\ 001........0 \\ ............. \\ -a_m ... -a_1 \end{bmatrix}, \qquad (5)$$

where $a_i$ – is coefficients of characteristic polynomial $f(\lambda)$ of matrix $\boldsymbol{A_0}$. The polynomial has the form $f(\lambda)=\lambda^m +a_1\lambda^{m-1}+...+a_{m-1}\lambda +a_m$ it must be determine from the equation:

$$|A_0 - \lambda I| = 0 \ . \qquad (6)$$

Then the procedure of synergism identification needs of calculation of matrix $\boldsymbol{S^{-1}}$ according to formula:

$$S^{-1} = \begin{bmatrix} C^T \\ C^T A \\ ............. \\ ............. \\ ............. \\ C^T A^{m-1} \end{bmatrix}, \qquad (7)$$

New vector $b$ we can find according to formula $b \rightarrow S^{-1}b$ and new value of $\boldsymbol{C^T}$ we calculate as $\boldsymbol{C^T}=\boldsymbol{e^T}=(1, 0, ..., 0)$.

At the end of calculation we find some matrix $X$:

$$X=(1-p)G + pI \ . \qquad (8)$$

Where special matrix $G$ has the form:

$$G = \begin{bmatrix} \frac{1}{m}................\frac{1}{m} \\ ........................ \\ ........................ \\ \frac{1}{m}..............\frac{1}{m} \end{bmatrix} \qquad (9)$$

The matrix $X$ has a special property $p=0$ $X$ (if it has not inverse matrix) and if $p=1$ $X=1$ . So parameter $p$ we slowly change and every time we determine matrix:

$$Q= X^{-1}FX \ . \qquad (10)$$

Matrix $Q$ equal matrix $A$ but for some one $p$ it may be eventually nonnegative matrix.

We must say that if may be that matrix $Q$ has not eventually nonnegative form but according to our procedure we determine special matrix $Q$ with minimal value of negative elements $q_{ij}$ (when $q_{ij} < 0$). Every $q_{ij}$ presents the negative connectedness between compartments and we postulate the value of synergism in BDS for such case.

For calculation of synergetic degree of muscles (value of synergism) we determine the special value $\chi$ according to formula:

$$\chi=k(\Sigma a^*_{ij}(<0))*(max\ a_{ij}(<0)) \ . \qquad (11)$$

If $\chi \rightarrow 0$ the synergetic interaction in BDS increase. Other way for $\chi>>0$ the synergetic property in BDS is loosed.

For example on fig.1 we present the diagram of implanting ferromagnetic particles moving after special pulse mechanical perturbation of muscles. The Markov parameter for every case provides the identification of matrix $A$ and its Perron root. For case b) (normal state of muscles) we obtained matrix $A_1$ such form:

$$A_1 = \begin{bmatrix} 1{,}35 & -0{,}25 & 0 & 0 & 0 \\ 1 & 2{,}2 & -4{,}93 & 0 & 0 \\ 0 & 1 & -1{,}67 & -0{,}67 & 0 \\ 0 & 0 & 1 & -1{,}68 & -0{,}03 \\ 0 & 0 & 0 & 1 & 0{,}24 \end{bmatrix} \qquad (12)$$

Its eigenvalues: - 0,436+i*0,293; - 0,436+ I*- 0,293; 0,367+ I*0,348; 0,367+ I*- 0,348; 0,579, so we have a Perron root 0,579 for such case and synergism may be.

After fool calculation the end form of $Q$ is:

$$Q = \begin{bmatrix} 0{,}071 & 1{,}099 & 0{,}082 & -0{,}107 & -0{,}144 \\ 0{,}071 & 0{,}099 & 1{,}082 & -0{,}107 & -0{,}144 \\ 0{,}071 & 0{,}099 & 0{,}082 & 0{,}893 & -0{,}144 \\ 0{,}071 & 0{,}099 & 0{,}082 & -0{,}107 & 0{,}856 \\ 0{,}699 & -0{,}424 & -0{,}348 & 0{,}457 & 0{,}616 \end{bmatrix} \qquad (13)$$

It is not nonnegative matrix but the value of synergism coefficient $\chi$ is not so large.

For other case the Perron roots are absent and the value of $\chi$ is so large. All our theory and software provides the registration of fool synergetic interaction on BDS or we can register the value $\chi$ presenting the synergetic degree in BDS.

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