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Design of Network-Based Fuzzy Knowledge Bases for Medical Decision-Making Support Systems

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Problems of design of medical decision-making support systems using network-based fuzzy knowledge bases are considered. It is shown that uniformly structured networks can be trained to solve almost all problems posed before medical specialists, including fuzzy-data problems with intersecting class structures.

Modern decision-making support systems for physicians of various specialties exert a substantial effect on quality of medical service. These systems provide consultation in prognostic, diagnostic, prophylactic, and therapeutic activities.

Many commercial systems of this class are presently available for specific medical purposes. Such commercially available systems are based on expert databases that are tunable to user problems [1-5].

In this work, design of network-based fuzzy knowledge bases (NBFKB) for medical decision-making support systems is discussed. Such bases capable of tuning to user problems were developed at the Department of Biomedical Engineering, Kursk State Technological University.

Selection of network systems for medical NBFKB is based on the following factors. Diagnostic and therapeutic processes contain several stages and human health hypotheses. At each stage of diagnostic and therapeutic processes the hypothesis is supported, rejected, or modified. Parallel hypotheses can be put forward in case of combined pathology. The tactics of monitoring methods can also be changed. This change can be fairly sharp. If a stage of decision-making procedure is represented as a node in the model of a subject area, branched transitions to other nodes are possible. Many researchers use network models of a subject area to implement such mechanisms [1, 3, 6, 7].

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Decision-making models are based on various mathematical methods and information knowledge databases. The NBFKB quality depends on model adequacy.

Many medical problems (particularly problems of early diagnosis) use different structures of fuzzy knowledge bases, whereas class structure is not clearly determined.

Fuzzy logic with decision rules tuned to a training procedure has been used as the main mathematical apparatus [5, 8].

This apparatus does not exclude other approaches (discriminant analysis, group argument method, reference methods, etc.). The reference methods solve the problem of scale adaptation to decision-making.

With due regard to variety of decision rules in network model nodes, a unified multifunctional decision module is suggested.

The problems solved using one unified multifunctional decision module are associated with a technological component of the general solution. This component can include preliminary diagnosis based on epicrisis and medical examination; retrieval of additional information from patient database; stage of diagnosis elucidation with regard to standard examination results; stage of diagnosis elucidation with regard to results of instrumental examination, etc.

A diagram of the decision module (DM) of a network information logical model is shown in Fig. 1. The decision module contains program input/output interfaces with given specifications. The input/output interfaces are for input/output of facts, data, decision rules, addresses, control information, and training information.

Interface I_1 provides input/output of human health state parameters to the decision module. Interface I_1 also provides input/output of facts and data related to other

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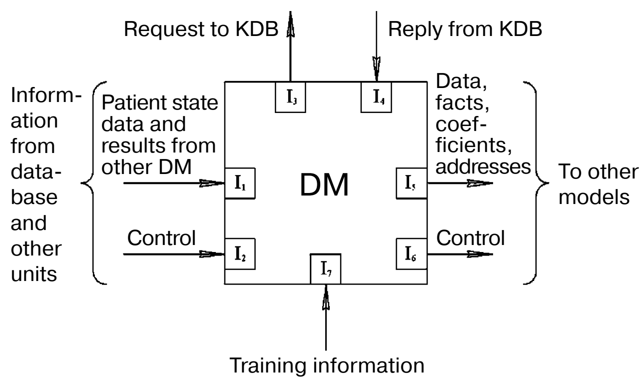

Fig. 1. Decision module of network information logical model.

DM. Interface I_2 provides input/output of information about working modes of the decision module. Interface I_3 provides communication with knowledge database (KDB). This information is required to correct a decision of the DM. It is yes/no response or request about tactics of therapy with regard to health state dynamics.

Interface I_4 provides initial DM loading and additional information required for DM activation. Interface I_5 provides output of information concerning DM-mediated solutions in KDB memory area or in other DM. Interface I_6 provides formation of control codes and their transmission to an address specified by interface I_5. Training information, correction decision rules in DM are transmitted to the module through interface I_7.

The network structure of a knowledge database is shown in Fig. 2. The number of each module in this structure consists of two characters: s is for row number (s = 1, ..., m) and t is for column number (t = 1. ..., k,...,1..., r). In the general case, the number of human health symptoms does not coincide with the number of nosologies, diagnoses, and correction schemes. Therefore, the matrix of the network model is not rectangular. Let the matrix of the network model for a diagnostic process be of prognostic value (row from the left to the right with due regard to disease ω_l specificity). The result of transition along the row from the left to the right depends on the diagnosis. The transition along the column is equivalent to diagnosis modification (combined nosology or change in therapeutic tactics).

Each network module is oriented toward a specific problem. The DM is loaded by the moment of its execution (according to its number st). Each network DM is characterized by a weighting coefficient (0-1). The weighting coefficient value is proportional to its importance. A vector of weighting coefficients determines its use in j nosology.

DM selection for work is implemented as follows:

1) by expert: using key words stored in the knowledge database depending on problem, diagnosis, and solution. Patient complaints and therapeutic methods (symptoms, functions, organs, nosology, diagnosis, disease stages, therapy types and stages, etc.) can be used as key words;

2) semiautomatically: the set of recommendations for therapy determines next stage of therapy;

3) automatically: the system provides transition of control commands from module to module using an interaction algorithm (to maximal confidence coefficient). The system is stopped by the user.

The stop criteria are:

– given quality of solution;

– expert or NBFKB command;

– given depth (number);

– given solution confidence;

– module of urgent situations;

– given weighting function threshold. Integral criterion of expert evaluation with regard to economic factor, organization capacity, laboriousness, etc.

Problem type and volume is determined by the DM in collaboration with user, expert, and engineer. The DM information volume should be consistent with problem interpretation and solubility. Module information should be sufficient for one session of expert communication with the object.

The network logical model of therapy provides a DM and a set of input characters (symptoms, diagnoses, etc.). This is accompanied by formulation of therapy hypothesis and confidence coefficients. To test the hypothesis, the DM elucidates the diagnosis on the basis of additional information. Input characters and additional information are accompanied by weighting coefficients and their contribution to the hypothesis. If the hypothesis is not proved, a new DM or new hypothesis is put forward. Backward testing is also possible. Diagnosis (prognosis) is continued until given confidence is attained. Therapy (prophylaxis) is continued until a given therapeutic effect is attained. The set of characters and additional DM information exerts an effect on solution confidence. The user is able to test individual characters and their contribution to the hypothesis. The necessity of additional examination, modification of hypothesis, or therapy tactics can also be tested.

If the resulting confidence coefficient is low (below threshold), the expert is suggested to recommend a new character. Special buffer memory of the network model contains information about numbers and DM use in each module. This allows the diagnostic process to be followed. Because the weight of each module can be determined, the role of the expert in DM-mediated diagnosis can be

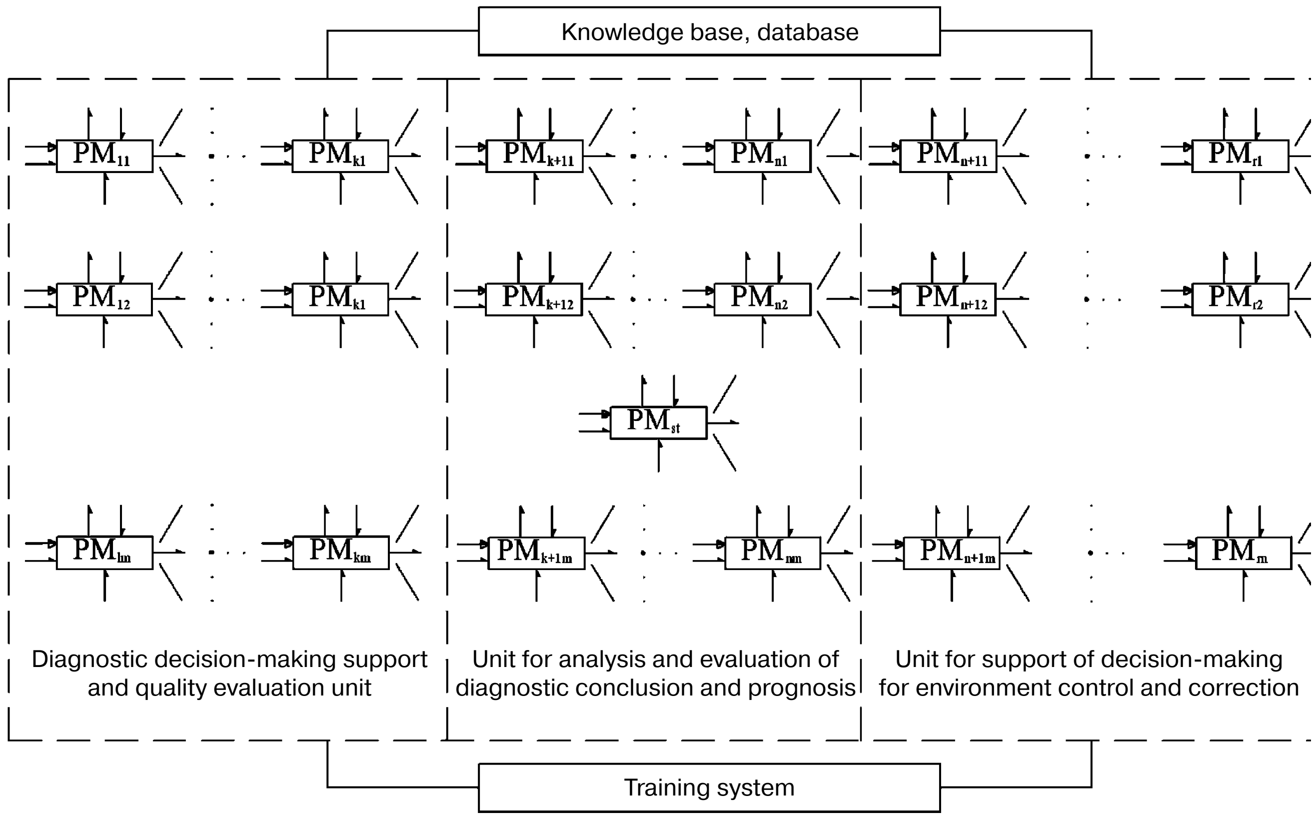

Fig. 2. Network structure of a knowledge database.

evaluated. Special quality control software provides an expert quality control system (QCS) (Fig. 2). The QCS efficiency is tested using weighting coefficients of DM or characters (symptoms). In case of i-th nosology, physician error is estimated by the expert as low working quality if a high weighting coefficient or DM character was ignored.

In the case of automatic therapy mode, the trajectory of transition between different DM units corresponds to maximal confidence coefficient. The system also analyzes other hypotheses with high confidence coefficients (above a threshold). After that, the system recommends the expert to test other variants of hypotheses. Such tactics in combination with monitoring of dynamic parameters provide detection of concomitant diseases, additional effects, and target organs. The functions, systems, and elements dependent on damaged organs can be diagnosed using special decision rules and DM at the stage of diagnosis. The functions, systems, and organs subjected to indirect effect are detected at the stage of health correction. The tactics of therapy are optimized at this stage with regard to individual patient specificity, environmental effects, and contraindications.

The search for a DM responsible for system error is mediated by the network model DM. If DM errors are at threshold level, an additional training system is connected to the module. This training system corrects decision rules and/or connections.

The DM types used in this work implement decision rules of necessary type (diagnosis of state class, prognosis of object state, correction of object state, etc.). In addition, the DM solves the following problems.

1. Analysis of input information coming from interface I_1 for its compliance with DM specification and DM control mediated by input information. The DM is activated using given and necessary input characters; given coefficients of other DM; input production rules; threshold of weight function (linear); vector of input characters of given class.

2. A goal-oriented request for additional information about the object using the knowledge database and DM solution elucidation.

3. Calculation of confidence coefficient of the DM solution and its dependence on module position in the network model, DM function, and additional informa-

tion obtained from interfaces I_1 and I_4. Calculation of DM weight. Calculation of DM contribution to expert problem solution.

4. Variants of problem solution at the DM working stage and formation of list of function and/or target organs and detection of contraindications. Calculation of confidence coefficient quality parameters. Transition to next stages of model construction using a DM of the network model. Urgent diagnostic solutions are of particular importance.

5. Selection of optimal tactics of work with the object and its dependence on input information coming to the DM through interfaces I_1 and I_3 with regard to individual specificity and contraindications.

6. Determination of the patient's health state and therapy monitoring.

7. Analysis of mechanism of decrease in the solution quality with indication of specific information about causes of this decrease:

– insufficient number of informative characters (list of characters);

– low confidence coefficients (reliability and confidence of characters);

– insufficient decision rule efficiency.

This mechanism provides information about solution confidence increase (insufficient characters, more accurate measurement of character parameters, correction of decision rule, mechanism of additional training).

8. Monitoring of list of dynamic parameters. The user compiles the list of dynamic parameters for diagnosis elucidation or therapeutic tactics. The DM decision rule is revised and/or elucidated for dynamic monitoring. The DM stops at a given confidence level or at a given number of measurement sessions or using the user's command. If dynamic monitoring requires an expert, a special buffer of intermediate results with DM number and DM working conditions is formed.

9. Training (additional training) mode increases DM solution quality. The training mode depends on solution rule type. Weighting coefficients of decision rules are changed, logical connections are changed, and confidence coefficients and decision thresholds are also changed. Request conditions and patient therapeutic tactics are adapted to decision-making.

The KBD was trained for prognosis and thrombosis diagnosis problems in central retina vein and its branches, gastric ulcer, skin diseases (acne rosacea, psoriasis, acne, genital herpes), osteochondrosis, postoperative complication in urological patients, etc. Results of clinical tests mediated by experts revealed that the expert systems suggested in this work provided sufficiently high quality. According to the [0, 1] scale, expert estimate of the decision rule is 0.9.

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