Method of Ergonomics Assessment of Technical Systems and Its Influence on Operators Heath on Basis of Hybrid Fuzzy Models

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Abstract. The paper discusses the problems of determining the ergonomics level of technical systems based on fuzzy mathematical models. The role of the ergonomics in development and occurrence of occupational diseases using sets of hybrid fuzzy decision was studied. Checking decision rules on representative test samples showed that the resulting system of fuzzy inference rules can solve the problem of predicting the appearance of cochlear jade with confidence above 0.87 early diagnosis of the disease which allows recommending the use of the results obtained in clinical practice.

Keywords: Ergonomics level · Technical systems · Fuzzy logic · Sets of hybrid decision rules · Prediction · Early diagnostics · Occupational diseases

1 Introduction

Numerous scientists research in different countries of the world point that quality of biotechnical systems work of various types and appointments depends on ergonomics of the technical subsystems contacting to the person. The indicators characterizing ergonomics of technical systems have essential impact on the person's functional state and health [1–3].

Considering ergonomics as the complex applied branch of science which is engaged in studying of the person in production environment and design of mechanisms, products and workplaces the most convenient for a worker that means interdisciplinary science should at creation of mathematical models describing influence of technical subsystems on a person, to use methods and means of the system analysis.

The indicators of ergonomics characterizing convenience and comfort of the person, contacting to technical systems, consist of a number of hygienic, anthropometrical, physiological (psychophysical) and psychological characteristics.

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In turn, each of these characteristics (subgroups) is described by a set of diverse indicators.

The ergonomic assessment of TS can be brought both on its separate components and on all system with use of tool, settlement and expert methods.

Traditionally an assessment of ergonomic indicators is given by comparison of defined values to the set or basic values. For basic values are often taken the values given in the state and industry standards, in sanitary standards and the rules, received in the best conventional products, etc.

As the complex generalizing level indicator of an ergonomic product is often used coefficient of working conditions of K_{WC} which is defined by work of coefficients of change of labor productivity ΔP_i- at change i- of ergonomic characteristic of a product. Often expert assessment of ergonomics of TS is carried out, using traditional system of mark estimates, and also a method of the alternative principle, defining compliance or discrepancy of the chosen indicator to the accepted norms. In the last option, the general assessment of level of ergonomics is defined by the relation of ergonomic properties number conforming to the chosen requirements to total number of the studied ergonomic properties. The analysis of the listed and other methods of an assessment of the TS ergonomic properties and the indicators used for this purpose shows that they don't answer, with sufficient degree of accuracy, a question of interrelation of level of ergonomics with a functional state and a health state of operators, changing from their interaction with the relevant technical systems.

It is connected first of all with complexity of receiving exact analytical models of an assessment of a condition of the person contacting to dynamically changing outside world including TS. On the other hand in a number of works [4–17] it was shown that in bad formalization conditions, at insufficient amount of information and at indistinctly defined classes enough good results will manage to be reached when using methodology of soft calculations, including the theory of fuzzy logic of decision-making and the theory of confidence adapted on the solution of classification tasks taking into account the analyzed structures of data [4, 5, 7, 8, 13, 16–18].

2 Research Methods

We will consider the problem of an assessment of ergonomics of technical systems in two options. As a problem of receiving the continuous scale characterizing the ergonomics level and as a problem of classification (referring to the TS and (or) her subsystems to one of the set ergonomics conditions). We will consider a problem of the health assessment of a person contacting to the HARDWARE as a problem of classification (referring to one of classes of diseases which can be provoked by the contact with the TS (prognosis) and to a class of diseases which are already present at the person and one of the factors promoting this disease was a contact of the person with the TS.

In all these options both the level (class) of ergonomics, and the predicted (defined) disease are determined by the set of the measured signs which in turn are not always accurately defined presented in full structure. Besides the concept of the ergonomics level (class), the prognosis and the diagnosis (especially early) are not usually accurately determined that doesn't allow to get the rigid analytical models of their description. Taking this into account, by the analogy with the theory of the fuzzy decision-making logic, as a Basic Element of the corresponding decision-making models we will enter the characteristic functions of accessory to the concepts of ergonomics level (class) and to the classes of predicted and (or) diagnosed diseases.

We will determine the level of the system's ergonomics as a whole through family of private levels of ergonomics by which the Basic Elements are the functions of ergonomics level $U_s(x_i)$ of the S subsystem of basic xi variables defined by hygienic, anthopometrical, physiological indicators and psychological characteristics with an area of definitions on an interval [0, 1].

At a choice of a form and parameters of the functions of ergonomics level it is necessary to be guided by those purposes for the sake of which the assessment of ergonomics level is made as they can differ a little from each other. For example, priorities can be given to: convenience and comfort of the user, minimization of harm to health on bodies, systems and an organism as a whole; ensured) the maximum reliability of BTS functioning; at the same time to several purposes.

As reference points for the choice of the maximum $U_s(x_i)$ meanings can serve: state and industry standards; sanitary standards and rules; indicators reached in the best technical samples at world and (or) regional levels; maximum level of safety; minimum negative influence on a state of health, etc.

One more reference point at a choice of the maximum $U_s(x_i)$ meanings is the way of their aggregation in final assessment model of ergonomics level of UE for which the condition has to be satisfied

$$UE = F_{ag}[U_s(x_i)] \leq 1, \quad (1)$$

where F_{ag} - functionality of aggregation.

Zero values $U_S(x_i)$ are selected for the values (intervals) of x_i not arranging the user.

The form and the $U_s(x_i)$ parameters can be got out and be specified during carrying out psychophysical, medicobiological, reliability and other experiments defined by the essence of solving tasks which largely define the selection of functional aggregation.

For example, if insufficient ergonomics level of at least one of private components has to be considered as critical on the relation to the whole system (subsystem) of s, the general level of ergonomics is defined by the expression:

$$UE_s = {}^{\min}_{\;i}[U_s(x_i)], \quad (2)$$

If at an expert level the decision that each private indicator of ergonomics level, forming an appropriate level of all subsystem (system) is made, increases the size of UES, then the accumulative interaction formula can be used:

$$UE_s(i+1) = UE_s(i) + UE_s(x_{i+1})[1 - UE_s(i)], \quad (3)$$

where $UE_s(1) = U_s(x_1)$.

In option when private indicators of ergonomics level bring defined (set by experts in the form of weight coefficients α_i) contribution to the general indicator of UE_s, can be used aggregating expression:

$$UE_s = \frac{\sum_{j=1}^{I} a_i * U_s(x_i)}{I}, \qquad (4)$$

where $0 \leq a_i \leq 1$; I - quantity of signs participating in calculation UE_s.

In general, the symptoms x_i can be obtained: by direct measurements on the test TC; measurements carried out on a specially created simulator, by measuring the mental and physical sensations; with known or specially created questionnaires etc. A particular interest is a group of indicators that characterize complex human reactions to its interaction with the TS. For example, such indicators should include the level of emotional stress, mental and physical fatigue, etc.

When passing to the classification levels of ergonomics the index UE_s is selected as the basic variable for membership functions to the selected class ergonomics, such as classes of non-ergonomic products ($\mu_n(UE)$); satisfactory level ($\mu_s(UE)$); good level ($\mu_g(UE)$); advanced level ($\mu_a(UE)$) [1, 2].

Figure 1 shows graphs options of fuzzy classification of level ergonomics.

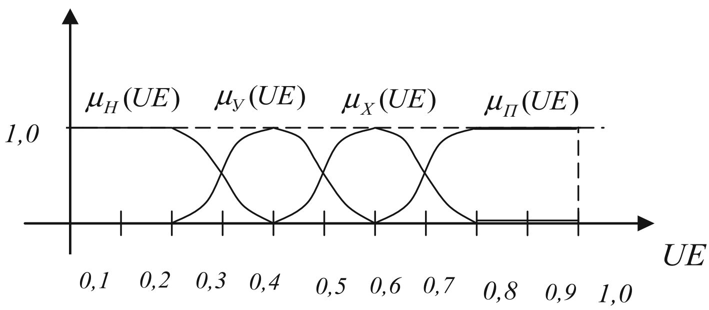

Fig. 1. Option of fuzzy classification of level ergonomics.

Solving the problem of assessing the impact of the level of ergonomics on human health it should be taken into account that significant risk factors for human rights are also the environmental conditions and individual risk factors connected with the characteristics of an organism of a particular person and his lifestyle.

In such feature space problems of health assessment, in particular the problems of forecasting and early diagnosis of diseases and the evaluation of the functional state of a person, as a classification problem, are characterized by incomplete and fuzzy representation of data with ill-defined boundaries intersecting classes, which makes it is necessary to use of fuzzy logic decision-making [4, 7–9, 11, 12, 15, 17–19].

One of the main problems of practical application of this mathematical apparatus is a difficulty to choose the shapes and parameters of elements of fuzzy decision rules and methods of their aggregation in the system of fuzzy decision rules. Most of these problems can be solved by the use of hybrid collectives fuzzy decision rules, the training of which is carried out by using data of exploratory analysis [6–9].

The practice of solving problems of prediction and medical diagnostics has shown that in the conditions of poor formalization with insufficient statistics and the choice of the type of decision rules, united in their groups, it's quite necessary to use a serial sequential analysis of Wald dialog recognition systems and fuzzy logic decision-making in its applications to solve classification problems [7–13]. In turn, the development of the theory of fuzzy logic decision-making has led to the realization that different structures of medical data (that is minimizing the classification errors) fit better for different types of fuzzy decision rules (Minimax surgery [4, 7, 9, 12, 13, 15], the membership function with the basic variable in distance to the separating surfaces and reference structures [10, 11], modifications iterative rules of E. Shortlifa [6, 7, 13, 20], etc.).

It was shown by the work of the Department of Biomedical Engineering South-western State University (BMI SWSU, Russia) that the choice of the elements of fuzzy decision rules and methods/their aggregation with the further joining into fuzzy groups is necessary to carry out, based on the methodology of exploratory analysis [7, 9].

To solve the problems of the synthesis of fuzzy decision rules at the Department of BMI SWSU it was developed a special software package of exploratory analysis with the recommendations of the selection, types of membership functions and methods of their aggregation, depending on the data structure, is characteristic for these or those types of health problems [6, 7, 9, 11]. It was found that for different groups of informative features involved in solving the selected task the most appropriate (in the sense of minimum classification error and professional understanding of the experts) are different types of fuzzy decision rules. Besides, in the space of informative features for its various hot spot may also be necessary to the use different classification rules.

This fact has allowed to make a conclusion about the necessity of developing mechanisms for the synthesis of different types of decision rules and with the further combining them into groups of hybrid solvers.

One of the methodological approaches to such synthesis is proposed in this work as the following sequence of actions.

1. If at the expert level, and in the course of exploratory analysis it is shown the possibility of the formation of the feature space or subspace, where each of the signs of x_i will be represented the system k of gradation x_{ik} and it is possible to make a statistical calculation of relative frequencies to the emergence of second k-th gradatsi i-th feature in alternative classes ω_l and $\omega_r - P(x_{ik}/\omega_l)$, $P(x_{ik}/\omega_r)$ we study the feasibility of using sequential procedure of Wald counting the diagnostic factor according to the formula [7, 9, 21]:

$$\mathrm{DF} = \sum\nolimits_{i=1}^{n} 10\lg\frac{P(x_{ik}/\omega_l)}{P(x_{ik}/\omega_r)}, \tag{5}$$

Where ω_l and ω_r alternative diagnostic classes (ranges); x_{ik} - meaning k-th graduation informative feature x_i, (i = 1,…, n), n - uniformity of feature space; P $P(x_{ik}/\omega_l)$ - a detail displays the k-th gradation of the i-th feature in class ω_l; $P(x_{ik}/\omega_r)$ - in the class ω_r.

When passing to the Valdovsky fuzzy classifier the confidence in the classification ω_l - UGV_l is determined by the membership function to ω_l with a base variable which is defined on a scale of DF [21].

$$UGV_l = \mu_l \tag{6}$$

The advantages of this procedure are the simplicity of the calculations, the absence of specific requirements for the statistical distribution of the studied dimensions and the possibilities of diagnosis with pre-established levels of reliability, even in the absence of some of the measurements. The limits of the application of this method are the requirement for the amount of the training sample and its representativeness, the area existence of uncertainty solutions that for values of α and β approaching unity (high quality classification) can be very wide and the independence of attributes involved in the diagnosis. Nevertheless, even with very pronounced dependence symptoms, the number of errors in serial diagnostic procedure is usually not higher than the settlement.

2. If in the course of analysis of intelligence which actively uses various methods of multivariate data in two-dimensional spaces is seen the quality of classification in these spaces, it is necessary to stop using the dialogue design of two-dimensional classification space [16].

In accordance with this method, a two-dimensional mapping of the space $F = Y_1 * Y_2$ is defined as the Cartesian product of two functions as:

$$Y_1 = \varphi_1(\mathrm{A}, X) \text{ и } Y_2 = \varphi_2(B, X), \tag{7}$$

where φ_1 and φ_2 –the functions of display multi-dimensional objects in two-dimensional space F; A and B - the vectors of adjustable parameters; X = $\{x_1, \ldots, x_n\}$–the vectors of objects of the multidimensional space of informative features.

On the base of learning objects in the space F in semi-automatic mode, with the involvement of domain boundaries are formed of alternative classes are formed ω_l and ω_r out of the minimum number of classification errors in the form of equation: $G_l = F_l(Y1, Y2)$.

In the transition to the fuzzy classification in two-dimensional space, the exact output of the method of designing two-dimensional classification of dialogue spaces is transformed into fuzzy decision on the definition of membership functions $\mu_l(x_i)$ to the class of ω_l with the main variable defined as the distance D_l from the display of the object till two-dimensional boundaries of class ω_l, described by equation glance $G_l = F_l(Y_1, Y_2)$.

We define the confidence of ω_l taken from a dialog design of two-dimensional classification space:

$$UGD_l = \mu_{\omega l}(D_l), \tag{8}$$

Using modifications of the classical fuzzy logic decision-making L. Zadeh focused on solving the problems of classification, the auxiliary functions are used $\mu_{\omega l}(x_i)$ and (or) $\mu_{\omega l}(Y_j)$ to the studied classes conditions ω_l basic variables defined factors of informative features x_i and (or) complex parameters Y_j, calculated informative indices $Y_j = f_j(x_1, x_2, \ldots)$, where f_j is a functional dependence connecting all or part of the informative features with Y_j [6, 7, 12, 13]. The most popular formula, aggregating in the use of membership functions are expressions as:

$$UGN_l = \min_i [\mu_\omega(x_i)], \quad UGN_l = \min_j [\mu_\omega(Y_j)], \quad UGN_l = \min_{i,j} [\mu_{\omega l}(x_i), \mu_\omega(Y_j)] \quad (9)$$

$$UGN_l = \max_i [\mu_\omega(x_i)], \quad UGN_l = \max_j [\mu_\omega(Y_j)], \quad UGN_l = \max_{i,j} [\mu_{\omega l}(x_i), \mu_\omega(Y_j)] \quad (10)$$

$$UGN_l = \max_q \min_i [\mu_\omega(x_i)], \quad UGN_l = \max_q \min_j [\mu_\omega(Y_j)], \quad UGN_l = \max_q \min_{i,j} [\mu_{\omega l}(x_i), \mu_\omega(Y_j)] \quad (11)$$

where q - a number of hyper-volumes covering the class ω_l.

Expressions like (9) should be used if the subspace or feature space all of them are like that no one of them requires the rejection from ω_l.

These rules from the geometrical point of view can be considered as the classification of hitting to the object studied in a fuzzy hyper parallelepiped limited to non-zero values of all using functions.

(10) it is necessary to use the expression, if the existence of any features enough to evaluate hypotheses ω_l.

If in the feature space is the subgroups satisfying (9) and (10), it is recommended to use the rules like (11).

Geometrically, this rule is an approximation of geometrical images corresponding to the studied classes of states by sets of fuzzy hyper-parallelepipeds with numbers q in the class ω_l.

4. If in the course of analysis, it is clear that between the studied classes of states can be dividing hyper plane as $Z_l = F_l(A_l, x_l)$, it is necessary to use the rules like:

$$UGG_l = \mu_{\omega l}[D_l(Z_l)], \quad (12)$$

where F_l –a detection separating the dividing surface (linear, piecewise linear and, square, etc.); D_l (Z_l) - a function of distance from the studied objects to the dividing surface Z_l [2].

5. If a group or all of the informative features x, or complex indicators Y, are like that each of them increases the confidence in the hypothesis (diagnosis W1), so private and (or) total confidence in UGS_l and ω_l recommended determined by the formulas [4, 6–9, 13].

$$\begin{aligned} UGS_l(p+1) &= UGS_l(p) + \mu_\omega(x_i)[1 - UGS_l(p)] \\ UGS_l(p+1) &= UGS_l(p) + \mu_\omega(Y_j)[1 - UGS_l(p)] \\ UGS_l(p+1) &= UGS_l(p) + US_l(p+1)[1 - UGS_l(p)] \end{aligned} \quad (13)$$

where p - the number of iterations per UGS_l; US_l(p + 1) - a private confidence in ω_l on the subspace with index $p + 1$ multi-dimensional feature space.

6. If the electrical characteristics of biologically active points (BAP) are used as the informative features, for example, their electrical resistance are so with the biophysics of these points and the specific output of information on them in the functions

[4, 6, 12, 18, 19, 22–24] it is recommended to use a hybrid decision rule consisting of the exact status and rules of fuzzy decision-making as:

$$\begin{aligned} & if\ \left(Y_{jl}\forall[DZG]_l\delta R_j \geq \delta R_j^{nop},\ else\right. \\ & \left\{UGB_l(j+1) = UGB_l(j) + \mu_{\omega l}\left(\delta R_{j+1}\right)[1 - UGB_l(j)]\right\} \\ & then\ (UGB_l = O), \end{aligned} \tag{14}$$

where Y_{jl}- a list of informative points on disease; ω_l, $\forall$ - community quantifier; $[DZG]_l$- a list of diagnostically significant moments the analysis of which lets to output the set of pathology out of many information; δR_j –a relative deviation of the resistance to the BAP with number j of the nominal exchange rate; δR_j^{nop}- threshold value δR_j, determined during the synthesis of decision rules; $\mu_{\omega e}\left(\delta R_{j+1}\right)$ - function belonging to the class ω_l of the main a base variable δR_{j+1}; UGB_l - confidence in the diagnosis of ω_l, $UGB_l(1) = \mu_{\omega l}(\delta R_1)$.

In relation to feature space of fuzzy rules is distributed depending on the particular object [8, 10].

Alternatively, when each of the rules develops their groups of features, for example, surveys are aggregated according to the rule (13), the data from traditional laboratory studies by the rule got in the processing by the rule (12), the results of the analysis of the energy characteristics of biologically active points –by the rule (14), etc.

In another version of all the informative features are processed by each of the rules included in the team. Mixed option is possible when different decision rules use mixed probably crossed, groups of information signs. Such groups may be created by different principle: by receiving information; by measuring process; by the information content; by the characteristics of data structures, etc.

The options of final aggregation decision rules may be different, too.

In a cautious strategy when a decision has to be taken into account with the necessary viewpoint of all members of the group, considering the possible doubt in the direction of alternative (class ω_l) it is good to use a type of aggregator:

$$UG_l = min\,(UGV_l, UGD_l, UGN_l, UGG_l, UGS_l, UGB_l), \tag{15}$$

If the problem "is not let pass" the objects of the class, or if the degree of confidence to each of the decision rules is about the same it is necessary to check the applicability of (the quality of) the essential rule as:

$$UG_l = max\,(UGV_l, UGD_l, UGN_l, UGG_l, UGS_l, UGB_l), \tag{16}$$

If the use of each of the rules adds a confidence in accepting decisions concerning ω_l hypothesis, it is good to use the iterative procedures for collecting, for example, by E. Shortlifu:

$$UG_l(s+1) = UG_l(s) + UGF_l(s+1) * [1 - UG_l(s)], \tag{17}$$

where s –a number of iterations in the calculation of confidence UG_l in ω_l classification;

$$UGF_l = (UGV_l, UGD_l, UGN_l, UGG_l, UGS_l, UGB_l), UG(1) = UGF(1) \quad (18)$$

In practice, there are tasks with the complex structure of datas when in the final decision rule it is necessary to combine the options of aggregation by the rules (15), (16), (17).

3 Practical Example

As an example, let's examine the problem of estimating the level of ergonomics such vehicles as the tractor. As the primary characteristics used for estimating the level of ergonomic cabin at the expert level were selected: the temperature in the cabin (x_1); the noise level in the cabin (x_2); the average load on the arm (x_3); the average load on the legs (x_4), the body vibration (x_5), the vibration on the hands (x_6), the vibration on the legs (x_7), the angle of inclination of the seat (x_8), height (x_9), distance to the main controls (x_{10}); the level of mental and emotional stress connected with the workplace (x_{11}) and the level of chronic physical fatigue (x_{12}) [1, 2].

For the construction of private functions on the basis of ergonomic conditions $x_1 - x_{10}$ two approaches were chosen: the method of psychophysical scaling and the construction of specialized test questionnaires.

The results of L. Kamozina were used to select the analytic expressions and graphing private level functions ergonomics. In this work there are the psychophysical scale sensations of a driver depending on the physical parameters of the effects. For example, for a characteristic x_1 - the temperature in the cabin is obtained psychophysical scale as:

$$S_T = \left(8,93 * 10^{-4} * T^b\right),, \quad (19)$$

T - physical temperature; S_T - thermal sensations of the probationer; b - the exponent depending on the individual subject's psychophysics, lying in the range of 1.96… 3.67. Studies have shown that most of the subjects tested as the most comfortable temperature call interval 22… 24° C [2].

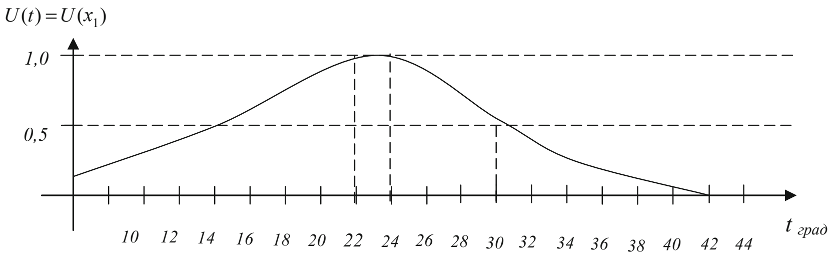

Fig. 2. Schedule of the level of ergonomics in terms of temperature

Considering the Delphi method, according to a survey of the expert group of 7 people, was built a private function in terms of the level of ergonomics average temperature in the cabin (see Fig. 2).

4 Conclusion

1. The method of indistinct models' synthesis for the description and the evaluation of the ergonomic level of technical systems based on aggregation of such diverse indicators as direct measurement results of ergonomic parameters; physical modeling, psychophysical scaling and test poll allows to estimate the ergonomic level of both separate elements and knots, as well as of technical systems in general and to consider their influence on the health of operators working in biotechnical systems.
2. The synthesized system of indistinct output rules allows to solve problems of forecasting the cochlear neuritis emergence with confidence higher than 0.9 in early diagnosis of this disease - with confidence not worse than 0.87 that allows to recommend the use of the received results in medical practice. In [25–31] several mathematical models for the interaction of the internal and biological active points of meridian structures have been proposed. The analysis of these models allows the specification of a list of occupational diseases for which reflex diagnostics and reflex therapy methods are most effective and also allows increasing the effectiveness of these procedures. It is shown that good results for the prediction and early diagnosis of diseases from the reaction energy of biologically active points (acupuncture points) are obtained using fuzzy logic decision making.

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