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BIOINFORMATION SYSTEMS WITH DETECTORS AND SIGNAL CODING CAPABILITIES

Introduction. *The integration of computer technologies into various fields of science allows the development of new methodologies, hybrid information systems with advanced capabilities, such as EcoIS bioinformation system for monitoring the environment with the use of biological data detectors.*

Problem Statement. *The development of innovation bioinformation systems with biological data detectors is a very important task, as they have numerous advantages: allow rapid diagnostics and testing of chemicals in the first moments of their action, may be incorporated easily into electronic registration systems, may serve as elementary analytical units with data coding capabilities, etc.*

Purpose. *The purpose of this research is to make a comprehensive analysis of different types of biological data detectors to develop a physical model of a biosensor capable of encoding signals and a bioinformation system with such detectors.*

Materials and Methods. *The comparative analysis of information systems with functions of ecomonitoring and different types of biosensors have been used; the data are taken from electrophysiological experiments on registration of chemosensitive transmembrane electric currents in voltage clamp and patch clamp modes.*

Results. *The physical model of biosensor has been developed and tested. The integration of the developed biosensors into the electronic bioinformation system by the example of EcoIS authors' system has been demonstrated. Neuron-like biosensor has been considered an abstraction in the unity of its functions: signal receiver — filter — analyzer — encoder/decoder, where the input information is obtained in the form of chemical structures or electrical signals, after the conversion (recoding) of information it is registered as electrical signals with changed characteristics. The prospects for developing the cutting-edge methods for information protection in systems with biosensors have been shown.*

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Conclusions. *This development may be used for creating a bioinformation system for environmental monitoring with integrated biosensor system and data protection based on the principles and achievements of contemporary biophysics.*

Keywords: information technology, information system, biosensor, signals coding, and ecological monitoring.

Bioinformation systems with detectors of biological origin

According to classic definition, the term "information system" (IS) means any system that is able to receive, to process, to record, and to transmit information. In accordance with the classical ideas of cybernetics, we distinguish three types of information systems [1, 2]. According to them, the term "information system" means: 1) the technical information systems (tIS) and 2) the living systems of the nature ("open" biological information systems), we propose to call them the natural information systems (nIS). The hybrid information systems (ISs) were developed over the last decade; they combine the characteristics of nIS and tIS [1, 2]. The combination of artificially created technical systems and natural systems based on the cutting-edge information and computer technologies (ICT) is one of progressive directions of modern science and technology. The invention of such hybrid systems allows overcoming numerous problems that may not be solved within the limits of one branch of knowledge and because of the limitations of Moore's Law [1].

The development of electronic information systems supplemented with biosensors (BS), elements of biological origin or their artificial analogs, is a specific direction which has become increasingly important in recent years. In previous publications on ISs [1—4], the authors have already discussed the issue of high quality of biomedical input data for such ISs [1, 5]. Based on previously obtained data [5—10], the authors have formulated one of the biosensor concepts, proceeding from long-term experience in studying the properties of brain neurons in biophysical experiments with recording transmembrane electric currents. The input of such biosensor receives information encoded in [6, 10]: a) the structure of chemical substances acting on the biological object (or biological fragment of the cell or tissue), and b) the characteristics of the input electrical information signals. The characteristics of electrical signals at the input and output are always different. While studying electrophysiology of neurons, we use the term "neuron-like" biosensor or its element, if they demonstrate some "neuron-like" properties. The "neuro-like" element is characterized by the set of characteristics that can be actually recorded digitally during biophysical experiments. This type of biosensor is called also "neurobiosensor" (NBS) [6, 9, 10]. The data given in this research are real experiment results of brain neurons studies obtained by the Dr. Klyuchko with his colleagues at the Bogomolets Institute of Physiology of the NAS of Ukraine. Further, these data have been processed and analyzed at the National Aviation University (Kyiv).

The combination of technical information systems (tIS) and biological (open) information systems (nIS), such as biosensor, in one complex system is an extremely powerful technique, because the resulting information complex has the capabilities and advantages of each of the components. Neurobiosensor (NBS) consists of a biological fragment (BF) connected with an electronic system (see Figs. 1, 2) [1, 8]. Combining the NBS biosensor with contemporary tIS results in the formation of a complex information system with databases (DB). The system is network-based, often with access to global Internet.

The methods for comparative analysis of the characteristics of input and output electrical information signals of biosensor have been applied; physical and mathematical biosensor models have been developed. For studying the biosensor properties, the methods of transmembrane electric currents recording in voltage-clamp and patch-clamp modes at hippocampal neuronal membra-

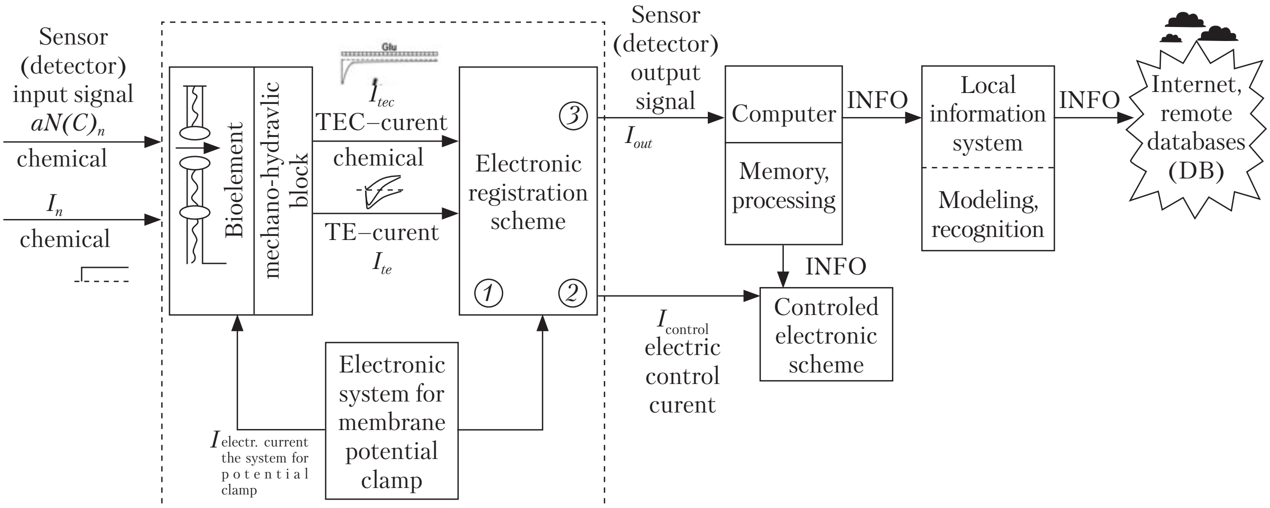

Fig. 1. Block diagram of technical biosensor system coupled to electronic information system and Internet. The information in the form of electrical or chemical signals is received primarily at the input of biosensor system (left). Encoded information in the form of electrical signals is drawn at biosensor output (near the arrows in the center, see the main text for details)

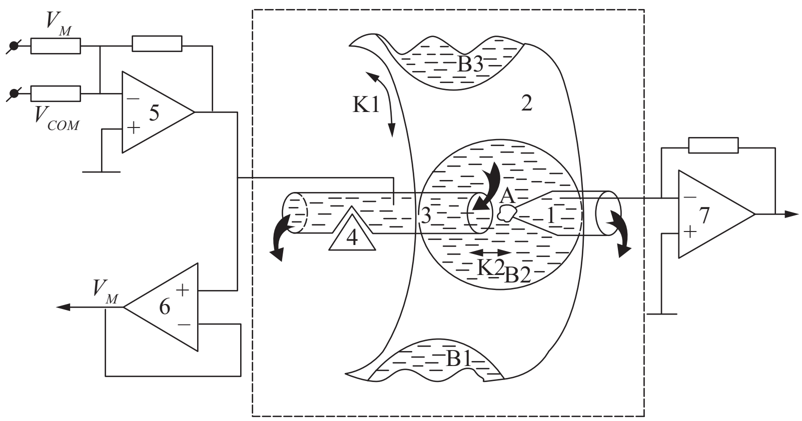

Fig. 2. The scheme of experimental device that has been used for the electrophysiological study of transmembrane ionic currents in the voltage-clamp mode: A — neuron at the pore of glass micropipette; *1* — micropipette is filled with solution for intracellular perfusion; *2* — mobile cassette with experiment chambers containing different solutions for the application (B1, B2, B3) in the three different chambers; arrow K1 indicates directions of movement of the chambers with the solutions; *3* — tube in which cell A moves from one chamber to another; the substances are applied to the surface of neuronal membrane in this tube according to the following procedures. Cell A on the micropipette *1* is inserted into tube *3* (arrow K2 indicates the direction of movement). When electromagnetic valve *4* is open, solution B2 is quickly applied; this solution is sucked into the tube due to negative hydrostatic pressure. The dark arrows indicate the directions of the solution flow during their application in tube *3* and the directions of the flow in micropipette 1 during the cell fixation at the pore. The dotted line limits the mechanical part of experiment device; *5* — amplifier of holding potential V_m and command V_{com}; *6* — potentiometer; *7* — amplifier of registered transmembrane currents [8]

nes have been used. Bioinformation systems with detectors of biological origin have been described in present research.

Below, in present research, neurobiosensors as technical devices are defined and described, their input and output chemical and electrical information signals are analyzed and the possibility to incorporate this biotechnical device into the electronic information systems due to biosensor output electrical signals is suggested. The general concept of biosensor, its definition and general characteristics are given. The physical model of biosensor is presented; some test results of this device are published. The biosensor physical model has been developed as part of this bioinformation system, and appropriate software has been developed as well. The incorporation of such biosensors that transmit the information in the form of electrical pulses to electronic bioinformation system is discussed by the example of EcoIS. The EcoIS information system with biosensors has been developed for ecological monitoring in a broad time framework: from the first moments of chemical substance influence on the organism to the months and years after it. This information system has been designed for the purpose of ecomonitoring of the influence of harmful technogenic pollutants on living organisms. The neuronlike biosensor is considered an abstraction in consistent unity of its functions: signal receiver—filter—analyzer—encoder/decoder. At the input of neurobiosensor, the information arrives in the form of chemical substances structures or electric signals, after the transformation (recoding) the information is registered in the form of electric signals with changed characteristics. In the concluding section, the phenomenon of input information encoding by biosensor and possibilities of information protection in such information systems have been analyzed.

The general concept of biosensors (neurobiosensors) as biological origin detectors

Several biosensor definitions and formulations of biosensor concept can be found in contemporary literature, as a result of a great variety of biosensor types and the tasks they perform, as well as a broad range of their application. Thus, the definition of the author corresponds to own experience of biosensor (neurobiosensor) study in the biophysical experiments described below. So, the authors consider the biosensor an analytical device (as well as bioinformation system) that includes a neuro-like element(s) with its (their) properties and functions as an acceptor (receiver of information signals), filter, bioanalyzer, and encoder/decoder of these signals. Electronic subsystem may be included as a part of biosensor; it receives output electrical signals from incorporated biological fragment (BF).

Some other authors have suggested different biosensor definitions. However, there are no contradictions between them, as they supplement each other. For example, other definition of biosensor, which largely coincides with the one formulated by the authors, because it reflects the conversion of information at biosensor input ("biological reaction") into the output electrical signals, "*Biosensor* is analytical device that converts a biological reaction into electrical signals. Biosensors shall be highly specific, independent on the physical parameters such as pH and temperature, and be reusable. Biosensor is analytical device used for detecting the chemical substances that combine a biological component with a physical and chemical detector" [7].

Concerning the biosensor structural and functional analysis, one may find the opinion that the biosensors consist of the *three parts* [7]:

- bioselective element (material of biological origin or element that mimics it). The sensitive element can be constructed with the use of bioengineering methods;
- transducer or converter (it works based on the physicochemical principles: optical, piezoelectric, electrochemical, etc.). This part of device converts the signal that appears as a result of analyte interaction with bioselective element into another signal that is easier for measurement;
- connected electronics that are responsible, first of all, for displaying the results in a user-friendly form [7]. In our case, described below, such electronic systems have to be responsible for the maintaining the vital functions of biological object.

The authors of this research have proposed a *functional analysis* of biosensor. According to this approach, the first two parts of the above list may be described as follows:

- the bioselective element corresponds to the sequence of the 3 functions: a) acceptor or receiver of information signals (chemical or electrical signals), b) filter of input signals, c) local analyzer (of input acting chemicals or input electrical signals);
- the converter (transducer) corresponds to the functions of encoding/decoding of input signals.

Classification of biosensors. Depending on the type of transducer, biosensors may be classified into optical, acoustic, calorimetric, thermal, and electrochemical ones. Electrochemical biosensors, consequently, are divided into potentiometric, amperometric, and conductometric ones [7].

Among the above types, *electrochemical biosensors* are the most interesting for us, because the biosensors invented by us belong to this type. The functions of the electrochemical biosensors are based usually on the enzymatic catalysis of reaction in which electrons are released or absorbed. Usually, such biosensor includes the three electrodes: the reference electrode, the working electrode, and the auxiliary electrode. The biological material is applied to the surface of working electrode, which specifically reacts with agent to be analyzed (analyte). The charged products of reaction create a potential at the working electrode, which is subtracted from the potential at the reference electrode to obtain the output signal. Current measurements are also used. In this case, the electron flux intensity is proportional to the analyte concentration. This procedure has to be done at a constant potential, or the potential can be measured at zero current (this gives a logarithmic response). Direct electrical determination of small peptides and proteins by their characteristic charge is possible with the use of biologically modified ion-selective field-effect transistors (ISFTs) [7].

Biosensors obtain input information in the form of electrical signals or chemical structures

Fragments of living organisms (biological fragments, BF) by themselves may act as biosensors [1, 8]. Many of them are able to interact with chemical elements and compounds Changes in the electrical properties of these objects, including occurrence of electric currents in them often are consequence of such interaction. So, according to the definition, such BF can be sensitive (sensory) part of biosensor. The study of such objects is within the competence of electrophysiological and biophysical researches, for example, with the use of the methods for transmembrane electric currents recording under voltage-clamp, patch-clamp, and other conditions. It is extremely important that in the process of such experiments, the numerical data obtained on the brain neurons can be digitized and input further to information systems. These numerical data characterize the real processes in living systems. Thus, thanks to such improvements in biological experiments, important biological research has been transferred from the descriptive field to the fields of exact sciences [1]. The complex of BF with experimental electrophysiological setup (EPS) and with electronic information systems (ISs) can be considered united information bioelectronic complex BF — EPS — ISs.

Here is a brief description of devices and methods, which in this research are considered basic ones for the experimental study of electric currents activated in NBS by chemicals [1, 8]. The experiments are performed on internally perfused neurons of the brain, with the use of the voltage-clamp and patch-clamp methods [1, 8]. The membrane potential is recorded with the help of an Ag-AgCI microelectrode, with the grounding electrode with Ag-AgC1 being in solution external to BF. A standard electronic circuit is used for single-electrode recording in the voltage-clamp mode. Both currents and voltages are PC-monitored; the results are recorded in the computer memory for the further analysis. All values and their changes are recorded in the form of digital values with great accuracy: the lower limit of the registration of electric current amplitudes is 0.1 nA, and that for potential changes is 0.1 mV. The scheme of experimental device used for the

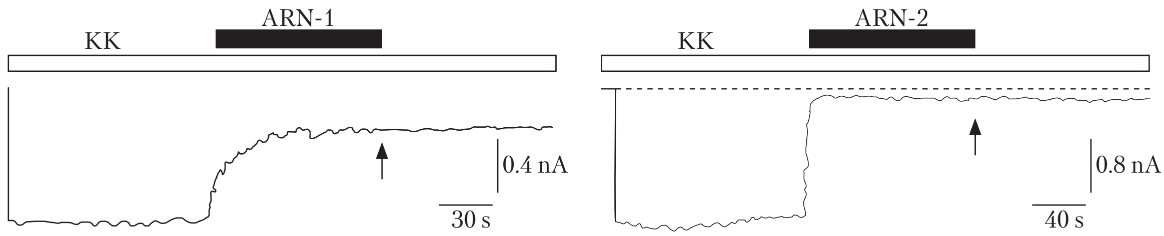

Fig. 3. Information signals from biosensor registered during the electrophysiological experiments [8—10]. At the biosensor input, kainate (KK) initiates steady transmembrane electric currents, over time, two different substances ARN-1 and ARN-2 are applied against the background of these currents. Both substances ARN-1 and ARN-2 reduce the current amplitudes with certain kinetic characteristics (the left and the middle parts of the record to the arrow). At the biosensor output, stationary electric currents with smaller amplitude are received (recording right after the arrow). The effect of ARN-1 and ARN-2 is characterized by some number of characteristics specific for these substances: the kinetic constants of current amplitudes decrease and so do the rates of current amplitudes and some other numerical values. This difference in the characteristics is visible on A and B as different rate of decrease in the current amplitudes. Both records are done on different neurons. Concentrations: 1 mmol/L KK, $3.0 \cdot 10^{-6}$ mol/L ARN-1, $3.2 \cdot 10^{-6}$ mol/L ARN-2; potential is 100 mV

electrophysiological study of transmembrane ionic currents in the voltage-clamp mode is shown on Figs. 1 and 2. The experimental methods were invented based on the methods previously developed by biophysical research groups led by Full Members of the Academy of Sciences of USSR and the NAS of Ukraine, Profs. Kostyuk and Kryshtal, and Dr. Klyuchko O.M. who worked in this research group with the mentioned techniques and objects [1, 8], namely: a) membranes of brain neurons as objects (BF); b) the study of transmembrane ion currents in the voltage-clamp mode, testing of effect of different substances on BF; c) combination of a) and b) with electronic technical information systems (tIS) [1, 8].

Fig. 1 features a block diagram of technical biosensor system developed and used by this research group successfully during several years. Fig. 2 illustrates the operation of biosensor, including its electronic measuring circuit. Information signals from the biosensor registered during electrophysiological experiment on rat brain neurons are shown on Fig. 3.

Hybrid bioinformation systems with embedded biosensors

The ability of NBS biosensor to generate and/or transmit and to output electrical information signals (not signals of other origin) is extremely important property that allows incorporating this object, NBS neurobiosensor, into the electrical systems (in our case, in the device for biophysical experiments), with the subsequent embedment of the formed complex into tIS with access to networked Internet systems [8].

The electrical nature of information signals at the biosensor output is a necessary condition for biosensor incorporation into the information system; they can be functionally linked, because such linkage is a result of electrical connections. Under these conditions, both individual differences of biosensors and separate individual features, characteristics of information system become less important: there are many types of such systems in the world now [1—5]. For example, let us consider briefly the comprehensive hybrid bioinformation system developed by Dr. Klyuchko O.M. [1, 8], which unites tIS and the above described “neuro-like” biosensor NBS (nIS) [6, 8, 10]. The purpose of this research is to develop a new biotechnical information system EcoIS for ecological monitoring in broad time range. EcoIS has been built with the use of contemporary information and computer technologies as well as knowledge about the state-of-the-art electronic information systems with databases. For this purpose, some modern methods of information security, the latest biotechnical and electronic information systems, as well as the possibilities of their application for environmental monitoring have been analyzed. The following methods have been used: comparative studies of the samples of technical devices, simulation and software modeling based on numerical results obtained in the experiments with the registration of chemosensitive transmembrane electric currents in neurons in the voltage-clamp and patch-camp modes and with the use of other methods. The applied biophysical methods have allowed revealing and identifying the substances that are dangerous for living organisms and making the first conclusions about their possible biological effects. As a result, an original system for environmental monitoring in a broad time range has been developed. It is combined with detector groups, databases, expert subsystem and interface; it is able to recognize some types of chemicals at its input and to output the data of their identification and, if necessary, messages about their harmfulness. During such monitoring, it is possible to study the effects of substances during various periods of time, from the first moments of their effect on single cells in organism to months and years on the whole organism. For today, the first results of practical use of the developed technical system can be generalized and summarized; some of such results cannot be obtained with the help of previously used devices and methods. The results of these research have been reported in numerous publications, which provide some data about the analysis of the developed technical system and its practical application, as well as some practical recommendations for environment monitoring [1, 8].

Biosensor as abstraction. Four main functions of neurobiosensor

Considering neurobiosensor (NBS) as abstraction, one can notice a set of important features common to many NBS. These common features are functionally determined and characteristic for NBS type of biosensor. Let us list these four NBS functions and, respectively, four NBS elements (Fig. 4) [3, 4, 6—9, 11].

1) Biosensor NBS as a receiver of information signals (acceptor) (Fig. 4). It is well known that the input of the NBS information comes in two ways, in the form of signals of two types.

Type 1. Encoded in the chemical structures of substances acting on BF membranes. In this case, the electrical signals that are registered at the NBS output have characteristics co-related directly with the signals at the input. In other words, the characteristics of such output electrical signals correspond to the structures of substances that interact with BF surface membranes (biosensor BF). Thus, at the BF level, the input chemical signals are converted into the electrical ones. In this case, the term "biosensor" often refers to the surface neuronal membrane and — he corresponding phenomena of chemicals interaction with it.

Type 2. The input NBS information is received in the form of electrical signals with certain characteristics, and these signals are perceived by the membranes structures of BF. At the NBS output, the signals of electrical nature are also registered, but they have the characteristics that are different from those of the input signals. In this case, at the BF level, the electrical signals with some characteristics have to be encoded to the electrical signals with other characteristics.

2) Biosensor NBS as filter of input information signals (Fig. 4). It is well known that NBS does not receive all information through the surface input membrane (because it often receives white noise of signals). The input information is perceived by NBS selectively, i.e. at the input, only the signals that carry chemicals with very specific structures and the electrical signals with well-defined characteristics are considered significant. The input signals are filtered because they have to interact *only with well-defined* molecular structures in membranes. In fact, above described functions 1) and 2) determine the NBS role as a *code key* in information perception and further transmission.

3) Biosensor NBS as primary elementary analyzer of input information signals (Fig. 4). The

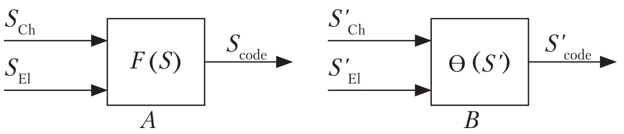

Fig. 4. Abstract presentation of NBS biosensor functions as encoder (A)/decoder (B) of the input information signals. Symbols: F — coding function; Θ — decoding function; S, S' — signals; S_{Ch}, S'_{Ch} — information signals encoded in chemical structures; S_{El}, S'_{El} — electrical information signals (see the main text for details)

structure of the surface NBS membrane (its composition of certain chemicals, their conformations, relative position in space, etc.) in combination with a) transformations that occur in the membranes caused by a chemical molecule approaching the surface and b) those chains transformations (including chemical reactions) that follow this determine the NBS function as analyzer of input information signals. In other words, the set of phenomena and properties of NBS 1), 2), 3) leads to biosensor "distinguishing" of what chemicals interact with it, as well as, to some extent, in what quantity [8—10]. The new methods of qualitative and quantitative analysis, which have been proposed by Dr. Klyuchko, are based on these properties of membranes and corresponding effects; four patents of Ukraine have been obtained for these methods; some details have been published in [6, 8—10].

4) Biosensor NBS as encoder/decoder of information (Fig. 4). The phenomenon of information encoding by biosensor and its implications are extremely important. As it has been shown above, the natural biosensor NBS performs the functions of devices that in engineering are called encoders/decoders of information. In numerous experiments, it has been registered that the NBS receives information in the form of information signals (ions or molecules of chemicals, or electrical signals with certain characteristics). At the NBS level, this information is recoded into electrical signals with other characteristics. Accordingly, this process runs in the opposite direction too (Fig. 4). The phenomena and processes of signal coding, which take place in the direction from left to right, may occur because of the sequence of events described in 1), 2), 3) plus chemical chains phenomena at the output of NBS biosensor. The phenomena and process of signal coding in the direction from right to left may be caused by the reverse sequence of events described above, which, however, have their own specificity. An example of practical application of neurobiosensor for encoding information about the structure of chemical substances in corresponding electric currents characteristics is shown in Fig. 3. The effect of substances ARN-1 and ARN-2 may be revealed by analyzing the numerical values that characterize the kinetics of these substances that block the effect of registered current amplitudes. There have been about few thousand such examples known for today. Being organized into appropriate databases, these numerical characteristics can be used to encode the information on relevant chemical substances [10—40].

Based on the current level of knowledge and results obtained in our experiments, it can be proved that the functions of NBS biosensor for encoding/decoding may be expressed in two ways: 1) in the tabular form, and 2) in the analytical form as a function or system of functions. The functions of information encoding and decoding by NBS biosensor are presented in Fig. 4. The examples of experimentally registered coding of the chemical signal (substances ARN-1 and ARN-2) into the electrical ones have been given represented above, in Fig. 3. The *electrical nature of information signals at the biosensor output is a necessary condition* for biosensor incorporation into information system; they can be functionally linked, because such linkage is a result of electrical connections.

Examples of possible ways to protect information with the help of the described methods

The above described techniques and results allow data protection in information systems with the use of these phenomena and principles.

1. *BF as key-lock*. The key-lock principle is extremely common in the nature, including the described objects: neurons, neuronal membranes, and other BFs. By incorporating BF into technical information systems, as it has been demonstrated above, the effects of information protection can be achieved, for example, in some segments of information network. Moreover, artificial synthetic analogs of BF (described above) have been now being elaborated. When making a device with a BF with specific type of molecules in information network (at least, cable), one may specifically "disconnect" a certain segment of BF device to prevent data leakage. That is, the specificity of organic molecules assembled in the BF leads to the situation where only signals having certain characteristics pass through the device thereby reducing the availability of information in the selected segment. The key to connect and to disconnect (or to the balance between confidentiality and availability of information in the system) is a device that contain BF with specific set of molecules. Such BF demonstrates a great variability to choose such keys assembled from organic molecules and their combinations.

2. *Confidentiality of information in systems with BS*. Confidentiality of information in systems with biosensors or artificially made BF in biosensors can be realized in the following way. Increasing the level of information confidentiality when using the devices with BF can be achieved by assembling specifically selected types of molecules, changing them, and etc. Since information transmitted directly depends on the types of molecules in device with BF, it is possible to set or to control this information to some extent.

The results of biosensor (neurobiosensor, NBS) research and analysis have been described in this research. The general concept of biosensor, its definition, general characteristics, and prototypes have been given. The physical model of biosensor has been presented; some test results of this device have been reported. The incorporation of such biosensors that transmit the information in the form of electrical pulses to electronic bioinformation system has been shown by the example of EcoIS. The physical model of biosensor has been designed as part of this bioinformation system, and appropriate software has been developed as well. The EcoIS information system with biosensors has been proposed by Dr. Klyuchko for ecological monitoring in a broad time range, from the first moments of chemical substance effect on the organism to the months and years after it. This information system has been designed for the purpose of eco-monitoring of the influence of harmful technogenic pollutants on living organisms.

The neuronlike biosensor is considered abstraction in consistent unity of its functions: signal receiver—filter—analyzer—encoder/decoder. The biosensor phenomena, processes, and functions have been briefly described. The possibilities of information coding by biosensor within the following model have been considered: at the input of NBS the information arrives coded in the form of chemical structures of active substances or in the form of electric signals with the set characteristics, after the transformation (re-coding) the information appears in the form of electric signals with the changed characteristics. It has been shown that the reverse phenomenon, i.e. information decoding is possible as well.

The applicability of biosensor as biotechnical device for coding information signals has been substantiated. It has been proved that the functions of NBS biosensor for encoding/decoding can be expressed in the two ways: 1) in the tabular form, and 2) in the analytical form as a function (or system of several functions). The proposed biotechnical device opens new opportunities for information protection in bioinformation systems. An example of practical application of neurobiosensor for encoding information on the structure of chemical substances in the corresponding electric currents has been given.

For today, there have been about few thousand such examples are known. Being organized into appropriate databases, they can be used to encode and to transmit information on relevant chemical substances. In this research, new specific mathematical methods have been used [41—43]. All proposed devices and methods have been protected with patents of Ukraine [6, 8—10, 44—45].

Some parts of this research are theoretical. In order to produce industrial samples of biosensors as part of information systems, it is necessary to make some additional studies in the future.

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БІОІНФОРМАЦІЙНІ СИСТЕМИ З ДЕТЕКТОРАМИ І МОЖЛИВОСТЯМИ КОДУВАННЯ СИГНАЛІВ

Вступ. Інтеграція комп'ютерних технологій в різні галузі науки дозволяє розробляти нові методології, гібридні інформаційні системи з розширеними можливостями, зокрема такі як біоінформаційна система «ЕкоІС» для екологічного моніторингу із застосуванням детекторів біологічних даних.

Проблематика. Розробка інноваційних біоінформаційних систем з детекторами біологічних даних є актуальною, оскільки останні мають низку переваг: дозволяють виконувати експрес-діагностику, тестування хімічних речовин вже у перші моменти після їхньої дії, легко інкорпоруються у електронні системи реєстрації, виступають як елементарний аналітичний блок з можливостями кодування даних тощо.

Мета. Здійснити комплексний аналіз різних типів детекторів біологічних даних та розробити фізичну модель біосенсора з можливостями кодування сигналів та розробку біоінформаційної системи з такими детекторами.

Матеріали і методи. Використано порівняльний аналіз інформаційних систем з функціями екомоніторингу, різних типів біосенсорів; дані електрофізіологічних експериментів з реєстрації хемочутливих трансмембранних електричних струмів у режимі фіксації потенціалу та patch clamp.

Результати. Розроблено фізичну модель біосенсора, здійснено його випробування. Продемонстровано введення розроблених біосенсорів до складу електронної біоінформаційної системи на прикладі авторської системи «ЕкоІС». Нейроноподібний біосенсор розглядався як абстракція із єдністю його функцій: приймач сигналу–фільтр–аналізатор–кодер/декодер, де на вхід інформація надходила у вигляді структур хімічних речовин або електричних сигналів, після перетворення (перекодування) інформацію реєстрували у вигляді електричних сигналів зі зміненими характеристиками. Показано перспективність розробки новітніх методів захисту інформації у системах за участю біосенсорів.

Висновки. Розробку можна застосовувати для створення біоінформаційної системи моніторингу довкілля з інкорпорованою біосенсорною системою та із захистом даних на основі принципів і досягнень сучасної біофізики.

Ключові слова: інформаційні технології, інформаційна система, біосенсор, кодування сигналів, екологічний моніторинг.