Research Article

Modeling of the Additional Channel of Feedback in Eye-Tracking and Neuro Computer Interfaces

Rusul J. Alsaedi[1]

[1]Al-Qasim Green University, Babil, Iraq
ralsaedi@kent.edu, rusul@uoqasim.edu.iq

Article History: Received: 10 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 10 May 2021

Abstract: The paper analyzes the features of the application of the additional computer-human communication channel within the neuro computer (brain-computer) and oculographic interfaces. The mathematical model of the functioning of this channel and its influence on the decision making by the user, taking into account the change in the accuracy of the definition of the user-generated command, depending on the time of the process analysis, is developed. The model is based on the approach according to which when receiving information about the nature of signal processing by the hardware and software part of the interface; the user can change his / her state, which influences the further processing of the results. The numerical modeling for neuro computer and oculografic interfaces was carried out; the values of the time ranges during which the presentation of the information on the results of the preliminary classification of the user's commands can provide an improvement in the results of work. The obtained results allow optimizing the use of the developed technologies of the additional human-computer communication channel in the aspect of increasing the speed of their work.

Keywords: (Neuro) Brain-computer interfaces, (Oculographic) Eye-tracking interfaces, Additional computer-man communication channel, NCI, OI.

1. Introduction and related work

The development of information technology (IT) in combination with the achievements of neuroscience in the recent decades has led to the emergence of a new type of human-computer interfaces implemented on other principles of control than a keyboard, joystick, mouse, and similar manipulators. The representatives of such interfaces include brain-computer interfaces (neuro-computer interfaces - NCI), where device control signals are recorded directly from the brain as electrical activity, optical phenomena or an MRI response [1, 2], and oculographic interfaces (OI), where teams become the direction of sight and / or movement of the pupil [3, 4]. Given the significant potential of these interfaces in terms of speed of their response in response to the user-generated commands, intuitive controls and recovery options for people with disabilities, there is a large number of the scientific groups work on this topic.

Nevertheless, the speed of the operation of both oculographic and neuro-computer interfaces is still inferior in speed, accuracy and ergonomics for existing keyboard and mouse based interfaces. Thus, the search for new approaches for improving oculographic and neuro computer interfaces and translating their theoretical capabilities into practical software and hardware solutions became relevant. Currently, several areas of these works can be noted.

Firstly, it is a search for new physiological phenomena in terms of the detection of brain signals or eye movements, which can be used as control commands for external devices (computers, self-propelled chassis, aircraft, etc.), signals about errors in recognition.

Secondly, the development of new methods for processing data from the brain will allow us to extract new information from existing data or new stable and accurate algorithms for extracting the eyes and pupil of a user from a video image.

Thirdly, the hybridization of the intellect of a computer and a person with the aim of providing, with insufficient bandwidth of the human-computer channel, the reaction of the latter, reproducing the characteristic patterns of the user behavior without its direct commands.

The palliative method for increasing the speed of the above-mentioned interfaces is to change; for example, their graphic part providing a large data rate due to the optimal arrangement of visual “buttons”. Another option is the formation of an additional communication channel [4] human computer, through which the user is informed of the nature of the operation of the NCI and OI. In particular, these are the results of the current processing of the user commands. Thus, the user sees how successful or unsuccessful the processing of information is about those physiological states that serve as commands. Seeing this, the user gets the opportunity to change their current physiological state in the desired direction, increasing the accuracy of the interface. Therefore, it is relevant to simulate the operation of NCI and OI in the presence of an additional computer-man communication channel.

The aim of the study is to simulate the operation of NCI and OI under the conditions of the presence of an additional computer-man communication channel taking into account various parameters of the accuracy of the interfaces in terms of recognition of the user commands.

2. Materials and research methods

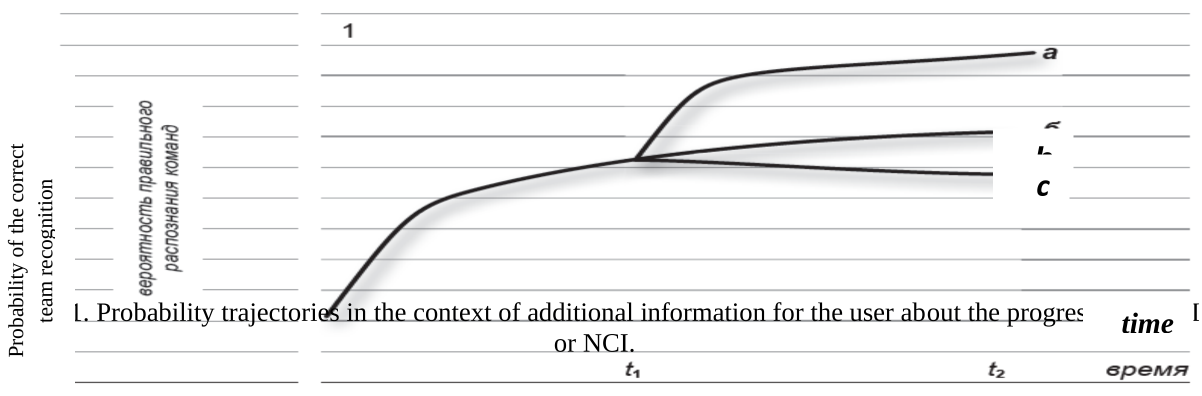
Consider the model of the operation of NCI and OI in the presence of an additional computer-man communication channel. At the first stage, we simulate the situation of the human-computer interface. One of the parameters of this work will be the probability function of recognition of the user commands by the interface. Obviously, as the time *t* increases during which the pattern analyzed as a command is evaluated (for example, the EEG values, or the position of the pupil); the accuracy of recognizing this command increases. Furthermore, with continued growth of the team's accumulation time, the accuracy of its recognition decreases due to objective physiological reasons which are fatigue and decreased user attention, the need to respond to new events, etc. However, since this time is long enough, the fact of a decrease in the recognition accuracy can be ignored, so suppose that the probability of the correct recognition of f_{bases} monotonically changes with time t according to the law.

$$f_{bases} = \frac{e^{\alpha t}}{\frac{(1-p_o)}{p_o} + e^{\alpha t}} \qquad (1)$$

Where $p_o = f_{bases}(0)$ – the probability of the correct recognition at the initial moment of time

$\alpha > 0$ - is the parameter responsible for the rate of change of the function (the larger α, the greater growth rate of $f_{bases}(t)$ with increasing t).

By time, in the future, we will understand the number of discrete readout of a signal registered by one or another device. At time t_1 (fig. 1), the user receives information about the result of the signal recognition act after which the user can change.



1. Probability trajectories in the context of additional information for the user about the progres ... or NCI.

ding or staying the same (in other words, at a given moment in time there is *a* trifurcation of possible user states). It can be seen from fig.1 that *a* - an option in which the user changes his / her state at time t_1 so that he / she increases the likelihood of the correct recognition of commands, *b* - leaves his / her state unchanged, *c* - changes his / her state at time t_1 so that increases the likelihood of the correct recognition of commands. The change in the state will cause the recognition probability may increase - it will be determined by the function $f_+(t)$ (option a), or decrease - there will be a transition to the function $f_-(t)$ (option c), or remain unchanged - $f_{bases}(t)$ (option b). Probably, the listed events are equal *to* p_+, p_- *and* p_0 respectively in the case of the correct recognition at $t = t_1$ *and* p'_+, p'_- *and* p'_0 in case of an incorrect. Note that in the period of time t_1, the interface does not make a final decision regarding the choice of *a* command generated by the user. The user is only informed of the current (intermediate) result of the data processing by the interface.

Further, at *time* $t = t_2$, a choice is made again. This choice is final - the interface makes a decision as to which command was generated by the user, and accordingly, which should be executed .A subset of the event space leading to correct recognition consists of 6 points:

1. $f_{base}\ (t_1)\ p_+\ f_+\ (t_2)$ - correct recognition in t_1 and in t_2 after increasing the probability.
2. $f_{base}\ (t_1)\ p_0\ f_{base}\ (t_2)$ - correct recognition in t_1 and in t_2 without changing.
3. $f_{base}\ (t_1)\ p_- f_-\ (t_2)$ - correct recognition in t_1 and in t_2 after reducing the probability.
4. $(1 - f_{base}\ (t_1))\ p'_+\ f_+\ (t_2)$ - incorrect recognition at t and correct recognition at t_2 after increasing the probability.
5. $(1 - f_{base}\ (t_1))\ p'_0\ f_{base}\ (t_2)$ - incorrect recognition at t and correct in t_2 without change.
6. $(1 - f_{base}\ (t_1))\ p'_-\ f_-\ (t_2)$ - incorrect recognition in t and correct in t_2 after reducing the probability.

We get that the recognition probability increased in comparison with the base case by a factor of Q, where

$$Q = \left[f_{bases}(t_1)p_+f_+(t_2) + f_{bases}(t_1)p_0f_{bases}(t_2) + f_{bases}(t_1)pf_-(t_2) + \left(1 - f_{bases}(t_1)\right)p'_+f_+(t_2) + \left(1 - f_{bases}(t_1)\right)p'_0f_{bases}(t_2) + \left(1 - f_{bases}(t_1)\right)p'_-f_-(t_2)\right] / f_{bases}(t_2) \quad (2)$$

Convert the resulting expression.

$$Q = \left(\frac{f_{bases}(t_1)}{f_{bases}(t_2)}\right)\left[p_+f_+(t_2)\right) + p_0f_{bases}(t_2) + pf_-(t_2) + \left(1 - \frac{f_{bases}(t_1)}{f_{bases}(t_2)}\right)\left[(p'_+f_+(t_2) + p'_0f_{bases}(t_2) + p'_-f_-(t_2)\right] \quad (3)$$

To obtain a convenient analytical estimate of Q, we introduce the assumption which is the transition probabilities at the trifurcation point do not depend on the result $p_+ = p'_+$, $p_- = p'_-$ and $p_0 = p'_0$, then we obtain.

$$Q = p_0 + p_+f_+(t_2) + \frac{p_-f_-(t_2)}{f_{bases}(t_2)} \quad (4)$$

Using the condition for maintaining the total probability $p_+ + p_0 + p_- = 1$, we bring Q to the form.

$$Q = 1 + p_+\frac{f_+(t_2) - f_{bases}(t_2)}{f_{bases}(t_2)} + p_-\frac{f_-(t_2) - f_{bases}(t_2)}{f_{bases}(t_2)} \quad (5)$$

The ratio of the probabilities in the new and basic case exceeds unity (i.e., it improves the recognition when choosing commands by the interface).

$$p_+(f_+(t_2) - f_{bases}(t_2)) > p_-(f_-(t_2) - f_-(t_2)) \quad (6)$$

Thus, the sufficient evidence has been obtained to determine the applicability of the method. Exceeding after trifurcation of f_+ values weighted by p_+ should be greater than the excess of the base probability over f_- taken with weight p_-. In this case, the new method is more likely to lead to the correct recognition by the interface of a signal or pattern generated by the user.

From (6), it follows that the model shows the possibility of increasing the speed of interfaces only provided that $\alpha_+ > \alpha_{bases}t_{bases}$, where t_{base} shows the time of measuring the probability of the recognition of commands based on the baseline functions. It is in this case that is possible to improve the probability of the recognition by the interface of the user commands when changing its state at time t_1.

3.

4. The results of the study and their discussion numerical simulation of the work of the nci in the presence of an additional communication channel computer man

Consider the situations that arise during the work of NCI, depending on the time t_1; they need to provide certain probabilities of transition from $f_{bases}\ (t_1)$ *to* $f_-\ (t1)$ *or to* $f_+\ (t_1)$. To get closer to the real indicators of the operation of the interfaces, we will take a discrete time in 0.1 sec. Thus, for an NCI recognizing 6 commands, the values of the function according to (1) will be $p_0 = 0.167$, α_{base} from 0.02 to 0.2 (fig. 2a). For OI, which has the best parameters for the speed of work and recognition of teams for 6 teams, we accept $p_0 = 0.167$, α_{bases} from 0.08 to 0.9 (fig. 2b). Consider the condition $\alpha_+ > \alpha_{bases}\ t_{bases}$ as applied to NCI. Obviously, we have two time limits. On the one hand, the user needs some time to realize the human computer being transmitted through the channel. On the other hand, if a change in the state of the user occurs after too long; then, there will be a situation in which the function $f_+\ (t)$, even having a significantly higher growth rate, will still be inferior in function to the functions $f_{bases}\ (t)$, making it; thus, fundamentally impossible improves the performance of NCI. Consider possible ranges of applicability of the parameter α_+ provided that the parameters α_{bases} *and* t_1 change (fig. 3). We draw attention to the fact that the time threshold of stimulus awareness is in the region of 100 ms [5]. Obviously, if at time t_1 the information about the current decision on the choice of commands by the software-hardware part of the interface is visualized for the user, then to the data in figure 3, it is necessary to take into account another ~ 100 ms for the process of the user recognition of the received data. We add an additional condition according to which at any point from t_1 *to* t_2 $f_{bases} < f_+ (t_1)$.

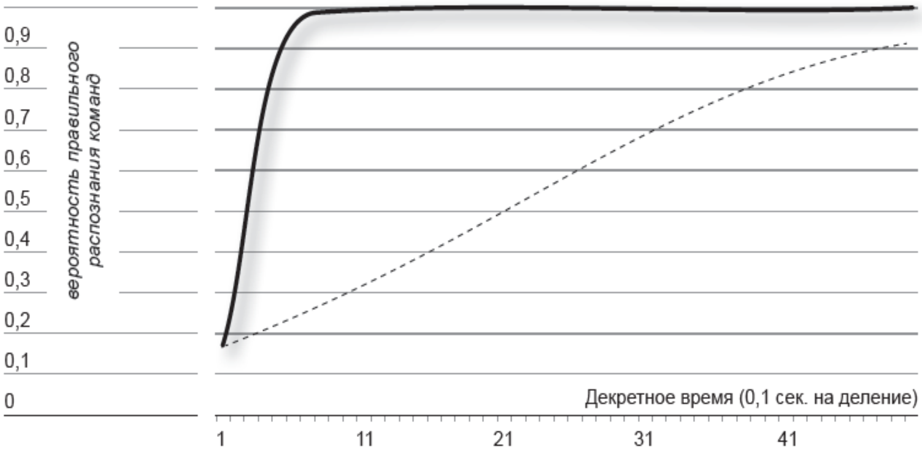


Fig.2a. Probability range under investigation, depending on time for NCI.

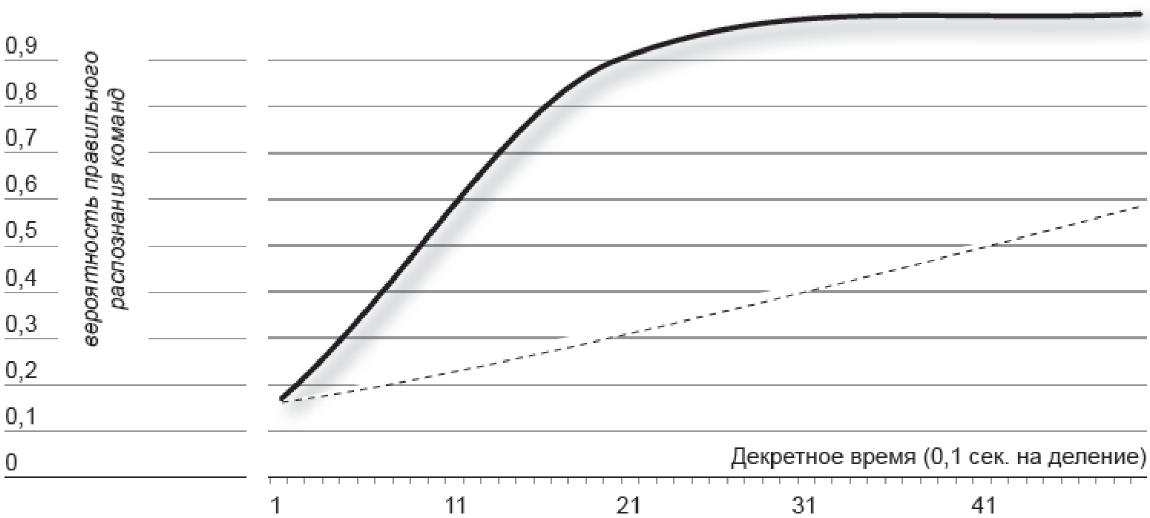
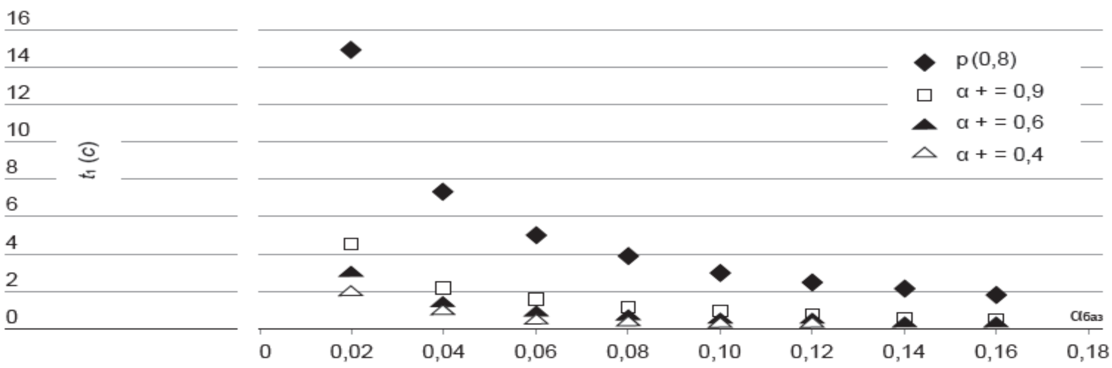


Fig.2b. Probability range under investigation, depending on time for OI.

Therefore, from fig. 3, it follows that below the indicated curves the condition $\alpha_+ > \alpha_{bases}$ t_{bases} is satisfied, so; for example, for $\alpha_{bases} = 0.02$ *and* $\alpha_+ = 0.6$, the user must change his / her state, knowing the data of the preliminary work earlier than three seconds after the start of the work of the NCI on the processing of a new teams. Given the stimulus recognition time, it is clear that the interface must inform the user about the pre-selection via a graphical channel earlier than 2.9 seconds. From fig. 3, it follows that starting from $\alpha_{bases} = 0.13$ the function of improving recognition of the user signals having $\alpha_+ = 0.4$ can no longer be effective in any period of time. The practical value is represented not so much by the parameters α as by the probability values of accurate recognition of the patterns of the brain activity of the user to determine the possible time ranges for the presentation of the preliminary data of the NCI. For this, the parameter *p* (0.8) was introduced in fig. 3 as a



reflecting time during which f_{bases} *(t)* provides an 80% probability of recognizing the pattern of the user's brain activity for a given α. The results are interpreted as follows. If it is empirically obtained that; for example, after 3 seconds of processing patterns of the brain activity of the user, there is 80% accuracy in recognizing the commands generated by him / her; despite of the fact that this result will be less for shorter periods of time, and longer for longer ones; then, $\alpha_{bases} = 0.1$ can be taken as a model parameter. It is obvious that if the user is able to change his / her "mental" state in such a way as to increase the likelihood recognition of commands; then, the information on preliminary results of work programmatically.

Fig.3. The dependence between the recognition function parameter NCI teams for 6 variants of α $_{bases}$ and time of adoption pre-solution by an interface previously; it is necessary to inform the user about the results of thepreliminary classification of his / her condition by the software and hardware part of the NCI.

The hardware complex, the user must be informed earlier than 0.9 seconds from the start of processing patterns of his / her brain activity. Moreover, 0.9 seconds is selected if it is empirically established that in the new "mental" state [6]; for example, with a significant concentration of attention, the available software and hardware solutions provide 80% accuracy of recognition of the user commands after 0.4 seconds. Thus, the data obtained allow using empirical results of work different types of NCI to determine the potential effectiveness of an additional computer-man communication channel, and; therefore, to assess the need and possibility of implementing an additional human-computer communication channel as applied to the tasks of the NCI.

5. The numerical simulation of the operation of the oi in conditions availability of an additional communication channel human computer

Unlike NCI, OI modeling has its own special the fichus associated with the iterative control process. Indeed, in the case of an NCI, the information about the preliminary interpretation of certain commands is sent to the user only once. The second time, the user sees the result of the operation of the software and hardware of the NCI even when the managed device is executing a command. In the case of OI, the user sees a cursor mark corresponding to the position of his / her pupil. Therefore, by changing the direction of the gaze, the user sees the response of the OI reaction, and; thereby, it can again within the next iteration modify its behavior. With this approach for modeling, it is more convenient to use the concept of "chain of commands" [7] of the form.
$\xi_1(n + 1) \Rightarrow \xi_2(n + 2) \Rightarrow \xi_3(n + 3) \Rightarrow \ldots \Rightarrow \xi_\lambda(n + \lambda)$.

In other words, if the command ξ_1 exists and is already executed at the moment of discrete time (n + 1); therefore, it is possible to execute the command ξ_2 (n + 2) provided that it exists, and if the command ξ_2 (n + 2), it is possible to execute the next command ξ_3 (n + 3) provided that it exists, etc. However, in contrast to [7], in this case, the command does not mean a completed "quantum of behavior" [8], but the interpretation of the current position of the pupil by the hardware-software part of the OI. At the same time, if the cursor marker moves to the side that the user wants, the command is perceived as successful, otherwise as an error. Thus, fig. 2b shows the final function of assessing the probability of the correct recognition of the commands when moving the pupil. We will take into account that in video oculographic interfaces; one of the limiting factors of their speed is the frame rate recorded by a video camera. As applied to our tasks [3], the frame reading frequency did not exceed 20 Hz, and; therefore, the OI cannot change the position of the cursor marker with a higher frequency. Using fig. 3, one can obtain the same results as when controlling by means of NCI; however, those ranges of functions *f (t)* show a high speed of the oculographic interface exceeding that of NCI ($\alpha_{bases} > 0.2$, which gives 80% accuracy of the command recognition after 0.4 s). The simulation results are presented in table 1.

Table1. Results of time assessment of presenting to the user of the information on the communication-personal communication channel.

α_{bases}	p (0,8)	α +	
		2,5	1,5
0,9	0,4	—	—
0,7	0,5	0,1	—
0,5	0,6	0,2	0,3
0,3	1	0,3	0,25

0,1	3	1	1

From table 1, it can be seen that at a high classification speed $\alpha_{bases} > 0.7$; there are no possibilities for using an additional channel; a computer is a person who informs the user about preliminary data for recognizing commands by the interface. The high speed of command recognition by the interface eliminates the need for an additional human-computer information channel. At the same time, relatively low values of $\alpha_{bases} < 0.1$ make it possible in general to use an additional communication channel, and the information will be communicated to the user for less than 0.3 seconds from the beginning of the recognition of the command by the hardware-software part of the interface. Thus, the use of an additional channel for OI, although it has limitations in terms of the time it takes to present stimuli to the user, it can nevertheless be used for interfaces with a high speed of operation.

6. Conclusions

The paper analyzes the features of using an additional computer-man communication channel within the framework of the neuro computer (brain-computer) and oculographic interfaces. The mathematical model of the functioning of this channel and its influence on the decision-making by the user has been developed, taking into account the change in the accuracy of determining the user-generated command depending on the time of the process analysis. The numerical modeling for neuro computer and oculographic interfaces was carried out; the values of time ranges were calculated, during which the presentation of the information on the results of the preliminary classification of the user commands can provide improved results. The results obtained allow us to optimize the use of the developed technologies of the additional human-computer communication channel in terms of increasing the speed of their work.

References

1. Schalk G., McFarland D.J., Hinterberger T., Birbaumer N., and Wolpaw J.R. “BCI2000 a General-Purpose Brain-Computer Interface (BCI) System,” in IEEE Transactions on Biomedical Engineering, 2004, vol. 51, Pp. 1034–1043.
2. Nicolas-Alonso L.F., and Gomez-Gil J. “Brain Computer Interfaces,” in a Review Sensors (Basel), 2012, 12 (2): 1211–1279.
3. Turovskij Ja.A., Kurgalin S.D., and Alekseev A.V. “Analysis of the Movement of the Human Eye during the Control of the Self-Propelled Chassis Using the Video-Oculographic Interface System,” in Sensornye sistemy, 2017, No1. S. 51–58.
4. Turovskij Ja.A., Kurgalin S.D., Vahtin A.A., Borzunov S.V., and Alekseev A.V. “Information Flows during the Formation of an Additional Feedback Channel for the Brain-Computer Interface,” in Tehnologii zhivyh system, 2016, T. 13.No 7. S. 34–40.
5. Kostandov Je.A. “Psychophysiology of Consciousness and the Unconscious,” in SPb.: Piter, 2004.
6. V.M. Verhljutov, P.A. Sokolov, V.L. Ushakov, and B.M. Velichkovskij “Overlapping Large-Scale Networks of the Human Brain, Recorded Fit at Rest and in the Performance of Mental Tasks,” 2015, S. 59–61.
7. Ja.A. Turovskij, S.D. Kurgalin, and S.V.Borzunov “Estimation of the Speed of Operation of the Neuro Computer Interface Realized with the Use of Hybrid Intelligence,” in Biomedicinskaja radiojelektronika, 2015, No 3. S. 61–70.
8. Pod red. K.V., and Sudakova. M. “Systemic Mechanisms of Behavior,” 1990, 240 s.