ISSN 2278-3091
Volume 8, No.6, November – December 2019
International Journal of Advanced Trends in Computer Science and Engineering
Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse89862019.pdf
https://doi.org/10.30534/ijatcse/2019/89862019

Information Technologies of the Processing of the Spaces of the States of a Complex Biophysical Object in the Intellectual Medical System HEALTH

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ABSTRACT

This article proposes information technologies for processing the state spaces of a complex biophysical object in an intelligent medical system HEALTH, which made it possible to improve the intelligent decision-making system in the field of cardiology by selecting a probable set of diagnoses with the appropriate coefficients of confidence and gradual refinement of it. Software implementation of the state space processing of a complex biophysical object in an intelligent medical system HEALTH implemented in an object-oriented programming environment. Laboratory operation of the hardware and software of the intelligent medical system HEALTH confirmed the high probability of making objective decisions in the medical subject area. It has been determined that an intelligent medical system has been developed HEALTH can be used both in clinical practice by novice specialists and during training of students and doctors in advanced training institutes.

Key words: Information Technologies, State of Space, Biophysical Object, Intelligent Medical System, Decision Making, Cardiology, Cardiovascular Disease, Diagnosis, Confidence Factor

1. INTRODUCTION

Intensive development and implementation in all spheres of human life of information technologies contributes to accelerating the processes of information exchange and faster response to changes in the situation, prompt analysis of data and making an adequate decision [1]–[3]. Modern systems theories regard any object as a coherent system characterized by triple interdependence:

– the interconnection of all parts in the system;
– dependence of each of its parts on the system;
– dependence of the whole system on its parts.

There are objective laws for the operation of complex systems, so they must be managed in accordance with these systemic laws.

From the set of complex systems it is possible to distinguish the system which consists of the set of spaces of states of a complex biophysical object (human), for which the characteristic of each of the states of the system object is essential.

The state of the system is defined as the set of variables needed to describe a complex system at a certain point in time according to the task of the research. The state variables of a system in a discrete system change instantly in different periods of time, and in continuous – continuously in time [4].

The complex system [5] is called such a system, the research of which must take into account the presence of a large number of interrelated and interacting elements. Complex systems operate under the conditions of a large number of random factors [6], inaccuracy and uncertainty [7], functional and territorial distribution.

Today, the use of intelligent decision-making (IDM) technologies to solve voluminous, difficult-to-formalize tasks in a variety of subject areas, such as intelligent medical diagnostics of the human space, is of great importance [8]. Such problems, as a rule, are characterized by the absence or complexity of formal algorithms for solving [9], incomplete and unclear source information [10], [11], unclear goals achieved. These features lead to the need for use in the decision-making process of knowledge obtained from a human expert in the subject area, and the development of IDMs, which collect and manage this knowledge [8], [9], [11], decide on the optimal way to achieve goals in the conditions of incompleteness and fuzziness [6], [11].

An analysis of recent publications [12]–[19] has shown that the issues under consideration have not been sufficiently researched, and that scientific results are not in all cases brought to practical implementation and need further research, which confirms the relevance and importance of theoretical and practical results obtained in the work.

2. ANALYSIS OF THE SUBJECT AREA AND STATEMENT OF THE RESEARCH PROBLEM

The formulation of a decision problem involves the following components: there are a plurality of deterministic, fuzzy, or probabilistic parameters characterized by the state of the object of research, the truth of which can be established with a certain degree of certainty, and the set of variants of decisions that are known in a related way to the state of the object research. It is necessary to get a reliable decision and calculate the degree of confidence in this decision.

An intelligent medical system has been developed HEALTH should be based on the knowledge by which it can make assumptions about possible diagnoses, make recommendations to clarify the decision, and make decisions whose level of competence is not lower than the level of the expert person.

Tasks for the intelligent medical system HEALTH is [5]:

– acceptance of a set of formal and heuristic knowledge from high-level specialists;

– use of knowledge by other specialists in this subject area or related professions;

– providing consultations aimed at increasing the level of decisions made.

Intelligent systems must function with the following components [5]:

– a knowledge base that incorporates expert knowledge, experience and intuition;

– databases;

– block logic output;

– explanatory block;

– user friendly interface.

If the system operates under conditions of uncertainty and severe constraints on resources, then there is a need to include additional modules in its structure [6].

Ways to improve the reliability of rapid assessment of patients' conditions for certain cardiovascular diseases should be proposed through the use of decision-making systems, as well as the intellectualization of decision-making procedures.

Since the choice of decision in medicine is made in the context of uncertainty about the symptomatology, which in fact implies consideration of a broader list of potential solutions, it is advisable to limit the initial set of potential decisions based on fuzzy preference.

Thus, the realization of this task is to determine some subset of decisions on the basis of formal evaluation and formation of each decision using the provisions and ideas of computational intelligence [9]–[11].

Intellectual decision-making tools in the medical system developed in the framework of this research HEALTH should provide [5]:

– the formation of patient data in the dialog mode, that is, the formation of medical history;

– carrying out an operative assessment of conditions by medical history or medical history from the archive;

– obtaining explanations of the data on the basis of which the final decision was made;

– view medical history from the archive;

– elimination of false information;

– formation of decisions with certain coefficients of certainty and drawing up of a medical opinion on treatment of the detected disease.

In the intelligent medical system Health it is necessary to use developed [4]–[11] and existing approaches [12]–[19], to carry out intelligent processing and evaluation of data, to provide the user with full information for decision-making.

3. METHODICAL ASPECTS OF STATE SPACE PROCESSING OF A COMPLEX BIOPHYSICAL OBJECT IN THE MEDICAL INTELLECTUAL SYSTEM HEALTH

Let there be a multitude of medical diagnostic features $\tilde{P}_j,\ j \in J$ for a multitude of diagnoses $\{D_j\},\ j \in J$ [6].

The whole set of signs $\tilde{P}_j,\ j \in J$ is divided into 4 groups by family property $\tilde{S}_j$, $\tilde{F}_j$, $\tilde{L}_j$, $\tilde{D}\tilde{S}_j$, that correspond to the four-stage state space processing of a complex biophysical object.

For each value of the set of features $\tilde{P}_j,\ j \in J$ its membership function is specified μ_j to each specific diagnosis $\{D_j\},\ j \in J$, that is, we get some plural

$$\{\mu_j(x)\},\ j \in J\ . \tag{1}$$

Confidence coefficients are set KU_j signs in diagnoses $\{D_j\},\ j \in J$, that is, we get some plural

$$\{KU_j(k)\},\ j \in J\ . \quad (2)$$

Some provisions of the approach using the equivalence of the values of the confidence coefficients and the membership functions are presented in [6], but the data of the study do not take into account the particular limitations and properties of the system.

Based on

$$|\{\mu_j(x)\}|=|\{KU_j(k)\}|\,, \quad (3)$$

it can be argued that there is an equivalence of the values of the confidence coefficients and the membership functions used in this study when solving the state space problem of complex biophysical object:

$$\begin{aligned}&\forall\mu_j(x),\forall KU_j(k),\mu_j(x)\in\\&\in\{\mu_j(x)\},KU_j(k)\in\\&\in\{KU_j(k)\big|\mu_j(x_0)=KU_j(k_0),\end{aligned} \quad (4)$$

$$\begin{aligned}&\forall\Delta\mu_j(x),\ \forall\Delta KU_j(k),\ \Delta\mu_j(x)\in\{\Delta\mu_j(x)\},\\&\Delta KU_j(k)\in\{\Delta KU_j(k)\}\big|\Delta\mu_j(x_0)=\Delta KU_j(k_0),\end{aligned} \quad (5)$$

moreover, it is necessary to consider that $\mu_j(x_0)$ is the upper bound of the estimate $KU_j(k_0)$

$$\mu_j(x_0) \ge KU_j(k_0)\,, \quad (6)$$

and $\Delta\mu_j(x_0)$ is accordingly the upper bound of the estimate $\Delta KU_j(k_0)$

$$\Delta\mu_j(x_0) \ge \Delta KU_j(k_0)\,. \quad (7)$$

The values (6) and (7) derive directly from the essence of fuzzy logic and the coefficient of confidence [6].

Thus, each diagnostic characteristic [6], [10] in the group is assigned a coefficient of confidence $\{KU_j(k_0)\}$, which matches, as research has shown, with membership function $\{\mu_j(x_0)\}$ values of the trait $\tilde{P}_j,\ j \in J$ to diagnoses $\{D_j\},\ j \in J$, that is

$$\mu_j(x_0) \approx KU_j(k_0)\,, \quad (8)$$

$$\Delta\mu_j(x_0) \approx \Delta KU_j(k_0)\,. \quad (9)$$

Then, if there is some set of membership functions $\{\mu_j(x_0)\}$, as well as the set of analytical dependencies that determine the confidence coefficients $\{KU_j(k_0)\}$, then with some approximation it will be executed (8) [6], [10].
For example, if in some cases we get the value of the function $\mu_j(x_0) = 0.82$, then the value of the confidence coefficient can be defined as (6) and given (8) the confidence coefficient $KU_j(k_0) \approx 0.82$, that is, it does not exceed the value of the membership function $\mu_j(x_0)$.

Determination of the coefficient of confidence $KU_j(k)$ in diagnoses $\{D_j\},\ j \in J$ on all grounds $\tilde{P}_j,\ j \in J$, belonging to a specific selected group $\tilde{S}_j$, $\tilde{F}_j$, $\tilde{L}_j$, $\tilde{D}\tilde{S}_j$, the ordering of the decreasing significance is carried out according to the expressions [6], [10]:

– for the group $\tilde{S}_j$ we define significant (not null) values of the membership functions $\mu_b(\tilde{S}_b)$:

$$\tilde{S}_j = \bigcup_{b=1}^{B} Pr_{\tilde{s}} \tilde{S}_b \to \mu_b(\tilde{S}_b)\,, \quad (10)$$

where $Pr_{\tilde{s}}$ – parameters that match the selected group $\tilde{S}_j$;

$\tilde{S}_b$ – the value of the selected parameter $Pr_{\tilde{s}}$ from the group $\tilde{S}_j$;

– for the group $\tilde{F}_j$ we define significant (not null) values of the membership functions $\mu_d(\tilde{F}_d)$:

$$\tilde{F}_j = \bigcup_{d=1}^{D} Pr_{\tilde{f}} \tilde{F}_d \to \mu_d(\tilde{F}_d)\,, \quad (11)$$

where $Pr_{\tilde{f}}$ – parameters that match the selected group $\tilde{F}_j$;

$\tilde{F}_d$ – the value of the selected parameter $Pr_{\tilde{f}}$ from the group $\tilde{F}_j$;

– for the group $\tilde{L}_j$ we define significant (not null) values of the membership functions $\mu_q(L_q)$:

$$\tilde{L}_j = \bigcup_{q=1}^{Q} Pr_{\tilde{l}} \tilde{L}_q \to \mu_q(L_q)\,, \quad (12)$$

where $Pr_{\tilde{l}}$ – parameters that match the selected group $\tilde{L}_j$;

– $\tilde{L}_q$ – the value of the selected parameter $Pr_{\tilde{l}}$ from the group $\tilde{L}_j$;

– for the group $\tilde{D}\tilde{S}_j$ we define significant (not null) values of the membership functions $\mu_h(\tilde{D}\tilde{S}_h)$:

$$\tilde{D}\tilde{S}_j = \bigcup_{h=1}^{H} Pr_{\tilde{d}\tilde{s}} \tilde{D}\tilde{S}_h \to \mu_h(\tilde{D}\tilde{S}_h)\,, \tag{13}$$

where $Pr_{\tilde{d}\tilde{s}}$ – parameters that match the selected group $\tilde{D}\tilde{S}_j$;

$\tilde{D}\tilde{S}_h$ – the value of the selected parameter $Pr_{\tilde{d}\tilde{s}}$ from the group $\tilde{D}\tilde{S}_j$.

Determination of the coefficient of confidence $KU_j(k)$ given (8) and (9)–(13) will have the form:

$$KU_j(k) = \frac{\sum_{b=0}^{B}\mu_b(\tilde{S}_b)}{|\tilde{S}_b|} \vee \frac{\sum_{d=0}^{D}\mu_d(\tilde{F}_d)}{|\tilde{F}_d|} \vee \frac{\sum_{q=0}^{Q}\mu_q(\tilde{L}_q)}{|\tilde{L}_q|} \vee \frac{\sum_{h=0}^{H}\mu_h(\tilde{D}\tilde{S}_h)}{|\tilde{D}\tilde{S}_h|}, \tag{14}$$

where $\mu_b(\tilde{S}_b)$, $\mu_d(\tilde{F}_d)$, $\mu_q(\tilde{L}_q)$, $\mu_h(\tilde{D}\tilde{S}_h)$ – affiliation functions for each attribute, corresponding to groups $\tilde{S}_j$, $\tilde{F}_j$, $\tilde{L}_j$ та $\tilde{D}\tilde{S}_j$, ordered by decreasing importance;

$|\tilde{S}_b|$, $|\tilde{F}_d|$, $|\tilde{L}_q|$, $|\tilde{D}\tilde{S}_h|$ – the power of the sets of significant features for which $\mu_b(\tilde{S}_b) \geq \varepsilon^*$, $\mu_d(\tilde{F}_d) \geq \varepsilon^*$, $\mu_q(\tilde{L}_q) \geq \varepsilon^*$, $\mu_h(\tilde{D}\tilde{S}_h) \geq \varepsilon^*$, ε^* – some minimum threshold, and

$$|\tilde{S}_b| \subset \tilde{S}_j, |\tilde{F}_d| \subset \tilde{F}_j, |\tilde{L}_q| \subset \tilde{L}_j, |\tilde{D}\tilde{S}_h| \subset \tilde{D}\tilde{S}_j\,. \tag{15}$$

Determination of the coefficient of confidence at some interval $\Delta KU_j(k)$ given (9), it has the form:

$$\Delta KU_j(k) = \frac{\sum_{j=0}^{n}\Delta\mu_j(\tilde{S}_j)Pl_i}{\sum Pl_i} \vee \frac{\sum_{j=0}^{n}\Delta\mu_j(\tilde{F}_j)Pl_i}{\sum Pl_i} \vee \frac{\sum_{j=0}^{n}\Delta\mu_j(\tilde{L}_j)Pl_i}{\sum Pl_i} \vee \frac{\sum_{j=0}^{n}\Delta\mu_j(\tilde{D}\tilde{S}_j)Pl_i}{\sum Pl_i}, \tag{16}$$

where $\Delta\mu_j(\tilde{S}_j)$, $\Delta\mu_j(\tilde{F}_j)$, $\Delta\mu_j(\tilde{L}_j)$, $\Delta\mu_j(\tilde{D}\tilde{S}_j)$ – the membership functions are given at intervals by each attribute and correspond to groups $\tilde{S}_j$, F_j, $\tilde{L}_j$ and $\tilde{D}\tilde{S}_j$;

Pl_i – elementary area corresponding to the obtained intersection region of all membership functions given at intervals by each trait and groups $\tilde{S}_j$, $\tilde{F}_j$, $\tilde{L}_j$ and $\tilde{D}\tilde{S}_j$.

Then

$$KU_{j(end)} = max\ KU_j(k)\,, \tag{17}$$

$$\Delta KU_{j(end)} = max\ \Delta KU_j(k)\,. \tag{18}$$

So the coefficient of confidence $KU_{j(end)}$ or $\Delta KU_{j(end)}$ in the diagnosis $\{D_j\}$, $j \in J$ based on all the coefficients $KU_j(k)$ or $\Delta KU_j(k)$, calculated for each group of related features, we determine according to (17), (18).

4. INFORMATION TECHNOLOGIES FOR SOLVING THE PROBLEMS OF STATE SPACE PROCESSING OF A COMPLEX BIOPHYSICAL OBJECT IN THE MEDICAL INTELLECTUAL SYSTEM HEALTH

The block diagram of the solution of the task contains more than 12 main blocks [7], which perform a number of functions [5], which provides the implementation of methodological aspects and the implementation of effective solutions.

Let's consider in more detail information technologies for solving the problems of state space processing of a complex biophysical object in the medical intellectual system HEALTH in conditions of considerable uncertainty (Figure 1).

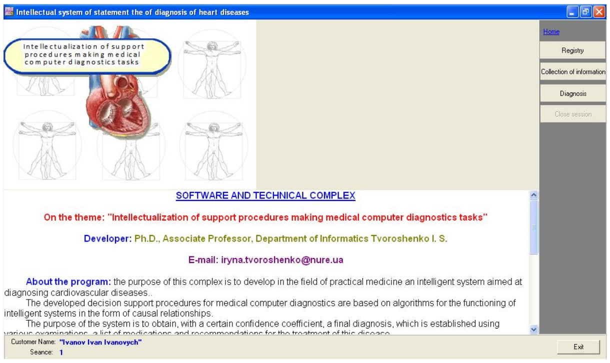

Figure 1: The main form of intelligent medical system

Generalized structure blocks implement the following information technologies (Figure 2).

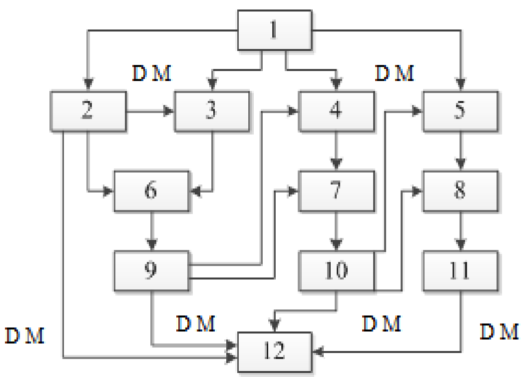

Figure 2: Block diagram of the solution of the task

1. A user registration system that provides dialog mode. The first stage of processing the state spaces of a complex biophysical object allows us to obtain many solutions using fuzzy logical inference based on subjective data $D_{ij}^{(1)}$ with certain coefficients of confidence KU_{ij} and the subsequent refinement of their state space on the set of solutions $D_{fj}^{(2)}$, $D_{lj}^{(3)}$, $D_{sj}^{(4)}$ or concludes that there is no solution to the task class $\tilde{D}_{end}$.

2. The second stage of processing the state spaces of a complex biophysical object allows us to obtain many solutions using fuzzy logic based on known factors $D_{fj}^{(2)}$ with certain coefficients of confidence KU_{fj}, to clarify the result of the first stage of processing the state spaces of a complex biophysical object $D_{ij}^{(1)}$, and further refine their states across multiple solutions $D_{lj}^{(3)}$, $D_{sj}^{(4)}$ or concludes that there is no solution to the problem class under consideration $\tilde{D}_{end}$.

3. The third stage of processing the state spaces of a complex biophysical object allows us to obtain many solutions using fuzzy inference based on the results of laboratory tests $D_{lj}^{(3)}$ with certain coefficients of confidence KU_{lj}. This step clarifies the result of the first and second stages of processing the state spaces of a complex biophysical object $D_{ij}^{(1)}$ and $D_{fj}^{(2)}$, and further refines their states across multiple solutions $D_{sj}^{(4)}$ or concludes that there is no solution to the problem class under consideration $\tilde{D}_{end}$.

4. The fourth stage of processing the state spaces of a complex biophysical object allows for multiple solutions to be obtained through fuzzy inference based on additional data $D_{sj}^{(4)}$ with certain coefficients of confidence KU_{sj}. This step clarifies the result of the first, second and third stages of processing the state spaces of a complex biophysical object $D_{ij}^{(1)}$, $D_{fj}^{(2)}$ and $D_{lj}^{(3)}$, and with the help of all the previous clarification of the state of the objects issues a final decision $D_{end}^{(4)}$ with the maximum confidence factor $KU_{sj} \rightarrow max$ or concludes that there is no solution to the task class $\tilde{D}_{end}$.

5. Processing and analysis of the information obtained after the first and second stages of processing the state spaces of a complex biophysical object allow us to select the most significant results and subsequently work only with them.

6. Processing and analysis of the information obtained after the third stage of processing the state spaces of a complex biophysical object, taking into account the results of the first and second stages of data processing, allows to select the most significant results and subsequently work only with them.

7. Processing and analysis of the results after the fourth stage of processing the state spaces of a complex biophysical object, taking into account the results of the previous three stages of data processing, allows to select the result with the highest coefficient of confidence.

8. The result after the first and second stages of processing the state spaces of a complex biophysical entity yields a plurality of solutions with certain confidence coefficients, as well as recommendations corresponding to these solutions, or recommendations for gathering the necessary additional information to improve the reliability of the task.

9. The result after the third stage of processing the state spaces of a complex biophysical object of the study produces many

decisions with certain coefficients of confidence, as well as recommendations that match these decisions, or recommendations on gathering the necessary additional information to improve the reliability of the decision.

10. The result, after the fourth stage of processing the state spaces of a complex biophysical object of the study, produces one solution with the maximum coefficient of confidence.

11. A final decision with a certain coefficient of confidence (Figure 3).

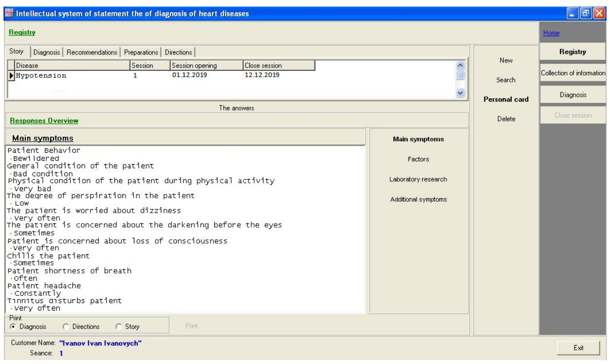

Figure 3: The result of the intelligent medical system

Some solutions to the relationship

$$R_{2,3}\,,\ R_{2,12}\,,\ R_{9,12}\,,\ R_{10,5}\,,\ R_{10,8}\,,\ R_{10,12}\,,\ R_{11,12} \quad (19)$$

can be specified DM (the decision maker).

This is usually determined by the responsibility of the decisions (19) and allows reducing the requirements to the level of qualification of the personnel, while increasing the reliability of the decisions.

The features of the implementation of this structure should include the following provisions [6]. If at some stage of processing the state spaces of a complex biophysical object we obtain only one solution in the resulting set, then it is considered to be dominant. The patient is provided with a list of necessary medicines and recommendations for the treatment of the detected disease, as well as the information on the basis of which the decision was obtained. Otherwise, the information technologies described above apply.

If the patient (according to DM) needs intensive treatment, such as surgery or recurs after treatment:

$$n > n^*,$$

where $n*$ – some constant, then the diagnosis must be verified by additional methods defined by DM.

5. CONCLUSION

The methodological aspects and the intellectual technologies of processing of state spaces of complex biophysical object, namely fuzzy cardiological symptoms and all related factors are developed.

The proposed approaches allow cardiology professionals, despite their seniority and work experience, to be diagnosed professionally. In addition, it provides an opportunity to warn the patient in advance of the danger and identify factors that contribute to the development of cardiovascular disease.

Features of work of the intellectual medical system are considered HEALTH. The software implementation of the system is implemented in an object-oriented programming environment.

The presented IDM has a number of significant advantages over the expert physician and existing analogues, can be used both in clinical practice by novice specialists and in the training of students and doctors in advanced training institutes.

The system allows generating and evaluating several alternatives in decision making, to treat contradictions that prevents and excludes superficial interpretation of the registered data, incorrect use of them, neglect of some types of data.

Experimental exploitation of hardware and software of the intelligent medical system HEALTH confirmed the high probability of making objective decisions on the topic of research.

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