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Intelligent sensor system for ranking the ionic composition of breast milk

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Abstract. The intelligent sensor system conducts a qualitative and highly accurate medical ranking of breast milk and dairy products based on a personalized approach. It can make the decision-making procedure for medical workers as objective as possible and ensure the implementation of high-quality, effective and safe hardware solutions in the field of artificial intelligence and personalized medicine into medical practice.

Keywords: sensory system, breast milk, digital images, biological environment

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Интеллектуальная сенсорная система ранжирования ионного состава грудного молока

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Аннотация. Интеллектуальная сенсорная система проводит качественное и высокоточное медицинское ранжирование грудного молока и молочных продуктов на основе персонализированного подхода. Она способна сделать процедуру принятия решений медицинскими работниками максимально объективной и обеспечить внедрение в медицинскую практику качественных, эффективных и безопасных аппаратных решений в области искусственного интеллекта и персонализированной медицины.

Ключевые слова: сенсорная система, грудное молоко, цифровые изображения, биологическая среда

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Introduction

The qualitative ionic composition of breast milk is the main factor that determines the fullness of growth, physical and intellectual health of newborns throughout life. The study of a multilevel system of mechanisms that determine and control the ionic composition of milk is an important problem of lactation physiology [1]. Breast milk is a dynamic body fluid; clinical evidence has been presented of changes in the composition of breast milk depending on the changing needs of the infant [2]. Breast milk can also actively stimulate the accelerated development of the newborn's defense systems and suppress excessive inflammation in response to various irritants until the intestine's own immune response develops [3].

The study solves the scientific problem of the complexity of identifying the functional state of the mother-newborn system using standard medical analysis methods. The purpose of this work is fundamental research of a comprehensive solution to the problem of identification and analysis of the state of complex multicomponent biological media: in particular, the qualitative ionic composition of breast milk, based on new intelligent methods of electrochemical analysis. Currently, most medical institutions, due to the lack of the necessary methodological and instrument base, are limited to the subjective interpretation of various types of analyses by medical personnel [4]. Interpretations can vary significantly depending on the specialist studying the results of indirect methods for determining the functional state of the mother-newborn system.

For the first time, a method of noninvasive diagnostics has been developed, it consists in the use of a set of electrochemical sensors with sensitivity to the main significant components of the investigated medium, and analysis using artificial neural-like systems and mathematical methods for processing arrays of multidimensional information, including the method of principal components. The proposed approach differs from existing methods in that it does not require high-precision determination of the content of certain components in biological media, and it is proposed to use a set of sensors that respond to the presence of several components of the analyzed medium at once. The resulting set of multidimensional data requires modern mathematical processing. For this purpose, the machine learning method (the principal component method) is used for data processing.

Materials and Methods

To solve the problem of controlling the qualitative ionic composition of breast milk, the construction was developed, and the main blocks of the intelligent sensor system were tested [5]. Electrochemical electrodes based on polymer plasticized potentiometric membranes were used as sensors [6]. The polymer base of the membranes in all the membranes was polyvinyl chloride. Di-2-ethylhexylsebacinate, *o*-nitrophenyloctyl ether and 2-fluorophenyl-2-ytrophenyl ether were used as a solvent-plasticizer.

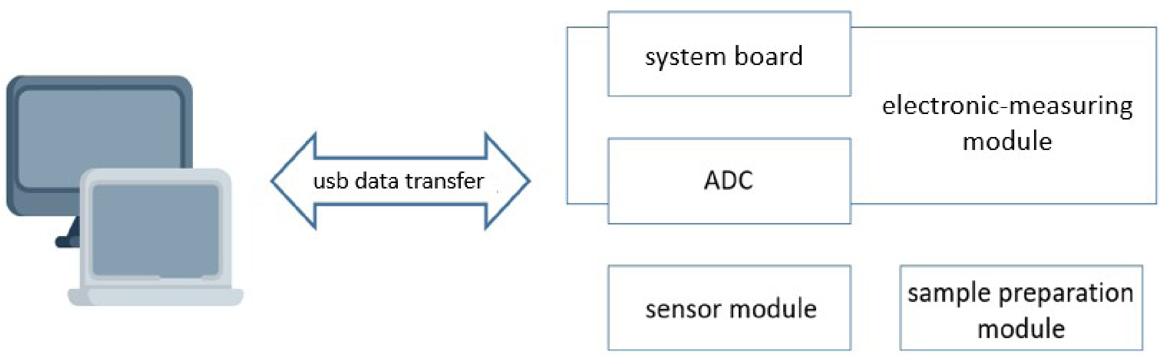

Fig. 1. Block diagram of an intelligent sensor system

The intelligent sensor system consists of two main blocks. The measuring unit includes sample preparation modules, a sensor, a microprocessor-measuring module. The information block includes modules for learning, recognition and visualization of images. The block diagram of the prototype sensor system is shown in Fig. 1.

The sample preparation module includes a device for installing sensors in the test medium, its temperature control and mixing.

The sensor module is represented by a set of polyselective electrochemical sensors with cross-sensitivity to biologically important components.

The learning and recognition module is presented as a mathematical model that implements the training of the system and the recognition of multidimensional "images" formed by the sensor module in the form of arrays of EMF values.

Experimental studies

At the preparatory phase of the research, the compositions of working solutions for calibration, conditioning, storage of sensors and evaluation of their cross-sensitivity were worked out, as well as methods for preparing sensors for measurement, evaluating their characteristics in control solutions.

The studies were conducted on fourteen female subjects during the second semester of lactation. Also nineteen samples of unpasteurized and whole cow's milk were examined to evaluate and demonstrate the efficiency of the intellectual sensory system for obtaining "digital images" of the milk samples under study and their visual representation. 6 potentiometric polyselective sensors (H+, Na+, K+, NH4+, F+, pH) with cross-sensitivity were used.

Results and Discussion

Digital image plotting.

A visual results representation of two of the most typical subjects during the second semester of lactation is presented in Fig. 2. One of these subjects had a viral infection during the last month of lactation. Visual results are represented in the form of "digital images" of their breast milk: heptahedrons with rays radiating from the center to the points of intersection of the faces. The length of the beam at the points of intersection of the faces corresponds to the result of measurements of the potential generated by each polyselective electrode.

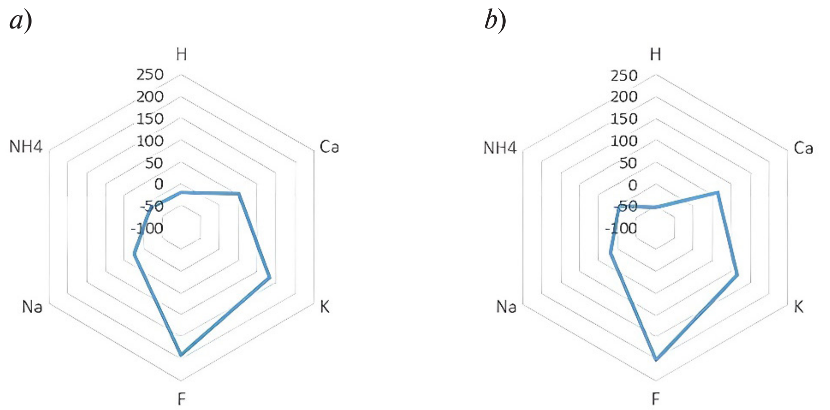

Fig. 2. "Digital images" of breast milk of a healthy woman (*a*) and a woman who has had a viral disease during the last month of lactation (*b*). The readout of electrochemical sensors (sensitive to certain ions) in the content of breast milk are marked on the axes of the radial diagram. It can be noticed that in the breast milk of a healthy woman, the content of hydrogen ions is higher than in the breast milk of a woman who suffered a viral disease in the last month of lactation

Furthermore, "digital images" of breast milk of women who suffered a breast infection during lactation were obtained. The observation of changes in the state of milk before and after taking antibacterial therapy was carried out. Examples of radial diagrams of breast milk in dynamics are shown in Fig. 3.

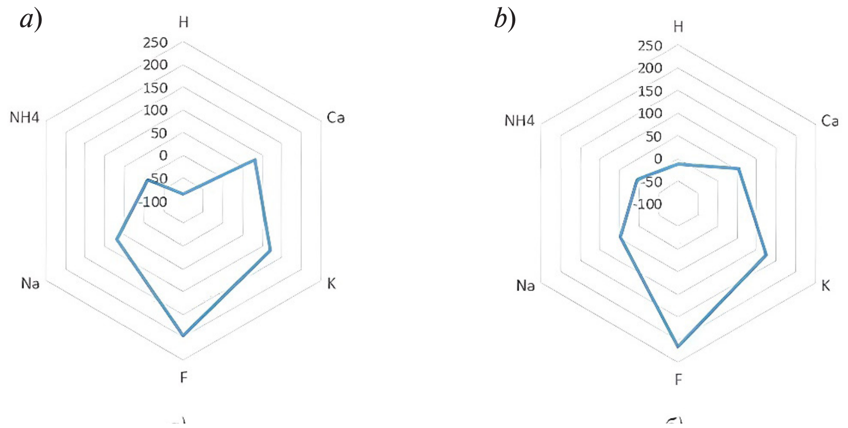

Fig. 3. Visual representation “digital image” of breast milk of a woman with an infectious breast disease before receiving antibacterial therapy (*a*) and after receiving therapy (*b*). The readout of electrochemical sensors (sensitive to certain ions) in the content of breast milk are marked on the axes of the radial diagram. As can be seen from the diagrams, after receiving antibacterial therapy the content of hydrogen ions increased significantly, and a slight increase in the content of fluorine and a decrease in the content of sodium and calcium can also be noted

The results of the conducted studies show that the “digital image” of breast milk of each of the subjects during the second semester of lactation in a healthy state has its own individual characteristics. Diseases modify it. It was found that the “digital images” of breast milk of women who have had diseases differ significantly from the diagrams of breast milk of healthy women. The capabilities of the studied sensory system to form individual “digital images” of the breast milk were used to form algorithms for training the sensory system to recognize the functional state of the mother-newborn system.

The principal component method.

Two multidimensional matrices of the form “objects-signs” were formed, where the rows correspond to the test objects, and the columns correspond to the features - the registered numerical standardized readings of each of the seven electrochemical sensors.

The first matrix was made up of breast milk samples, the second matrix contained data from the analysis of ultra-pasteurized and whole cow’s milk. Since each test object in the matrix is described by a high-dimension vector, the dimension of the data space should be reduced with minimal loss of their informativeness at the subsequent stage of information analysis [7].

In addition, the task of visualizing multidimensional data was set. Traditionally, dimensionality reduction methods are used for this. Such methods are based on the analysis of the variances of the array data in coordinate directions or methods of finding a vector in the studied multidimensional space, in the direction of which the variance is maximal [8]. Currently, one of the most modern method of solving the problem of compressing amount of information is the principal component method (PCA), which allows the transition from the original coordinate system to a new orthogonal basis in the multidimensional space under consideration [9].

The principal component method is based on the processing of the correlation matrix, namely, the search for eigenvalues and eigenvectors. The selection of the first two components of PC1 and PC2 eigenvectors corresponding to the largest eigenvalues, the construction on the plane (PC1, PC2) as points of “digital images” of milk and the analysis of their relative positions constitute a complete cycle of analysis. The number of components (as well as the sum of all the obtained eigenvalues) is equal to the number of initial features. To calculate the percentage of variance per component, each variance related to each component is divided by the sum of the cumulative total variance for all components. Then the components are discarded so that the proportion of dispersion of the remaining components is 80–90% [10]. All components together make up 100% of the total variance of the initial features.

After calculations, it was found that the first and second main components of PC1 and PC2 together explain 73.1% of the initial data. The visualization of the proportion of the variance explained by different components is shown in Fig. 4.

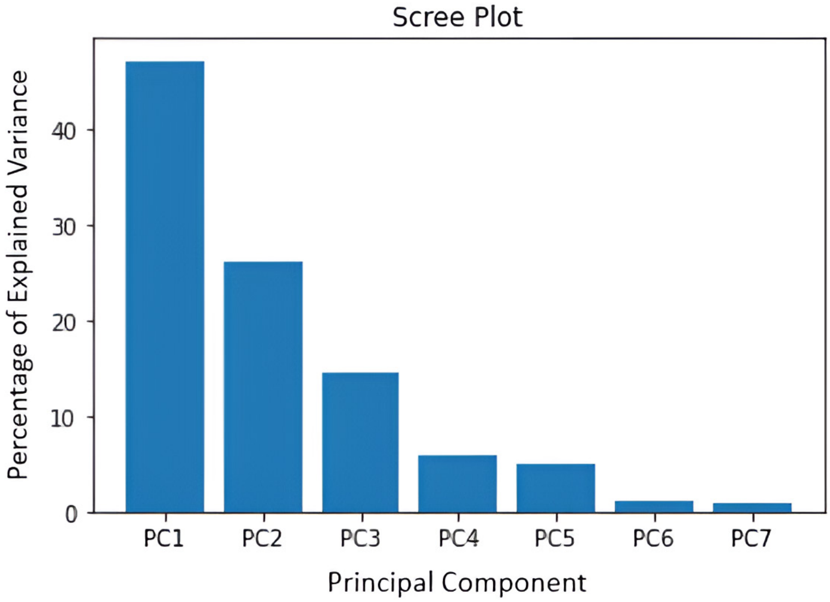

Fig. 4. Contributions of each component to the overall variability of the initial data (features). The first 7 components are presented. The features are registered numerical readings of electrochemical sensors

Obviously, the first and second main components (PC1 and PC2) make the greatest contribution. Thus, only 2 main components can be left.

The observations were visualized in a new space of reduced dimension in the axes of the first two main components. The result is shown in Fig. 5. Each tested biological medium (breast or cow's milk) is characterized by a two-dimensional point in a Cartesian rectangular coordinate system. The resulting point can be attributed to one of the formed clusters.

Fig. 5 shows "digital images" of biological media of breast and cow's milk projected onto the plane of the first two main components, representing the numerical readout of the electrochemical sensors.

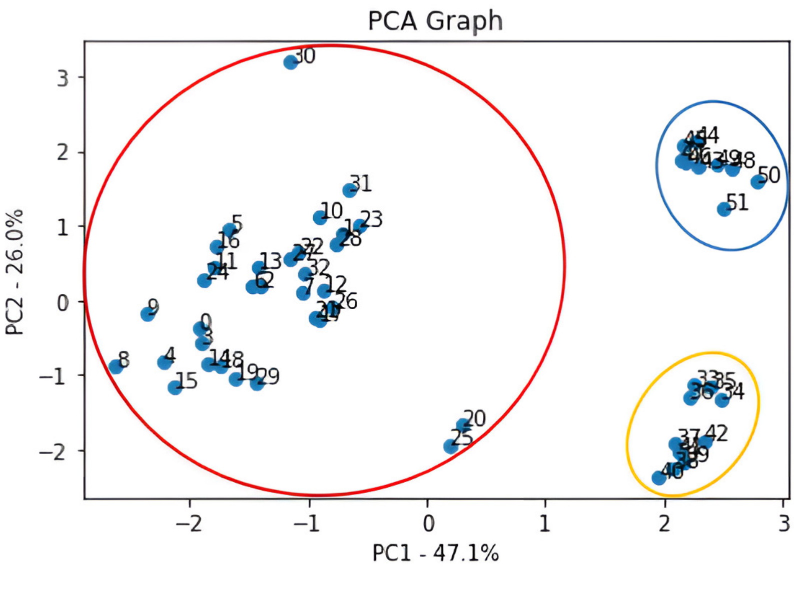

Fig. 5. "Digital images" of biological media of breast and cow's milk projected onto the plane of the first two principal components. The biggest cluster highlighted in red is breast milk, upper blue is whole milk, lower yellow is ultra-pasteurized milk

The cluster highlighted in red is breast milk (milk samples were taken from each subject at the beginning and at the end of feeding), blue is whole milk, yellow is ultra–pasteurized milk.

During the research the following trends were identified:

1. There is a tendency for biological media to group. That indicates their similarity according to certain criteria.

2. The groups of whole and ultra-pasteurized milk are greatly different from each other and from breast milk. This is visually displayed as three different groups of points in the space of the first two main components.

Conclusion

A model of an intelligent sensor system for imaging biological medium based on the analysis of the output signals of a set of polyselective sensors with cross-sensitivity has been developed, manufactured and tested. It has been experimentally shown that the "digital image" of breast milk of subjects in a healthy state has its own individual characteristics. Diseases modify it. It has been established that the "digital images" of breast milk of women who have had diseases differ significantly from the "digital images" of breast milk of healthy women.

Using of projection methods to build a "digital image" of biological environments is quite promising and allows getting the result in a simple visual form as a set of points on the plane of the first two principal components. The study shows the possibility of ranking milk by similarity groups.

The research results indicate the high efficiency of a new methodological approach to solving the problems of identification and analysis of the state of complex multicomponent biological medium, namely the qualitative ionic composition of breast milk, based on new intelligent methods of electrochemical analysis. The presented intelligent sensor system can be used to create a new generation of diagnostic systems for medical purposes.

Acknowledgments

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