A multidimensional approach to assessing the elemental status of an organism

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Abstract. Multidimensional space is a convenient means of representing large amounts of information. This fully applies to information on the elemental status of population groups. The novelty of the approach of this study is based on the fact that the totality of the weight parts of all elements of the periodic table together makes up the weight of a person. In a multidimensional space, organisms with the same weight have the same sum of coordinates and are located on one hyperplane. Since for any norms it is important to have a ratio between the quantities that reflect the content of the chemical elements – a ray becomes the standard, for each point of which the ratio between the coordinates is observed. Large amounts of data will adequately represent the proximity an organism to one or another class, that is, increasing the accuracy of diagnosing the elemental status. The algorithm for diagnosing, therefore, should include finding the corresponding hyperplane, the point of intersection with the ray and determining the proximity to this point.

1. Introduction

With the advent of modern technology, diagnostic possibilities extend greatly. Volumes of the analyzed information grow, including the data of functional, biochemical, genetic and molecular studies, which greatly complicates the work of the doctor. Using of multidimensional space as a way to represent a large amount of heterogeneous information is the most rational. In the multidimensional space, the target area of the "healthy organism" and the current state of the subject are determined. This allows you to compare the methods in terms of their effectiveness and helps to purposefully formulate a strategy of recovery treatment for a particular patient. The application of this method makes it possible to take into account the adaptation processes in assessing the health status of the individual, including relying on the accumulated data on the elemental status – one of the fundamental indicators of health [1–3]. For this purpose, in the multidimensional space, as target, it is possible to identify local areas reflecting the adaptation of the indigenous population to the conditions of a particular biogeochemical province.

The study is devoted to the development of a multidimensional model of space in which it is possible to identify regional norms of elemental status for different age and gender categories of the population. Now there is a problem of diagnostic evaluation and complex interpretation of a huge number of health indicators. In this regard, there is pressing need for data systematization and automation of the processing of data, and development of a computer support system for making medical decisions. A large amount of objective information, on the one hand, allows to rationalize the diagnostic process and formulate a treatment strategy, and on the other hand, the absence of a systematizing model makes a complete analysis of the obtained research results impossible.
This contradiction allows to formulate a problem of imperfection of the theoretical foundations for the development of tools for diagnosing the elemental status of the organism. It is necessary to create a model for multidimensional and systematic representation of available information using methods of multidimensional geometry.

2. Theory
Multidimensional geometry is associated with pattern recognition and with automatic classification almost from the moment of its origin. The method of the multidimensional feature space used in the classification is one of the most important in the theory of pattern recognition in our time. It is most often associated with the decision of the question of the proximity of a given object displayed in a multidimensional space with a point with coordinates equal to the values of the characteristics for the so-called standard – the center of the cloud of points reflecting the objects of the given class and grouped by virtue of a common property or finding a given point in a given region.

Ideas of multidimensional space were expressed in the 18th century by I. Kant and J. D'Alembert, and multidimensional geometry was constructed by A. Cayley, G. Grassmann, and L. Schleiff in the before last century [4]. The advantage of the method with small dimensions is visualization. Even three-dimensional space can be illustrated in two-dimensional paintings, drawings and figures, which greatly helps the study. However, with more measurements, the visibility of this method is lost. Nevertheless, the multidimensional representation [5], supplemented for example by the agent-oriented approach [6], in which the patient, the method of treatment and the physician play an active role, have great prospects.

In this paper we consider a problem in which objects belonging to a given class have the same relationship between coordinates, and as the general property the sum of all coordinates is chosen. This formulation follows, for example, from the practical task of determining the elemental status of a person, in which the weight components of all elements of the periodic table are plotted, then the sum of all the coordinates of a single point is equal to the weight of a person.

Investigating this question, we note that points with the same sum of coordinates are located on the plane described by equation

$$\sum_{i=1}^{n} x_i + D = 0$$

A distinctive property of this formula is the unit coefficients for all coordinates.

For two coordinates, this property is possessed by a straight line that runs at an angle of 45 degrees to the coordinate axes. The figure shows that for each point of this line, one coordinate increase results in an equal reduction of the other, so that the sum will be saved.

Similar arguments in three-dimensional space lead to a plane inclined at identical angles to all coordinate planes.

On the other hand, the locus of points having the same relationship between coordinates is a ray emanating from the origin, described by equation

$$x_i = t x_{Ai}$$

where $x_{Ai}$ are the components of the radius of the vector specifying the line, $t$ is an arbitrary parameter that allows one to run through this ray.

In order to classify a given point $B$, that is, to answer the question whether the given point belongs to the class given by the ray (2), it is necessary first to construct a plane with the same sum of coordinates as the point $B$. To do this, we substitute its coordinates in equation (1) and we find the parameter $D$. Finally, the equation of the plane is

$$\sum_{i=1}^{n} x_i - \sum_{i=1}^{n} x_{Bi} = 0$$
Now it is necessary to find the point \( C \) of intersection of the given ray with the plane defined in this way, for which we substitute the coordinates (2) in equation (3) and determine the required point \( C \) in terms of the parameter \( t \)

\[
t = \frac{\sum_{i=1}^{n} x_{Bi}}{\sum_{i=1}^{n} x_{Ai}}
\]

(4)

Now it seems that you can simply enter the degree of proximity of a given point to the point of intersection (or the point's entry into the circle of a given radius with the center at the intersection point, see the picture) as a criterion for belonging to a given class and thereby solve the question of its belonging to a given class. However, this method works only when the values of all the coordinates are close to each other. In the case when there is at least one coordinate with a small absolute value, the circle in the figure ceases to be a circle.

It would seem that this problem can be solved by scaling, but this breaks the constraint (1), in which the coefficients at all coordinates must be unitary. The only way out of the situation that emerges can be a coordinate-wise criterion for assigning a given point to a selected class.

In this case we take the coordinates of the intersection point and for each of them we set the degree of proximity, the latter should depend on the absolute value of the coordinate, for example, in a linear fashion. The slide shows that the range of occurrence is greater, the larger the absolute value of the coordinate is.

The criterion for the occurrence of a point in a given class will take the form of a system \( n \) of non-strict inequalities of the type

\[
|x_{Bi} - x_{Cj}| \leq \alpha x_{Cj}, \text{ with } i = 1, ..., n
\]

(5)

The question of the occurrence of a point in a given class is solved positively only when all these non-strict inequalities are satisfied.

3. Method

We will especially discuss the problem of determining the standard of the class in view of the fact that it is not a point, as in most often happens, but a ray. Objects belonging to a given class usually form a cloud of points and there are two possible ways of constructing the desired ray.

The first is based on this or that averaging and carrying out the ray from the origin to the resulting averaged point.

\[
x_{Ai} = \frac{\sum_{i=1}^{n} x_{i}}{n}
\]

(6)

The second implies carrying out a ray through a cloud of points using the least squares method, that is, so that the sum of the squares of distances from points to the ray is minimal.

Let the ray be described by equation (2). Then for each \( j \)-point from the cloud it is necessary to find the shortest distance to this ray. First, we construct a plane passing through this point perpendicular to the given ray

\[
\sum_{i=1}^{n} x_{Ai} x_{i} - \sum_{i=1}^{n} x_{Ak} x_{kj} = 0
\]

(7)

We find the intersection point of the ray with the plane, given by the value of the parameter \( t \) from equation (2)

\[
t = \frac{\sum_{i=1}^{n} x_{Ai} x_{ij}}{\sum_{i=1}^{n} x_{Ai}^2}
\]

(8)

Now you can find the distance between the \( j \)-point and the intersection point

\[
d = \sqrt{\sum_{i=1}^{n} (x_{ij} - \frac{\sum_{i=1}^{n} x_{Ai} x_{ij}}{\sum_{i=1}^{n} x_{Ai}^2} x_{Ai})^2}
\]

(9)
Then the sum of the squares of the distances to all m points of the cloud will be

\[ F(x_{Ai}) = \sum_{i=1}^{m} \sum_{j=1}^{n} \left( x_{ij} - \frac{\sum_{j=1}^{n} x_{Ai} x_{ij}}{\sum_{i=1}^{n} x_{Ai}^2} x_{Ai} \right)^2 \] (10)

Differentiating this sum over each of the components of the vector forming the ray and equating the derivative to zero, we obtain n equations for the determination of all components.

\[ \frac{\partial F(x_{Ai})}{\partial x_{Ai}} = \sum_{i=1}^{m} \sum_{j=1}^{n} 2 \left[ x_{ij} - \frac{\sum_{j=1}^{n} x_{Ai} x_{ij}}{\sum_{i=1}^{n} x_{Ai}^2} x_{Ai} \right] \times \frac{2(\sum_{i=1}^{n} x_{Ai} x_{ij}) x_{Ai} - (x_{ij} + \sum_{i=1}^{n} x_{Ai} x_{ij}) \sum_{i=1}^{n} x_{Ai}^2}{(\sum_{i=1}^{n} x_{Ai}^2)^2} = 0 \] (11)

To make zero, this expression can be either expressed in square brackets, or the numerator of a fraction. In the first case it is necessary to solve a system of n square equations

\[ x_{ij} x_{Ai}^2 + (\sum_{k=1,k\neq i}^{n} x_{Ak} x_{k}) x_{Ai} - x_{ij} = 0, \quad i = 1, \ldots, n \] (12)

In the second case we arrive at a system of cubic equations

\[ x_{ij} x_{Ai}^3 + (\sum_{k=1,k\neq i}^{n} x_{Ak} x_{k}) x_{Ai}^2 - (\sum_{k=1,k\neq i}^{n} x_{Ak} x_{k}) x_{Ai} - x_{ij} \sum_{k=1,k\neq i}^{n} x_{Ak} x_{k}^2 - (\sum_{k=1,k\neq i}^{n} x_{Ak} x_{k})^2 = 0, \quad i = 1, \ldots, n \] (13)

Obviously, these equations can be solved numerically for large dimensions.

A specific task should suggest which of these ways to choose for practical use. For the task formulated at the beginning of the report, the second method is more suitable, in spite of its cumbersome nature. This is due to the heterogeneity of the statistical material with respect to the weight of the subjects.

4. Data and modeling results

The mathematical model is based on an extensive database, formed as a result of a comprehensive clinical and physiological examination and determination of the elemental composition of the biosubstrates of 910 persons of different sex and age. The determination of the content of chemical elements in biosubstrates was carried out by atomic-emission and mass-spectrometry methods. Using the Elan 9000 mass spectrometer (Perkin Elmer, USA), the content of As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Se, Si, Sn, Ti, V was determined and the Optima 2000 V atomic emission spectrometer (Perkin Elmer, USA) was used to determine Ca, Mg, P, Zn, K, Na. In total, data on the content of 24 chemical elements were obtained. The evaluation of physical development was carried out according to recommendations adopted by WHO and uniform anthropometric methods [7] using standard measuring instruments. Anthropometric data were estimated from centile tables developed for this age category [8] and were used to calculate the body mass index (BMI). The results were interpreted according to the developed standards.

For descriptive reasons, the results are shown in figure 1 in relative units. In this case, the norm is reflected by a single line for all elements, the maximum and minimum possible change by two other lines located at a distance from the norm proportional to the parameter \(\alpha\) from formula (5) (in this case, we choose lines with the values 0.5 and 1.5 as these lines).

5. Discussion

The results obtained show that patients 2 and 4 have an excess in content of Ca and Mg. Patient 2 exceeded the concentration of Zn, and patient 4 – Ti. In addition, Patient 5 has an excess of Se.

The lowered concentration of elements is much more widely presented. All patients have a lower concentration of Cd, K, Li, Na, Pb. In four patients out of five, Hg, I, Sn is not sufficient. Three of the five patients have a lower concentration of Cr and Mn, two of them – As, Co, Fe. Finally, patient 1 lacks copper and silicon, patient 5 lacks nickel. This way of presenting information makes it easy to analyze the dynamics of the correction of elemental status by comparing the two graphs before and after taking the drugs. For receiving more complete idea of the general regularities of accumulation or loss of chemical elements in an organism additional axes can be introduced in the multidimensional
space, over which the values of physiological, anthropometric, metabolic and other indices are placed. Then assessing the dispersion of the concentrations of elements, one can find additional symptoms important for the doctor-diagnostician. For example, a small dispersion of the physiological index for some elements in a certain group of patients may indicate a strong correlation.

![Graph of the relative concentration of elements for five patients](image)

**Figure 1.** Graph of the relative concentration of elements for five patients

6. Conclusions
Thus, the multidimensional representation of information and the developed processing algorithm allow to increase the accuracy of the assessing of the elemental status of the organism. The results of this study allow us to create a system to support the assessing the elemental status of the organism, taking into account the ecologo-physiological adaptation. Corresponding algorithms and their software implementation make it possible to minimize the influence of the subjectivity on the accuracy of diagnosis and the formation of the most effective treatment strategy. Thus, the doctor's work is transferred to another level with a quick orientation in a large amount of information about the patient and a justified choice of the strategy for correcting the elemental status.

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References
[1] Burtseva T I, Notova S V, Skalny A V and Zhivaev N G 2015 Modeling of the system of ecological monitoring for the state of selenium status of the population *Innovations and investments* 6 p 149–152
[2] Notova S V, Laryushina I E, Kiyaeva E V, Tsypin A P and Ermakova N V 2016 Elemental status of students of different social groups *Human Ecology* 12 p 43–48
[3] Notova S V, Alidzhanova I E, Kiyaeva E V and Akimov S S 2015 Indicators of psychophysiological adaptation of students of different social groups *Human Ecology* 11 p 41–47
[4] Yushkevich A P 1972 *The history of mathematics (volume 3). Mathematics of the XVIII century* (Moscow: Nauka)
[5] Pishukhin A M and Ahmadyanova G F 2015 Designing an educational route in the competence space *Vestnik of the Orenburg State University* 3 p 21–24
[6] Akhmedyanova G F et al 2013 Agent-oriented approach to modeling the learning process *Fundamental research* 11-3 p 521–524
[7] Martirosov E G and Rudnev S G 2002 Composition of the human body. New technologies and methods Sport, medicine and health 3 p 5–9

[8] Kuznetsova M V and Setko N P 2005 Tables for assessing the physical development of boys and girls aged 17–21 in Orenburg: a manual for physicians (Orenburg)