DOI: 10.14529/ctcr180103

# MERGE OF MICROELECTRONICS AND HUMAN NERVOUS SYSTEM

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The main theoretical aspects necessary for understanding the functioning of biological neural networks for the purpose of their subsequent reproduction in the form of equivalent electronic devices are considered in the article. The devices used for the last 4 years for direct interaction with neurons and their drawbacks are considered, as well as a model of a flexible and effective device, that does not face the problems discussed and allows interacting directly with the human nervous system at several levels.

*Keywords: brain-machine interface, neural network, multi-electrode array, membrane potential.*

## Introduction

Fusion of a human and computer, humanity's cyborgization, mind-controlled electronic devices – all of these prospects of life development on Earth, which seemed more like dreams of science fiction writers from the past, are being trans-formed into the largely realistic, if not inevitable, prospects of development of human evolution, considering the daily increase in the level of technology development. The broadest development of artificial intelligence, whose possibilities are today the subject of the most demanded and complicated study among any other sciences related to computer technologies, as well as researches in the field of machine learning and development along with an idea of replacing the live labor with the artificial intelligence, which is capable of studying how to solve any problem instead of using preinstalled algorithms, force to take thought about merging the artificial intelligence with the human brain and, on the other hand, to fear the threat to humanity from much overdeveloped artificial intelligence. These fears are exacerbated with the latest news about the research of the capabilities of artificial intelligence to create machines that are also endowed with artificial intelligence and at the same time perform the tasks assigned to them much more efficiently than similar machines created directly by a human. In the foreseeable future, this can lead to a collision between humanity and developed artificial consciousness, that is why the leading researchers, scientists and CEOs of IT corporations put forward proposals for the development and introduction of technologies that allow uniting the human brain's regions with computers and, in this way, provide the opportunity to the humans to "even the odds" in the fight against artificial intelligence.

## 1. Functioning of human neural networks

The idea of combining the human brain with an artificial neural network is based on developments in the fields of neuroprosthetics. In order to organize a radio channel with a remote device, it is necessary to have at least some transmitter. To perform the alleged communication functions of the human brain and some (at this stage of consideration abstract) device, the transmitter must be connected directly to the brain [1]. This is the first obstacle in the way of implanting implants which strengthen the abilities of the brain.

The nervous system controls the interaction of all human insides, muscles and systems of the body with the brain. The central nervous system, that consists of the brain and spinal cord, is the source of high-level and low-level signals. These signals, with the help of the neurons of the peripheral nervous system, are delivered to the controlled entities of the organism. The human brain consists of neurons too, there are about 86 billion neurons in it (about 16 billion in the cerebral cortex and 70 billion in the cerebellum). There are about 100 billion neurons in the whole body. Neurons in the brain gather in neural circuits which are connected to the corresponding regions of brain. Thus neurons are connected among themselves in some chains, responsible for certain functions. Thus, the interaction between all body systems and functioning of them separately without affecting each other are maintained. The neuron consists of the body of a neuron, of a dendrite and an axon. The body of a neuron in the simplest case is surrounded by a cell membrane, which is often supplemented with a protective layer of myelin. All of them, forming links between themselves, the so-called synapses – these are the connections between neurons without direct contact between them, and links with the brain regions, provide brain control of the sense organs, muscles, insides and all body systems. The peripheral somatic nervous system is responsible for the motor skills (i.e. muscles) and tactile sensations (i.e. the skin), the peripheral autonomic nervous system is responsible for internal organs, blood circulation and lymphatic system. The enteric autonomic peripheral nervous system supports the contraction of the smooth muscles of organs that contain them (the stomach, the organs of the intestinal cavity). The sympathetic autonomic peripheral nervous system is responsible for emotions, the expenditure of forces and resources. The parasympathetic autonomic peripheral nervous system, which is associated with it, regulates the accumulation of forces and the processes of rest and recovery of the organism. The sensory peripheral nervous system coordinates the work of the sensory organs. Accordingly, each of the types of peripheral nervous system delivers signals from the organs to the central nervous system (by motor neurons) and back (via sensory neurons). Absolutely all the processes that take place in the human body are associated with the work of the nervous system.

The entire environment is an external irritant to human. The human body reacts to the irritation by generating an excitement. Excitation is the process of generating some potential by receptors or sensory neurons in response to a stimulus (for example, a receptor). The potential is then transmitted through synapses directly into neurons. As the stimulus can act the impact of the external environment or internal processes, for example, a nerve impulse sent by the brain regions. The potential inside the human body is an electric field that is different from the field that passes through metallic conductors, but has some similarity with it, which makes it possible to simulate this kind of a field artificially. The cell membrane, that surrounds the body of a neuron, consists of special proteins and lipids. This structure makes the membrane similar to the dielectric.

On the inner surface of the membrane a negative charge is maintained due the presence of particular negatively charged proteins and due to the constant outflow of the positively charged potassium ions from inside the membrane to the outside of the cell through the tandem pore domain potassium channels which are constitutively open and which are located along the membrane. On the outer surface, a positive charge is maintained due to the fact that positively charged sodium ions on the surface of the membrane cannot pass through the voltage-gated sodium channels on the membrane which are closed when the neurons are not excited by the stimuli, and due to the fact that the concentration of these ions outside the membrane is constantly increasing because of the functioning of a sodium-potassium adenosine triphosphatase (known as a sodium-potassium pump), that is also located on the membrane and transfers the positive potassium ions into the body of the neuron in the ratio of 2 to 3. Thus, the presence of positive and negative electric charges around the body of the neuron generates a certain potential difference, called the membrane potential. The membrane potential can be measured by an ordinary voltmeter. At resting state, the sodium-potassium pump creates a potential difference of approximately –10 mV by taking three sodium ions from the internal surface of the membrane and by inserting two positive potassium ions into it with the help of negatively charged proteins attracted by the pump. The excess of positive potassium ions inside the neuron cell leads to their rapid withdrawal from it through the tandem pore domain potassium channels. Sooner or later all the positive potassium ions inside the cell are repelled by the like charged ions outside it and, in turn, are attracted by negatively charged proteins. Thus, the release of potassium from the cell stops eventually and the potential that is called the membrane resting potential, is established at a constant value. Positive sodium ions outside the cell are much less in quantity than the negative ions inside it, so the resting potential is negative. In muscle cells, it varies from –95 to –60 mV, in neurons if varies from –90 to –60 mV. The membrane is an insulator that maintains this voltage, but both around the body of the neuron itself and in the cytoplasm inside it a neutral charge is maintained. Thus, the membrane is equivalent to the capacitor, whose plates are equivalent to the cell walls of the membrane. This aspect is fundamental in the artificial simulation of a neuron as an electrical circuit. For example, in the well-known Hodgkin-Huxley model, which recreates the scheme for creating membrane potentials, the membrane appears as a capacitor, voltage-gated channels as some nonlinear conductances, leak channels as passive conductivities. The source of the action potentials considered below is the set of voltage sources according to this model. When the very potential of rest is changed, the cell adapts itself without causing exciting or inhibitory impulses, but the change in the resting potential itself affects the sensitivity of the neurons to the effect. Without limiting the generality that the resting potential is formed only under the influence of outflow of positive potassium ions, its value can be approximately calculated from the Walter Nernst equation, which connects some electrode potential (in this case, membrane potential), which appears when a current in some solution occurs, with the quantity of particles (ions in this case) participating in this process. This is extremely important in the theoretical modeling of the device, that recreates the work of the human nervous system. An excessive decrease of the resting potential can lead to a loss of neuron sensitivity, since a much greater stimulus will be needed to overcome the resting potential. If the resting potential, on the contrary, is too high, it causes the increase of the responsiveness of neurons to such an extent, that they are constantly in a state of stimulation by stimuli, that is, it constantly sends signals to the brain. This leads to a rapid wear of the membrane shell, of chemical synaptic connections between neurons and leads to brain damage.

The development of a reaction to a stimulus is accompanied by a change in the membrane potential. In the eighties of the XVIII century Luigi Galvani discovered that excitable tissues are sensitive to a weak electric current. Nervous and muscular tissues are excitable. Neurons are electric conductors. The current passes through the body of the neuron, reaches the axons, then it is transmitted through the synapse to the dendrite of another neuron and so on. All neurons have synaptic connections (single neurons that depart, for example, from the spinal cord, has a single connection with the spinal cord itself). Synaptic connections do not bind neurons directly; the synapse is a certain gap, filled with a special substance. The overwhelming majority of all current conduction processes have a chemical basis – the chemical substances (neurotransmitters), which, when interacting with signal receiver proteins, generate a new similar signal, are transmitted from the signal source through the synaptic gap. This signal is called the action potential. The action potential is the main signal supporting the functioning of the entire nervous system [2]. It is the action potential that is an informative message from the neuron to the brain and vice versa. In itself, the action potential in a neuron cannot arise. In response to a stimulus, a specified neurotransmitter is produced by some cells (for example, receptors, in the case of an external stimulus, or by sensory neurons in the case of an internal stimulus) of the remainder of the axon of the transmitter (presynapse); this neurotransmitter creates some electric field after chemical transformations by passing through the synaptic gap to the receptors of the neuron dendrite (postsynapse). Depending on what side of the presynapse neurotransmitters come from – from inhibitory transmitters from inhibitory neurons or excitatory mediators from excitatory neurons – the receiver processes various signals. Excitatory mediators cause the influx of positively charged sodium ions into the body of the neuron, the inhibitory ones cause the outflow of positive potassium ions from the cell. As a result of the violation of the balance of charges, the membrane potential alters, deviating from the resting potential. The so-called postsynaptic potential is developed. The inhibitory potential reduces the value of the membrane potential, keeping it at a level no higher than the resting potential, and the excitatory one tends to increase the membrane potential in order to reach and exceed a certain critical value, called the threshold potential. The threshold potential of neurons is approximately –55 mV. Thus, the neuron receiving the signals in a sense "sums up" all the incoming signals, both inhibit and excite. Such a model can be easily implemented artificially and this is used in existing devices that simulate the work of the nervous system. In general, it is enough to distinguish between inhibitory and excitatory signals and perform the appropriate action, for example, to relax or contract the muscle, respectively. It is neurotransmitters that can be recognized, since inhibitory and excitatory neurons activate different mediators for electrical current generation. However, such a device is aimed only at recognizing signals coming from the brain to the muscle, that is, it does not replace the neural circuit itself and does not use it as a conductor, it bypasses it, causing the endpoint organ or system to perform an action, that is supposed by the brain and is recognized by the device, implanted in the body. This requires additional invasive interventions in the body. A much greater problem is the need for proper recognition of nerve impulses flow through the sensory neurons from the central nervous system.

If after the neuron processed a series of pulses from inhibitory or excitatory neurons (specifically, only a part of the neuron takes part in processing, it is called an axon hillock), it turns out, that the total postsynaptic potential has reached the threshold potential, then voltage-gated sodium channels, located along the perimeter of the neuron's body, open. As a result, positive sodium ions are rapidly drawn in on the inner side of the membrane of the nerve cell. The charge inside the membrane becomes positive, and outside it becomes negative due to the influence of the negative chlorine ions there, which make an insignificant contribution to the formation of resting potential, but which strongly affect the deviation of the membrane potential from resting state. This process is the origin of the action potential. Because of an instant change in the signs of charges, the membrane potential rises to a certain positive value (usually within 40 mV), which leads to the closure of sodium channels and the opening of voltage-gated potassium channels. The latter participate only in the generation of an action potential, causing an outflow of positive potassium ions from the cell. This leads to a decrease of the membrane potential and gradually leads to its equalization to the resting potential value with the aid of sodium-potassium ATPase and tandem pore domain potassium channels. During the restoration of the potential to the resting potential, the voltage-gated sodium channels are temporarily blocked, without closing, but without reacting to any action potential, then they are finally closed, if there is no need to open them again. The transduction of an impulse across the neuron in the overwhelming majority of situations does not occur continuously throughout the neuron, since such a transduction method has an extremely low velocity (meters per second). As mentioned earlier, the body of the neuron is covered, in addition to the cell membrane, with a myelin sheath. It is also a dielectric, but it covers the neuron not with a solid shell, but with interrupted areas, between which there is some space called nodes of Ranvier. Only at the nodes of Ranvier the occurrence of the action potential is possible, only on the nodes the tandem pore domain channels and voltage-gated channels are located. Thus, lower costs for exciting the action potential, the possibility of transmitting potentials at a greater frequency and for a much greater distance are provided. The action potential is transmitted intermittently between the nodes, and, unlike direct transmission through the neuron without the myelin sheath, to maintain the level of potential and eliminate signal attenuation, which can lead to termination of the action potential and negative consequences for the nervous system, a new action potential arises at each node of Ranvier. Thus, the action potential is transmitted along the neuron's body to the axon wavily – it arises in one area of the neuron, is then transferred to the other, and on the first area, the membrane potential returns to the resting state. The signal leaks occur at the moment of transfer of the action potential between the nodes. Despite the myelin isolation of the neuron's body, it is possible to intercept an electrical signal conducted along the neuron. By recognizing neurotransmitters, what kind of presynapses cause the action potential in the neuron and by intercepting the signal itself, or by aligning the functioning of the receiving device with a specific neuron, inhibitory or excitatory, it is possible to ensure the delivery of the signal directly to the necessary organ in the presence of transgressions in sensory conductive paths, that prevent the signal from reaching the body systems, or transgressions in the motor ways, that prevent the achievement of a signal from the central nervous system. Despite the fact that the postsynaptic potentials, initiating the onset of the action potential, can assume different values and the main role is played only by their total sum, the actual action potential itself does not depend on what signals and in what quantity enter the dendrite of the receiving neuron. All signals that pass ultimately through all the neurons of the nervous system are the same in structure. The only differences, that determine the functioning of different systems of the body, consist of the fact, that the signals are carried out in various nerve circuits, that are, in a general sense, isolated from each other and responsible for various functions of the central nervous system. Thus, there is no need to generate various electrical pulses, it is enough just to ensure the interaction of the device with neurons in such a way, that the device intercepts the action potentials of the necessary neural circuits, for example, chains, that regulate the contraction and relaxation of a particular muscle or interact with a certain perception organ.

If the inhibitory postsynaptic potential prevails over the excitatory, then the action potential does not occur. In the case when a neuron, being under the influence of the action potential, takes an inhibitory potential, the membrane potential restores the value of a resting state. The inhibitory potential makes the nerve cell less susceptible to stimuli, reducing its resting potential. Thus, the regulation of all human organs and systems is maintained. For example, the process of movement can be generalized as a simultaneous contraction of a certain muscle and relaxation of the antagonist muscle to the first one. While the arisen action potential causes the contraction of the muscle fibers of the activating muscle, carried out by sensory neurons from the peripheral somatic nervous system them, the inhibitory potential sent to the muscle fibers of the antagonist muscle inhibits its excitation, thereby providing relaxation of the muscle.

**2. Applicability of electronics in modeling the functioning of neurons**

By studying the physical nature of the functioning of the nervous system, it can be concluded that theoretically it is easy to align a certain device with the central nervous system – it is enough only to recognize the neural circuit necessary for the interaction and to connect it with a generator, that sends either impulses to endpoint systems or pulses that open the voltage-gated channels of neurons for the purpose of changing the membrane potential and of generating the action potential for the subsequent transfer of it between interneurons up to the center nervous system. However, the main problem lies in the diversity of neurons and neural circuits. Despite the uniformity of action potentials passing through neurons within a single neural network, most of the body systems are tied to individual neurons, and it is impossible to ensure their joint operation within the organization of high-level signals by modern devices that communicate with the human neural network. This is the problem of so-called spatial resolution. Spatial resolution shows how many isolated signals from different neurons the device is able to recognize as separate entities. It can be concluded that emulation of such complex behavior of the nervous system is impossible, considering that, for example, the reaction of the spinal cord to receiving signals from neurons about touching the heated surface is different depending on the degree of concentration of the person on his sensations. As mentioned earlier, there are about 86 billion neurons in the human brain. Even though they are connected in the network, forming in the widest possible consideration the lobes of the brain, the problem of recognizing the signals, coming from them to each other and to organs and systems, requires the creation of a device, that has the highest spatial resolution.

The most popular today are the so-called multielectrode Utah arrays (only invasive arrays are considered), developed by Dr. Richard Norman of the University of Berkeley [3]. They are up to 128 ultrathin conductive silicon needle electrodes with a length of no more than 6 mm, isolated from each other electrically by the substance of parilene. Each electrode, when placed near some small neural circuit (within tens of neurons), is capable of processing signals within this circuit or capable of initiating processes, that lead to the occurrence of action potentials in them. The array can work with the motor and sensory parts of the cerebral cortex, with the spinal cord and, accordingly, with neurons of the peripheral nervous system. The multielectrode array is placed at a depth of no more than 1.5 mm in the cerebral cortex or in the spinal cord, directly contacting the neuronal chains responsible for the specific functions of the organism. Today's researches of arrays are carried out in the field of neuroprosthetics and restoration of conduction of neurons and muscle fibers [4–5]. Being placed in the motor section of the cerebral cortex in the area, that regulates the movement of the fingers of the hand, the electrode array is able to detect action potentials, coming from the brain, by intercepting changes in the potentials at the nodes of Ranvier, when a person wants to move his fingers with a strong-willed effort. The processes associated with fine motor skill originate from the motor parts of the cerebral cortex in the form of a pulse, that moves into the white matter of the brain, then enters the cerebellum, that is responsible for coordinating the movement and the vestibular apparatus supporting balance. Then the impulse reaches the muscles and stimulates them to start moving [6]. After this, depending on the situation, additional signals are sent to different parts of the brain, for example, signals from the nerve endings, “notifying” the brain of pain. After the movement, the sequence of pulses is sent backwards, informing the brain of the results of the movement. Most often, paralysis of the limbs (quadriplegia) is accompanied by a spinal cord injury, as a result of which the action potentials coming from the brain to the limbs and vice versa, after reaching the neurons of the spinal cord, cannot be directed further into the motor cortex of the brain. The multielectrode array in this case is capable of either acting as a spinal cord, directing the action potentials from the brain to the muscles, inducing ion currents in them and causing them to contract, or, when connected to electrodes implanted in the muscles, is capable of sending signals to the electrodes, causing generation of electric current, which stimulates the muscle to contract, as it happens when a person comes into contact with a high-voltage wire [7]. The first method is rather complicated in implementation, but it allows to maximize the use of healthy neurons and provides minimal intervention in comparison with the second, in which undamaged neurons, whose connection with the brain is broken, are not used at all. However, since the array is capable of processing an extremely small number of independent neural circuits, the correct provision of muscle tone cannot be achieved and the motions turn out to be sharp and poorly controlled.

Theoretically, the solution to the problem of the limited application of multi-electrode arrays is either an increase in the number of electrodes supplied to neural circuits, or the placement of multiple arrays in different parts of the cerebral cortex. At the same time, the discovery of neuroplasticity about 20 years ago now allows such systems to be implanted in the brain as if they are human own neurons. Neuroplasticity is the feature of neurons to constantly form new links and to break off existing ones between themselves. Neurons gradually form bonds with a multielectrode array implanted directly into some neural circuit of the brain, as it is recognized as a current-conducting element capable of generating or transmitting postsynaptic potentials. However, the problem here is that the implantation of a foreign body in the brain at the same time inevitably causes the formation of new scar tissue around it, which leads to the attenuation of signals, that are guided along the sensory neurons to the organs. Thus, the device becomes ineffective after several months. This happened with the first devices, that allowed a person to see through the cameras connected to the neurons of the visual area in the brain. A few months after the successful implantation of the corresponding electrodes, their signal was screened by a tissue grown up around them, which made the device useless. At the same time, important is the fact, that the nature of the currents conducted by the electrodes in the neurons, differs from the nature of the ion currents circulating in the neurons during the normal functioning of the nervous system. This causes depletion of neurons and their rapid malfunction, which completely negates the utility of multielectrode arrays in the long-term period. In addition, it has been experimentally established that an increase in the number of electrodes intercepting action potentials leads to a decrease in the sensitivity of neurons, i.e. the decrease in the resting potential.

Another effective solution is the implantation of multielectrode arrays not in the brain regions, but directly into the nerve chains that survived after trauma and are associated with human dysfunctional systems. This approach is used in neuroprosthetics to control a foreign limb by strong-willed effort.

### 3. Evaluation of the possibility of creating a direct brain-computer interface

The idea of an American businessman Elon Musk is to unite a human’s limbic system and the neocortex, that interact with each other, along with some kind of a digital “layer” of artificial intelligence functioning “above” the neocortex [8]. The limbic system and the neocortex are inextricably linked with each other, combining the emotions and memory of a person together. The limbic system itself regulates some of the human senses, the formation of emotions, motivation, sleeping process, memory, the endocrine system, adaptation to external stimuli, the learning process (partially) and some basic instincts. The hippocampus, which is a part of the limbic system, allows short-term memory to be transferred to long-term memory, processing it during a person's sleep. The neocortex determines the person's thinking and conscious activity, it is also responsible for fine motor skills and coordination. As the higher nervous activity of a person functions, the neocortex sends various signals to other parts of the brain, coordinating human movements, its perception and other functions of the nervous system. The symbiosis of the limbic system and the neocortex can be characterized as the functioning of the operating system installed on the computer. Without an operating system, computer’s components can somehow work on their own, feeding on electricity and passing electric currents through themselves, but they cannot function as assumed during the production process, because there is no system, that controls them, sends them requests and signals and, most importantly, the system, that provides interoperability of different hardware structures. The brain performs a completely identical function in relation to the organs, muscles and nerves.

These problems are currently an insurmountable barrier to the creation of a brain-computer interface in the form in which it is represented by Elon Musk. Only the process of signal transmission through neurons has been studied by human, but the way how these signals provide the hippocampus with the ability to memorize and reproduce images, the way how the different parts of the brain interact with each other, with the spinal cord and the endpoint organs, is still unexplored. The hippocampus, like the entire brain, is represented by neurons and other cells, and functions in the same way as the entire nervous system, however, the mechanism of memorizing and functioning of short-term and long-term memory has not been studied, because at today’s stage of researches in these areas, it is impossible to identify, how the action potentials sent to hippocampus cause in it the processes of memorizing and reproducing information from memory. Moreover, the so-called “brain atlas”, that describes how in certain parts of the cortex of the cerebral hemispheres information is processed and produced, has also not been made up yet. As a result, neither the modeling of brain activity in the form of the interrelated work of all human systems, nor, even more, its integration with existing algorithms of the operation of artificial neural networks, is not possible. Today's approaches to creating a brain-machine interface are based on the use of existing electronic devices, and although an ordinary transistor with a size several times smaller than a neural circuit is capable of processing billions of operations per second, while a neuron processes several hundreds, a direct connection between the electronic device and the neural network is impossible. Typically, a transistor consisting of a base, an emitter and a collector (in the case of a field-effect transistor, source, drain and gate), allows to establish three connections to it. The neuron dendrite may have several thousand appendages, which are joined through synapses by axons of other neurons. Moreover, the computers, that exist today in electronics, function with electrical currents, converting them, amplifying or weakening them if necessary. The action potentials in neurons have a various nature of currents and are generally unchanged, which indicates problems in compatibility between the electronic device and the neural network of a human. The brain is a jelly-like substance that does not have a stable solid form. Immediate implantation of some third-party device can lead to side effects due to this process of formation of new glial tissues around the foreign body. The foreign body will be rejected by the brain, even though the neuroplasticity will ensure the integration of, for example, multi-electrode arrays with neurons, of which it consists. The implantation of multi-electrode arrays is extremely useful in eliminating the effects of Parkinson's disease, amyotrophic lateral sclerosis and others, if it is necessary to stimulate the nervous system in the event of tremors and seizures. Their application in neuroprosthetics is also quite promising.

**4. The concept of an effective prototype of a brain-computer interface**

A more promising approach to external influence on the nervous system is not the use of electric currents and devices that track the action potentials of neurons, but an integrated approach to the simulation of events leading to the occurrence of an action potential. The device should be as flexible as possible, easy, ideally, repeating the structure of the nerves themselves, to reduce the likelihood of brain rejection. In this case, during physical deformation, it does not lose its properties. Such devices are produced in the form of fibers with a thickness of about 0.5 mm by the method of hot drawing, which is usually used when creating glass tubes [9]. The method makes it possible to obtain several hundred fibers from a small blank. To make the fibers elastic, similar to the elasticity of the neurons themselves, special polymeric materials and metals with a low melting point are used. The device was tested on mice and it was concluded, that considering the non-stop movements of the animals such fibers placed in the head do not lose elasticity and, most importantly, the properties needed for intercepting the action potentials. At the same time, they operate at several levels, for example, chemical, and not only at the level of electrical pulses, as multi-electrode arrays [9].

In addition to these developments, instead of directly generating currents, that stimulate neurons, a potential device can also monitor the sources of action potentials-neurotransmitters. Using the patch-clamp method, ion currents arising in a single neuron due to chemical reactions, the causes of these currents and the mechanisms of opening all ion channels, and not just voltage-gated ones, can be investigated with the highest accuracy. Causing the conditions necessary to open the voltage-gated channels of the necessary neurons, that are responsible for certain functions of the organism, it is possible to control and create action potentials, which ultimately lead to the development of a reaction to the stimulus. This can be achieved, for example, by injecting a solution of magnetic nanoparticles into the human bloodstream. Spreading through the veins into the neural network of the brain, these particles, when grouped around the neurons chosen to be controlled, under the influence of a magnetic field cause the occurrence of an action potential in neurons. The average frequency of the earth's magnetic field is 8 Hz, and the human body hardly reacts to the field of this frequency and small amplitude, which allows the use of particles tuned to a frequency of several Hertz without affecting the body. Similar particles can be not only magnetic nanoparticles, but also some inhibitors. In general, the chemical composition of many neurotransmitters is studied, so such an influence on neurons is more effective, much less invasive and practically free of side effects. Obviously, this approach has the lowest spatial resolution among others, but in the future, it allows at least to adjust the brain activity, including improving memorizing and reproducing images by pinpointing the neurons of the cerebral cortex, limbic system and neocortex, regulating only the processes associated with memory and creative thinking. Such fibers can last longer during intense usage in real life. This is a key aspect of preventing degenerative disorders of the nervous system.

**Conclusion**

For more than 20 years, the development of an interface linking electronic devices to the human nervous system has been under way. The method of intercepting the potentials of the action of neurons and stimulating them with external electric currents has found the widest application in the treatment of diseases associated with impaired functioning of sensory organs and the restoration of the conductivity of sensory conducting paths. Potential application of devices, that restore action potential transduction chain between the nervous system and interneurons receptors, muscle tissues, or organs is large, however, it is limited by the incompatibility with the brain, that regulates the functioning of the entire human body. Ideas about connecting thinking regions of the brain to the artificial neural network in order to exchange information and improve human cognitive abilities is currently just the ambitious fiction until the moment when the human brain will be completely studied and the device will be manufactured, that is not based on the current developments in microelectronics, but mimics human neural network and is capable of not just operating near the neurons but of simulating their functioning, thus providing a direct fusion of electronics and biological human neural networks.

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***Received 10 May 2017***

УДК 004.032.26 DOI: 10.14529/ctcr180103

# СЛИЯНИЕ МИКРОЭЛЕКТРОНИКИ И НЕРВНОЙ СИСТЕМЫ ЧЕЛОВЕКА

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Рассмотрены основные теоретические аспекты, необходимые для понимания функционирования биологических нейронных сетей с целью их последующего воспроизводства в виде эквивалентных электронных устройств. Рассмотрены устройства, применяемые последние 4 года для прямого взаимодействия с нейронами, их недостатки, а также предложена модель гибкого и эффективного устройства, не сталкивающегося с рассмотренными проблемами и позволяющего на нескольких уровнях взаимодействовать напрямую с нервной системой человека.

*Ключевые слова: нейрокомпьютерный интерфейс, нейронная сеть, многоэлектродный массив, мембранный потенциал.*

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***Поступила в редакцию 10 мая 2017 г.***

**ОБРАЗЕЦ ЦИТИРОВАНИЯ**

Medvedev, M.P. Merge of Microelectronics and Human Nervous System / M.P. Medvedev, S.A. Ivanov // Вестник ЮУрГУ. Серия «Компьютерные технологии, управление, радиоэлектроника». – 2018. – Т. 18, № 1. – С. 28–36. DOI: 10.14529/ctcr180103

**FOR CITATION**

Medvedev M.P., Ivanov S.A. Merge of Microelectronics and Human Nervous System. *Bulletin of the South Ural State University. Ser. Computer Technologies, Automatic Control, Radio Electronics*, 2018, vol. 18, no. 1, pp. 28–36. DOI: 10.14529/ctcr180103