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Methods of Using Fuzzy Interval Logic During Processing of Space States of Complex Biophysical Objects

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ABSTRACT

This article proposes a technique for using fuzzy interval logic during multi-stage processing of state spaces of complex biophysical objects in the medical system HEALTH. The proposed method of selecting the best diagnoses in the context of fuzzy background information was used to solve the practical problems of computer medical diagnostics. The theoretical and practical results formulated are the basis for the construction of systems and tools for computational intelligence. The diagnostic system is implemented on the basis of modern information technologies and computers. The presented computerized medical diagnostics system can be used in medical practice for the diagnosis of cardiovascular diseases, planning of health events and conducting of social and hygienic monitoring in medical institutions. Laboratory operation of fuzzy intellectual system HEALTH confirmed the high probability of making objective decisions in the medical subject area.

Key words: Fuzzy Interval Logic, State of Space, Biophysical Object, Computer Medical Diagnostics, Decision Making, Cardiology, Cardiovascular Disease, Diagnosis, Confidence Factor.

1. INTRODUCTION

Effective solutions in complex systems of management and data processing of artificial intelligence systems of different subject areas require prompt consideration of many contradictory factors [1]–[3]. First of all, they should include:

– significantly fuzzy nature of interacting dynamic processes and spaces of their states;

– complex parallel-sequential interaction of processes under uncertainty;

– significant complexity of the tasks to be solved;

– a significant proportion of the human factor that determines the quality and level of modern solutions.

Obviously, the requirements of effective solutions give grounds to argue for the need for a comprehensive systems approach based on the application or development of models, methods and tools to solve large-scale problems in practice.

Mathematical models based on the apparatus of fuzzy sets, reflecting relatively simple processes and procedures, do not explicitly take into account the parallelism and dynamics in their interaction, the set of parameters and features of the domain [4].

There are a variety of methods that allow you to effectively make decisions with known and fixed parameters. Difficulties arise in the context of uncertain or fuzzy data and knowledge, which strongly influences decision-making procedures [5]–[7].

This is especially evident in computer diagnostics [8], which have found application in various fields of application and have proven to be an effective tool for solving problems in complex situations [9]–[12].

Research of decision-making processes in complex conditions of functioning of a biophysical object occupies a special place in information technologies [5].

The technique of using interval logic in models that take into account the fuzzy and uncertainty of the parameters given by interval values is proposed in the article.

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

Problems of decision making under conditions of significant uncertainty and fuzzy presentation of interacting processes require the solution of many theoretical and applied problems in modeling procedures of fuzzy logical inference [9].

There is a considerable amount of work, research, models, methods and software that, with varying degrees of efficiency, addresses some aspects of computing intelligence systems and approaches [13]–[16].

An analysis of recent publications has shown that the issues discussed are under-researched, and that scientific results are not in all cases brought to practical implementation and need further study [17]–[20].

This confirms the relevance and importance of the theoretical and practical results obtained in the work.

The formulation of the decision-making problem includes the following components:

– the set of deterministic, fuzzy, or probabilistic parameters that characterize the state of a research object (human), the truth of which can be established with a degree of certainty;

– many variants of decisions (diagnoses) that are in some way related to the condition of the object of study.

There is an urgent need to create a methodology for a comprehensive systematic approach for choosing a reliable diagnosis with a given degree of certainty, as the only problem to develop new effective mathematical fuzzy models, taking into account the advantages of existing models, formal criteria and approaches, modern technologies, methods and tools for solving the theoretical tools and practical tasks.

The purpose of the research is to increase the reliability of the decisions made in the tasks of computer diagnostics of cardiovascular diseases, which is necessary in clinical practice and social and hygienic monitoring.

3. FEATURES OF STATE PROCESSING OF COMPLEX BIOPHYSICAL OBJECTS

Decision-making on complex biophysical objects often necessitates the consideration of fuzzy object properties given at some range of values of linguistic variables of the species, for example, "accuracy" set at interval "high" – "average", "expected costs" defined at interval "small" – "medium".

Such performances are typical of real-time computer medical diagnostics, decision making in emergencies, processing and implementation of fuzzy requests in the uncertainty of large distributed systems in the Internet and some other systems [5].

One of the main problems that arise in the synthesis of automated systems is the formalization of output indicators, the nomenclature of which contains numerical and non-numerical (linguistic) characteristics.

Numerical indicators are determined by direct observation and measurements (height, body weight, blood pressure) and can be easily obtained without special medical examination, evaluation of non-numerical indicators (lifestyle, genetic predisposition to the occurrence of disorders) requires some subjective judgments and special surveys [10].

The representation of parameters in fuzzy intervals is primarily related to the ignorance of exact values. The choice of the decision has to be made in the context of uncertain information about the symptomatology, which actually involves consideration of a wider list of potentially possible diagnoses.

There is a problem of limiting the initial set of potential diagnoses on the basis of multi-stage diagnostics, which allows clarifying and localizing possible diagnoses [7].

Limited on time and material resources, experts usually do not have a clear judgment about the benefits between diagnoses on a variety of grounds. It is advisable to present the opinions of experts in the form of fuzzy relations of superiority on the original set of diagnoses by the set of features, in the form of a set of matrices, whose elements are numbers from the interval $\{0, 1\}$, and the i-th element of the k-th matrix characterizes the degree of superiority of the i-th diagnosis for the j-th diagnosis on the k-th.

This approach makes it possible to develop a fairly simple and effective procedure for selecting better diagnoses. The resulting model has a greater number of degrees of freedom with respect to input, output parameters and existing solutions.

Thus, the task of narrowing down the initial set of diagnoses characterized by fuzzy qualitative information to a subset of rational diagnoses is realized using formal analysis and selection procedures based on fuzzy knowledge bases and rules. Linguistic variables are used to describe knowledge bases, the meanings of which are defined by fuzzy subsets expressed in the form of words or sentences in natural or special language.

The experience of developing a computer-based medical technique based on fuzzy logic shows that it is advisable to choose a particular kind of membership function among triangular, Gaussian, elliptical, and trapezoidal functions.

4. METHOD OF USING FUZZY INTERVAL LOGIC DURING STATE SPACE PROCESSING

The basic steps of algorithmic support of the technique of multi-stage processing of state spaces of complex biophysical objects are realized as follows.

Step 1. User registration in HEALTH medical system (Fig. 1).

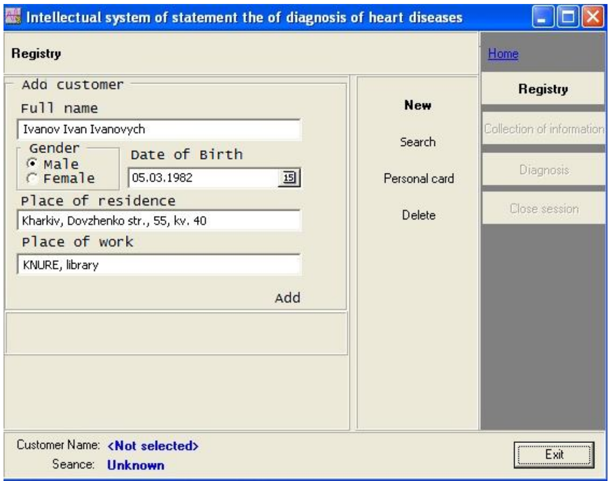

Figure 1: Result of user registration in the medical system HEALTH

Step 2. Enter objective and subjective data.

Step 3. Formation of a database of objective and subjective data.

Step 4. Creating a fuzzy knowledge base in the form of "If X, then Y" product rules.

Step 5. Fuzzy logical deduction of the first stage of processing of state spaces of complex biophysical objects.

Step 6. Determining the set of possible solutions in the first stage of processing state spaces of complex biophysical objects $\left|D_{ij}^{(1)}\right|$.

Step 7. Calculate the set of confidence coefficients $\{KU_{ij}\}$, corresponding $|D_{ij}^{(1)}|$, where i – symptom, j – disease.

Step 8. Analysis of the obtained coefficients of confidence $\{KU_{ij}\}$:

– if $\{KU_{ij}\} \geq 0.5$, then we go to step 11;

– if $\{KU_{ij}\} < 0.5$, then we go to step 9.

Step 9. To determine the set of solutions $\{D_{ij}^{(1)}\}$ taking into account the analogy of symptomatology in various diseases, it was decided not to consider in the further processing of many decisions $\{D_{ij}^{(1)}\}$, what are the values $KU_{ij} < 0.5$. Ago

$$0 \leq \mu(\{D_{ij}^{(1)}\}) < 0.5 \,. \tag{1}$$

Step 10. Issue information about the absence of the disease (Fig. 2).

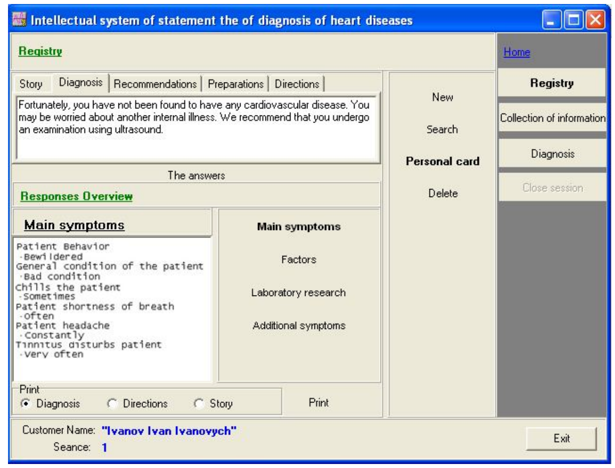

Figure 2: Information about the absence of the disease

Step 11. Determining multiple solutions $\{D_{ij}^{(1)}\}$, what are the values $KU_{ij} \geq 0.5$:

$$0.5 \leq \mu(\{D_{ij}^{(1)}\}) \leq 1 \,. \tag{2}$$

Step 12. Analysis of the obtained set of solutions $\{D_{ij}^{(1)}\}$:

– if $\{D_{ij}^{(1)}\} = 1$, then we go to step 13 or step 14;

– if $\{D_{ij}^{(1)}\} > 1$, then we go to step 14.

Step 13. Issuing the final decision (Fig. 3).

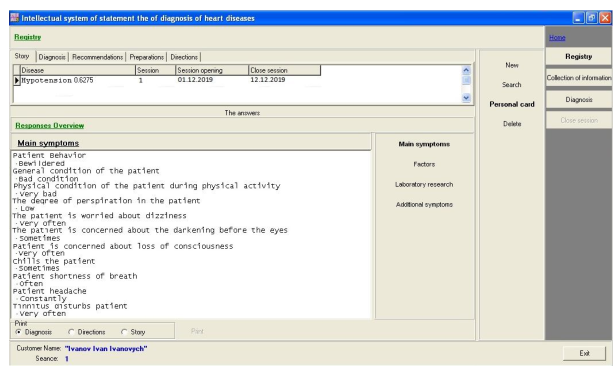

Figure 3: The result of the final diagnosis

Step 14. Introduction of factors affecting the patient.

Step 15. Formation of factors database.

Step 16. Fuzzy logical conclusion of the second stage of processing of state spaces of complex biophysical objects.

Step 17. Determining the set of possible solutions in the second stage of processing the state spaces of complex biophysical objects $|D_{fj}^{(2)}|$.

Step 18. Calculating the set of confidence coefficients $\{KU_{fj}\}$, corresponding $|D_{fj}^{(2)}|$, where f – factor, j – disease.

Step 19. Analysis of the obtained coefficients of confidence $\{KU_{fj}\}$:

– if $\{KU_{fj}\} \geq 0.5$, then $\{D_{fj}^{(2)}\} \neq 0$, go to step 20;

– if $\{KU_{fj}\} < 0.5$, then $\{D_{fj}^{(2)}\} = 0$, go to step 21.

Step 20. Similarly (2) we define the set of solutions $\{D_{fj}^{(2)}\}$, what are the values $KU_{fj} \geq 0.5$:

$$0.5 \leq \mu(\{D_{fj}^{(2)}\}) \leq 1. \quad (3)$$

Step 21. Processing and analysis of the results obtained after the first and second stages of processing the state spaces of complex biophysical objects:

– if

$$(\{D_{ij}^{(1)}\} \cap \{D_{ij}^{(2)}\}) = \varnothing,$$

then

$$(\{D_{ij}^{(1)}\} \cup \{D_{ij}^{(2)}\}) = \{D_{fj}'^{(2)}\}; \quad (4)$$

– if

$$(\{D_{ij}^{(1)}\} \cap \{D_{ij}^{(2)}\}) \neq \varnothing,$$

then

$$(\{D_{ij}^{(1)}\} \cap \{D_{ij}^{(2)}\}) = \{D_{fj}'^{(2)}\}. \quad (5)$$

Step 22. Analysis of the obtained set of solutions $\{D_{fj}'^{(2)}\}$:

– if $\{D_{fj}'^{(2)}\} = 1$, then we go to step 13 or step 23;

– if $\{D_{fj}'^{(2)}\} > 1$, then we go to step 23.

Step 23. Issue a referral for laboratory examination in accordance with the set $\{D_{fj}'^{(2)}\}$.

Step 24. Conducting laboratory tests.

Step 25. Formation of database of results of laboratory examinations.

Step 26. Fuzzy logical conclusion of the third stage of processing the state spaces of complex biophysical objects.

Step 27. Determining the set of possible solutions in the third stage of processing the state spaces of complex biophysical objects $|D_{lj}^{(3)}|$.

Step 28. Calculating the set of confidence coefficients $\{KU_{lj}\}$, corresponding $|D_{lj}^{(3)}|$, where l – the result of a laboratory examination, j – disease, $l \in L$, $j \in J$.

Step 29. Analysis of obtained coefficients of confidence $\{KU_{lj}\}$:

– if $\{KU_{lj}\} \geq 0.5$, then $\{D_{lj}^{(3)}\} \neq 0$, go to step 30;

– if $\{KU_{lj}\} < 0.5$, then $\{D_{lj}^{(3)}\} = 0$, go to step 31.

Step 30. Similarly (2) we define the set of solutions $\{D_{lj}^{(3)}\}$, where is the value $KU_{lj} \geq 0.5$:

$$0.5 \leq \mu(\{D_{lj}^{(3)}\}) \leq 1. \quad (6)$$

Step 31. Processing and analysis of the information obtained after the third stage of processing the state spaces of complex biophysical objects, taking into account the results obtained after the first and second stages of modeling:

– if

$$(\{D_{fj}'^{(2)}\} \cap \{D_{lj}^{(3)}\}) = \varnothing,$$

then

$$(\{D_{fj}'^{(2)}\} \cup \{D_{lj}^{(3)}\}) = \{D_{lj}'^{(3)}\}; \quad (7)$$

– if

$$(\{D_{fj}'^{(2)}\} \cap \{D_{lj}^{(3)}\}) \neq \varnothing,$$

then

$$(\{D_{fj}'^{(2)}\} \cap \{D_{lj}^{(3)}\}) = \{D_{lj}'^{(3)}\}. \quad (8)$$

Step 32. Analysis of the resulting set of solutions $\{D_{lj}'^{(3)}\}$:

– if $\{D_{lj}'^{(3)}\} = 1$, then we go to step 13 or step 33;

– if $\{D_{lj}'^{(3)}\} > 1$, then we go to step 33.

Step 33. Introduce additional symptoms.

Step 34. Formation of a database of additional symptoms.

Step 35. Fuzzy logical conclusion of the fourth stage of processing the state spaces of complex biophysical objects.

Step 36: Identify the set of possible solutions in the fourth stage of processing state spaces of complex biophysical objects $|D_{dj}^{(4)}|$.

Step 37. Calculate the set of confidence coefficients $\{KU_{dj}\}$, corresponding $|D_{dj}^{(4)}|$, where d – an additional symptom j – disease.

Step 38. Analysis of the obtained coefficients of confidence $\{KU_{dj}\}$:

– if $\{KU_{dj}\} \geq 0.5$, then $\{D_{dj}^{(4)}\} \neq 0$, go to step 39;

– if $\{KU_{dj}\} < 0.5$, then $\{D_{dj}^{(4)}\} = 0$, go to step 40.

Step 39. Similarly (2) we define the set of solutions $\{D_{dj}^{(4)}\}$, what are the values $KU_{dj} \geq 0.5$:

$$0.5 \leq \mu(\{D_{dj}^{(4)}\}) \leq 1. \quad (9)$$

Step 40. Processing and analysis of the results obtained after the fourth stage of processing the state spaces of complex biophysical objects, taking into account the results obtained after all the previous stages of modeling:

– if

$$(\{D_{lj}'^{(3)}\} \cap \{D_{dj}^{(4)}\}) = \varnothing,$$

then

$$(\{D_{lj}'^{(3)}\} \cup \{D_{dj}^{(4)}\}) = \{D_{dj}'^{(4)}\}; \quad (10)$$

– if

$$(\{D_{lj}'^{(3)}\} \cap \{D_{dj}^{(4)}\}) \neq \varnothing,$$

then

$$(\{D_{lj}'^{(3)}\} \cap \{D_{dj}^{(4)}\}) = \{D_{dj}'^{(4)}\}. \quad (11)$$

Step 41. Analysis of the obtained set of solutions $\{D_{dj}'^{(4)}\}$:

– if $\{D_{dj}'^{(4)}\} = 1$, then we go to step 13;

– if $\{D_{dj}'^{(4)}\} > 1$, then we go to step 42.

Step 42. Choosing a solution with a maximum confidence ratio:

$$\mu_{max}\{D_{dj}'^{(4)}\}, \quad (12)$$

we go to step 13.

A feature of this technique is the multi-stage processing of state spaces of complex biophysical objects, which allows specifying and localizing possible solutions.

5. CONCLUSION

A technique for using fuzzy interval logic during multi-stage processing of state spaces of complex biophysical objects has been proposed and implemented. The above approach makes adequate use of expert opinion, which significantly increases the objectivity of the results obtained and does not require large computational costs.

The proposed method of selecting the best diagnoses in the context of fuzzy background information was used to solve the practical problems of computer medical diagnostics HEALTH.

The diagnostic system is implemented on the basis of modern information technologies and computers. The computerized medical diagnostics system is introduced HEALTH can be used in medical practice for the diagnosis of cardiovascular diseases, planning wellness events and conducting social and hygienic monitoring in medical institutions.

The practical significance of the obtained results is that the formulated theoretical and practical results are the basis for the construction of systems and tools of computational intelligence.

Efficiency of results is confirmed by practical implementations. In the application of computer-aided medical diagnostics for complex diseases, this technique made it possible to significantly increase the reliability of the decisions made in the conditions of uncertainty, which in some practical cases was not solved on the basis of traditional approaches.

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