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Linguistic Model Description of the State of the Medical Diagnostics Object and Analysis of Methods for Forming the Membership Function

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Abstract

This article discusses a three-level model of an automated medical diagnostic system. The proposed method for describing the state of the diagnostic object is presented. The model of the patient's condition and the diagnostic model are discussed. Methods for constructing membership functions of fuzzy sets are considered. The method of statistical data was highlighted as the least susceptible to the subjective influences of experts. The use of the proposed models allows us to meet all the requirements set for both the method of automated model building and the method for assessing the state of the diagnostic object. From these analyzes, conclusions were drawn.

Keywords: state of the diagnostic object, automated medical diagnostic system, linguistic variable, membership function, operation, optimization.

1. Introduction

It is not always possible to measure the set of symptoms that characterize a particular disease, i.e., it is not possible to quantify the manifestation of a particular symptom. In most cases, the patient can verbally describe the degree of symptom signs. Therefore, nominal or qualitative (rank, interval, indeterminate, and other) measurements can be used to describe the patient’s current condition.

Based on the methods and models of demonstration of previously studied knowledge, it is proposed to use a model of the linguistic type to reflect the laws.

During the study of existing decision support systems in solving medical diagnostic problems, it was found that many systems are based on the operation of three-level models. This is primarily due to the fact that the International Classification of Diseases [1] divides all diseases into three levels: 1) classes; 2) blocks; 3) diagnoses.

In the first degree, diseases of a particular system of the body (e.g., diseases of the respiratory system, diseases of the nervous system) may be an example. The next level includes a narrow range of disease classes (for example, for diseases of the respiratory system at this level, such diseases can be described as follows: acute respiratory infections of the upper respiratory tract, influenza, pneumonia, etc.).

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In an automated medical diagnostics system, it is proposed to use a three-tier model to describe all possible conditions of the system.

2. Main part

The description of the state of the diagnostic object at each sublevel of the multilevel procedure can be presented as follows:

$$s_k = F(s_{k-1}, x_k) + w_k, \quad (1)$$

$$y_k = H(s_k) + v_k,$$

$$s_k \in S, x_k \in X, y_k \in Y, v_k \in V, w_k \in W \qquad (2)$$

Where s_k - is the state of the diagnostic object at the kth moment of time;

x_k - n-dimensional vector available for measurement and significantly affecting the state of the object;

$F(\cdot)$ - a model displaying a transition to a new state under the influence of input variables;

y_k - a vector of output variables available for observation or estimation with accuracy up to *V*;

$H(\cdot)$ - a model of transformation of the state s_k into measured or estimated values of the output variables;

w_k - a variable that takes random values from the sets *W*, characterizes the residual uncertainty of the object;

v_k - a variable that takes random values from the sets *V*, characterizes the measurement or estimation error;

S - a finite set of values of the state of the diagnostic object (set of diseases);

X - a finite set of values of factors affecting the state of the object;

Y - the set of possible values of the output observable indicators;

W - the set of possible values of external uncontrollable factors;

V - the set of possible values of the model error.

The state of the object at each level is determined from the patient's health state model (1) and the diagnostic model (2), each of which is identified by its own unique set of input and output variables.

In this case, the automated medical diagnostics system will operate not with the values of x_k, y_k, s_k, but with the membership functions of these values to the fuzzy sets of the corresponding linguistic variables:

$$M_1 : \bigcup_{j=1}^{l_x} \bigcap_{i=1}^{n} \mu_{a_{ji}}(x_i) \rightarrow \mu_{d_j}(s_k),\ a_{ji} \in A_j \subseteq A,\ d_j \in D \qquad (3)$$

$$M_2 : \mu_{d_j}(s_k) \rightarrow \bigcap_{m=1}^{l_y} \mu_{b_{jm}}(y),\ b_m \in B_j \qquad (4)$$

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where n - the number of input variables;

a_{ji} , - j^{th} fuzzy set of the i^{th} input indicator;

l_k - the number of conjunctions defined on the values of the input variables;

b_{j_m} - the j^{th} fuzzy set of the m^{th} output variable;

l_y - is the number of conjunctions defined on the values of the output variables;

d_j - is the j^{th} fuzzy set corresponding to the k^{th} state of the system from the set D;

D - is the set of fuzzy sets of the linguistic variable "Patient's state".

Models (3), (4) are built in the training mode of an automated medical diagnostics system based on data samples containing accurate (verified) information about the states of the object s or in the form $\mu_{d_j}(s)$.

After building the models, the automated medical diagnostics system can be used in operational mode for medical diagnostics. The operating mode begins with the collection of the values of the input and output indicators that affect the object being diagnosed. Depending on the information received could be three options for medical diagnostics:

- with the information mainly about the input variables, the current state of the object can be diagnosed on the basis of the patient's health state model (3), which describes both the prehistory of the object states and such indicators as the patient's lifestyle, bad habits, etc.;

- with the information mainly about the output variables, the current state of the object can be diagnosed on the basis of the diagnostic model (4), which reflects the change in the state of the object being diagnosed depending on the symptoms manifested at a given time;

- with the information about both the input and output variables, from the values of the input variables, using the model of the patient's health state (3), it is possible to select a certain finite subset S' or D', preliminarily containing the desired state, and then, from the values of the output variables, determine from the obtained subset is the only state using the diagnostic model (4).

Such mutual control will allow not only to provide the required reliability for decision making, but will also allow you to control the correctness of the presentation of input information, which is especially important in the case of representing the values of variables in the form of linguistic variables. In addition, the use of the model of the patient's health status allows increasing the accuracy of the diagnostic solution due to the fact that the patient's history of diseases is used.

The use of models (3), (4) allows satisfying all the set requirements for both the method of automated building of models and the method for assessing the state of the diagnostic object.

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2. Methods

Based on the choice of a linguistic model as a diagnostic model, it is concluded that all input and output variables should be represented as a linguistic variable. Linguistic variable can be represented by the tuple [2, 3]:

$$\langle \beta, T, X, G, M \rangle,$$

where β - the name of the linguistic variable;

T - basic fuzzy set of a set of linguistic variables or a set of its values, each of which is the name of a fuzzy variable;

X - the scope of definition of fuzzy variables that are included in the definition of a linguistic variable;

G - some syntactic procedure that describes the process of forming new values for a given linguistic variable;

M - a semantic procedure that allows each new value of a given linguistic variable, obtained using the G procedure, to be associated with some meaningful content by forming a corresponding fuzzy set.

One of the main tasks solved in the formation of a linguistic model is the choice of a method for specifying membership functions of fuzzy sets of linguistic variables [4]. The most widespread in the construction of membership functions of fuzzy sets are direct and indirect methods. A complete classification of methods for constructing membership functions is shown in Figure 1.

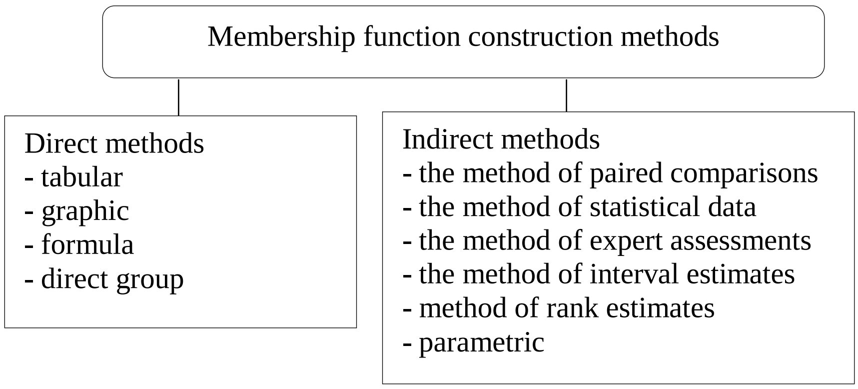

Figure 1. Classification of methods for constructing membership functions

In direct methods, an expert or a group of experts simply assigns a membership function $\mu_A(x)$ value for each $x \in X$ [5, 6]. As a rule, direct methods for constructing membership functions are used for properties that can be measured on a certain quantitative scale. For example, such physical quantities as speed, time, distance, pressure, temperature and others have corresponding units and standards for their measurement.

Direct group methods are varieties of direct methods, when, for example, to a group of experts a specific object is presented, and each of the experts must give one of two answers: whether or not this object belongs to a given set. Then the

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number of affirmative answers divided by the total number of experts gives the value of the function of the object's membership in this fuzzy set.

Direct methods are also direct assignment of the membership function by a table, graph or formula.

Direct methods are used mainly as auxiliary methods, since they are characterized more as subjective.

Indirect methods are used for determining membership model values in cases where there are no obvious measurable properties that can be used to build fuzzy models.

In indirect methods, the values of the membership function are selected in such a way as to satisfy the previously formulated conditions. Expert data is considered only a source for further processing. Additional conditions can be imposed both on the type of information received and on the order of its processing. These methods include the statistical method, the method of paired comparisons, the method of expert estimates and others.

The method of constructing a membership function based on paired comparisons is based on processing assessment matrices that reflect an expert’s opinion about the relative belonging of elements to a set or the degree of their manifestation of a property formalized by a set. In several works, it is shown that this method can be used both for solving the problems of developing alternatives, and for comparing them and choosing the best one [7, 8].

In the method of statistical data, as the degree of membership of an element in a set, an estimate of the frequency of using a concept defined by a fuzzy set is taken to characterize an element. This method can be used to formalize the problem of choosing alternatives, since experts can determine a specific set of acceptable alternatives and remove unnecessary ones.

The method for constructing the membership function is based on the use of fuzzy numbers, approximately equal to some clear number, and approximate interval estimates reflecting the opinions of experts on the issue under consideration. The task is reduced to finding the parameters of a predetermined (exponential) function, in solving which the results of an expert survey are used. This method is most expedient to use when solving the problems of developing and evaluating alternatives.

The construction of a membership function based on the method of interval estimates is used for the formalized representation of selection problems in which there is no clear line between acceptable and unacceptable (in the space of uncontrollable parameters) and between ideal and unsatisfactory states (in the space of criteria).

Based on the analysis of the methods of membership function formation, it can be concluded that all methods to one degree or another are based on the subjective setting of the membership function values. On the example of the designed decision support system, as a person influencing the formations of the membership function, there can be an expert in a problem area setting up a decision support system, or a knowledge engineer, or an information technology specialist. Among the considered methods, one can single out the method of statistical data, as the

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least susceptible to the subjective influences of experts (an expert can only delete unnecessary or outdated data from the data sample).

Conclusion

In the course of the research carried out on this topic, an approach to the construction of an automated system of medical diagnostics is proposed, which consists in the fact that the diagnostic process is a multi-level procedure. The assessment of the patient's condition at each level is based on the analysis of two models:

- models of the patient's health state, reflecting the prehistory of diseases of the object of diagnosis, as well as factors such as living conditions of the patient, bad habits, etc.;

- a diagnostic model that allows you to determine the current disease by the symptoms that appear at the current time.

This work shows that the proposed automated system of medical diagnostics can be based on a model reflecting the patient's health status and the dependence of the values of informative variables on this condition. And, accordingly, build a knowledge base of automated medical diagnostic systems based on such models.

Due to the heterogeneity of the data, the a priori unknown of most of the patterns of occurrence of diseases from the influence of various factors, the uncertainty of the influence of other factors, models of the logical-linguistic type can be used as a model placed in the knowledge base

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