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APPLICATION OF FUZZY LOGIC TECHNIQUE IN MEDICINE

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Abstract. The article presents a brief analysis of three areas of using of fuzzy logic technology in medicine: the fuzzy logic for making decisions in medical diagnostics based on a fuzzy expert system, a fuzzy inference system for remote monitoring of vital functions and a healthcare system for individual physiological monitoring using a wireless body network with a routing algorithm based on the fuzzy logic.

Keywords: fuzzy logic, fuzzy expert systems, making decision, healthcare system, medical diagnosis, wearable sensor, routing algorithm, wireless body area network.

Introduction

Fuzzy set theory and fuzzy logic have a number of characteristics that make them highly suitable for modelling uncertain information upon which medical concept forming, patient state interpretation and diagnostic as well as therapeutic making decision is usually based. Firstly, medical entities such as symptoms, signs, test results, diseases and diagnoses, therapeutic and prognostic information can be defined as fuzzy sets. The inherent vagueness of these entities will thus be conserved. Secondly, fuzzy logic offers reasoning methods capable of drawing strict as well as approximate inferences. Medicine demands this broad range of possibilities because the body of medical theory includes definitional, causal, statistical, and heuristic knowledge. Practical medicine even has to accept incomplete medical theories where only vague and uncertain empirical information guides the necessary medical procedures. Finally, fuzzy automata may be used as high level patient monitoring devices with real time access to medical information systems.

A Fuzzy logic system (FLS) is mainly comprised of four components: fuzzifier, defuzzifier, fuzzy rule base and fuzzy inference engine. These components are arranged as follows in any Fuzzy Logic System.

Fuzzification is the first process that takes place in the FLS. A numeric or crisp input value is given to the fuzzifier. The crisp input value is required to be converted to the corresponding fuzzy value as the rules for determining the result, are defined for fuzzy inputs. This task is performed by the fuzzifier and then the fuzzy input values are supplied to the fuzzy inference engine, which is responsible for computing the set of outputs based on the IF-THEN rules defined in the fuzzy rule base.

Usually, when more than one inputs are required, AND operator is used to combine them. The last process in the FLS is defuzzification. It coverts the fuzzy output values into their corresponding crisp values. There are different methods for fuzzification and defuzzification. Some widely used fuzzifiers are singleton fuzzifier, gaussian fuzzifier and trapezoidal or triangle fuzzifier. Singleton fuzzifier is the simplest fuzzifier which basically assigns a precise value to the given input and hence no fuzziness is introduced by fuzzification in this case. Gaussian and triangular fuzzifiers are used to suppress the noise in the given inputs. Examples of defuzzifiers are maximum defuzzifier, mean of maxima defuzzifier, centroid defuzzifier, height defuzzifier, modified height defuzzifier, center of sets and center of sums.

The advantages of fuzzy logic are its simplicity, flexibility of combining conventional control techniques, ability to model nonlinear functions and imprecise information, use of empirical knowledge and dependency on heuristics. Due to the basic characteristics of ad hoc networks like uncertainty due to dynamic topology and mobility of nodes, limited resources and unstable links; a precise and accurate model is not possible to implement. In such an environment, fuzzy logic theory has been proved a good approach for routing compared to other routing methods. Fuzzy logic can be used to solve the problem of routing in ad hoc networks where the final outcome is based on the factors with uncertainty.

The fuzzy logic for making decisions in medical diagnostics based on a fuzzy expert system

Clinical decision support systems (CDSS) are broadly classified into two main groups (Fig. 1): knowledge based CDSS, non-knowledge based CDSS.

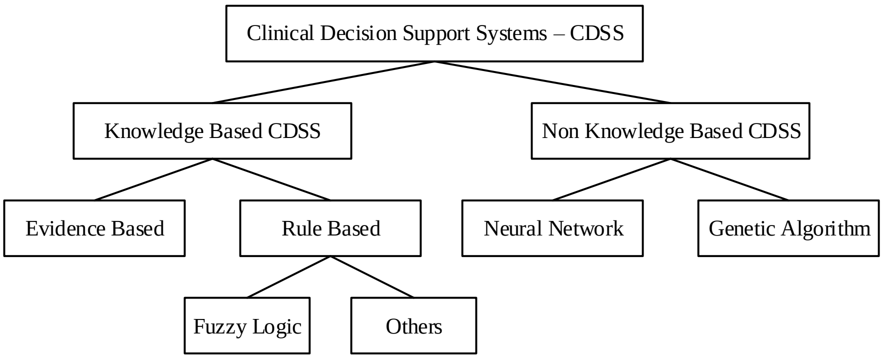

Fig. 1. Types of clinical decision support systems

The knowledge based clinical decision support system contains rules mostly in the form of IF/THEN statements. The data is usually associated with these rules. For example, if the pain intensity is up to a certain level then generate warning. The knowledge based generally consists of three main parts: knowledge base, inference rules and a mechanism to communicate. Knowledge base contains the rules, inference engine combines rules with the patient data and the communication mechanism is used to show the result to the users as well as to provide input to the system.

Rule-based systems and evidence based systems tend to capture the knowledge of domain experts into expressions that can be evaluated as rules. When a large number of rules have been compiled into a rule base, the working knowledge will be evaluated against rule base by combining rules until a conclusion is obtained. It is helpful for storing a large amount of data and information. However it is difficult for an expert to transfer their knowledge into distinct rules. CDSS without a knowledge base are called as nonknowledge based CDSS. These systems instead used a form of artificial intelligence called as machine learning. Non-knowledge based CDSS are then further divided into two main categories: neural network and genetic algorithms.

To derive relationship between the symptoms and diagnosis, neural networks use the nodes and weighted connections. This fulfills doesn't need to write rules for input. However, the system fails to explain the reason for using the data in a particular way. So its reliability and accountability can be a reason. Genetic algorithms are based on evolutionary process. Selection algorithm evaluates components of solutions to a problem. Solution that comes on top are recombined and the process that runs again until a proper solution is observed. The generic system goes through an iterative procedure to produce the purpose the best solution of a problem.

Diagnostic systems are used to monitor the behavior of a process and identify certain pre-defined patterns that associate with well-known problems. These problems, once identified, imply suggestions for specific treatment. Most diagnostic systems are in the form of a rule-based expert system: a set of rules is used to describe certain patterns. Observed data are collected and used to evaluate these rules. If the rules are logically satisfied, the pattern is identified, and a problem associated with that pattern is suggested. Each particular problem might imply a specific treatment.

Most current health monitoring systems only check the body's temperature, blood pressure, and heart rate against individual upper and lower limits and start an audible alarm should each signal move out of its predefined range (either above the upper limit or below the lower limit). Then, human experts will have to examine the patient and probe the patient's body further for additional data that lead to proper diagnosis and its corresponding treatment.

Other more complicated systems normally involve more sensors that provide more data but still follow the same pattern of independently checking individual sets of data against some upper and lower limits. The warning alarm from these systems only carries a meaning that there is something wrong with the patient.

In a life threatening situation, reducing the time between the warning and the time proper treatment is given to the patient by preparing proper equipment for specific treatment in advance would significantly increase the patient's chance of surviving.

The term «medical knowledge» is a superimposed concept for the relationships between symptoms and diagnoses a physician may find in books, journals, monographs, but also in practical experience. Fuzzy logic and neural networks are complementary technologies and when brought together can provide intelligent systems. Neuro-fuzzy model incorporates the generic advantages of artificial neural networks in modeling imprecise data and qualitative knowledge as well as transmission of uncertainty. Researchers used the neuro-fuzzy approaches to build more intelligent decision making systems and presented the applications and supportive tools for the physicians.

The Adaptive neuro-fuzzy inference system (ANFIS) is a simple data learning technique that uses fuzzy logic to transform given inputs into a desired output with the help of highly interconnected Neural Network processing elements and information connections, which are weighted to map the numerical inputs into an output. ANFIS combines the benefits of the two machine learning techniques (fuzzy logic and neural network) into a single technique.

The ANFIS system training process begins by obtaining a training data set (input/output data pairs) and testing data sets. Two vectors are used to train the ANFIS system: input and output. The training data is a set of input and output vectors. It is used to find the premise parameters for the membership functions. A threshold value for the error between the actual and desired output is determined. The consequent parameters are found using the least squares method. If this error is larger than the threshold value, then the premise parameters are updated using the gradient decent method. The process is terminated if the error is less than the threshold value. ANFIS training learning rules use hybrid learning, combining the gradient descent and the least squares method. Aim of using ANFIS for health monitoring is to achieve the best performance possible. ANFIS training begins by creating a set of suitable training data in order to be able to train the neuro-fuzzy system.

A fuzzy inference system for remote monitoring of vital functions

The wearable wireless sensor network is applied to monitor the physiological information (heart rate, blood oxygen, breath, blood pressure, body temperature, etc.) and movement information (the speed, gait, trajectory, and the consumption of energy in the sport) of human body and the external environment (temperature, humidity, gas composition, location) dynamically and continuously for a long time.

To improve clinician performance, fuzzy logic-based expert systems have shown potential for imitating human thought processes in the complex circumstances of clinical decision. A key advantage of using fuzzy logic in such situations is that the fuzzy rules can be programmed easily, and as a result they are easily understood by clinicians. It is different from neural networks and other regression approaches, where the system behaves more like a black box to clinicians. Here fuzzy logic holds great promise for increasing efficiency and reliability in health care delivery situations requiring decisions based on vital signs information.

Fuzzy logic control system is capable of generating accurate result from approximate, insufficient or vague information. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may rage between completely true or completely false.

The expert system must check for combinations of data instead of individual data and for example a fuzzy rule-based expert health monitoring system with three basic sensors: body temperature, heart rate, and blood pressure will identify twenty-seven different scenarios instead of three in the conventional system.

Fig. 2 shows the block diagram of health condition using fuzzy logic system to interpret the results of the most commonly used medical measurements: blood pressure and temperature.

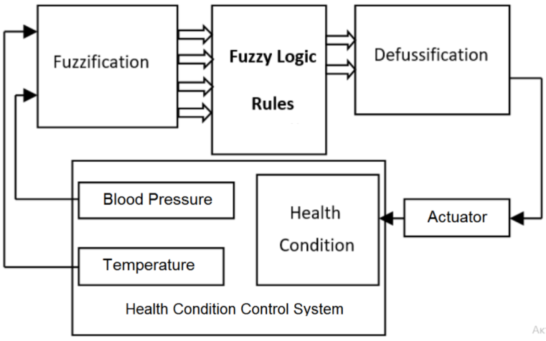

Fig. 2. Block diagram of health condition using fuzzy logic system

Fuzzification process for two variables need two separate fuzzifiers. Each fuzzifier consists of input BP value to crisp value, operation region of a crisp value detector, fuzzy set membership function value and selection arrangement. The design of fuzzifier is shown in Fig. 3.

An inference engine is a component of the system that applies logical rules to the knowledge base to deduce new information. For Fig. 3 the system's inference engine accepts four inputs from fuzzifier and applies the MIN-MAX composition to attain the output R values. Fig. 4 shows this type of inference process where the MIN-MAX inference method uses MIN-AND operation among the four inputs.

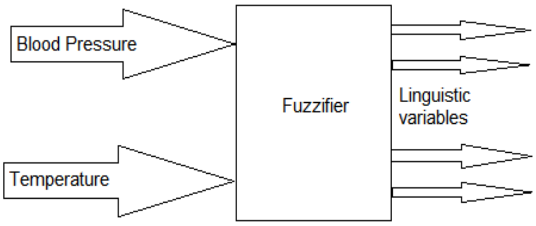

Fig. 3. Fuzzifier block

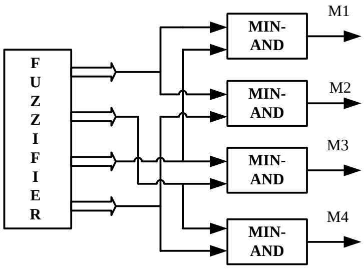

Fig. 4. Block diagram of min-max inference engine

Number of active rules = a^b, where a is maximum number of overlapped fuzzy sets and b is number of inputs. For example if a = 5 and b = 2, so the total number of active rules are 25.The total number of rules is equal to the product of number of functions accompanied by the input variables in their working range.

A healthcare system for individual physiological monitoring using a wireless body network with a routing algorithm based on the fuzzy logic

Focus on the wearable wireless sensor network among bodies, the wearable sensor node which is placed on the mobile human bodies constitutes the sensor network, the network topology of which changes fiercely (Fig. 5).

The wearable wireless sensor network which is applied in the individual physiological information monitoring is currently in the continuous research. And because the mobility of the human body is bigger and the topology changes dramatically, these require that sensor nodes transmit data in real time with high reliability and the energy of the nodes consumes balance which can prolong the network life. Therefore, new requirements for traditional wireless sensor network routing protocol are put forward.

The typical protocol of wireless sensor network mostly takes into account single performance. Many papers make improvement for these protocols: some take into account reducing the time delay performance and some take into account the energy utilization performance to make the network balance. All of them rarely involve the multiobjective optimization problem. Which are important for the application of the wireless sensor network in the wearable field.

The wireless sensor network (WSN) uses the CTP routing protocol (Collection tree protocol) to communicate between the sink node and sensor nodes. In order to guarantee the safety of communication, communication between the sensor nodes can be encrypted. The sensor node transmits its data or others nodes' data to the sink node by multihops transmission. The sink node collects all the data and then uploads them to a central data receiving control platform.

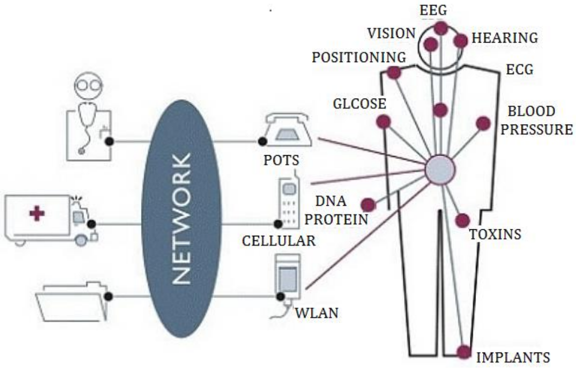

Fig. 5. Remote system for individual physiological monitoring of vital signs

Collection tree protocol is an aggregation protocol based on tree structure and sensor node delivery data to the sink node by unicast multihop. CTP uses the *ETX* value as the routing gradient (expected transmission count), and the *ETX* value of sink node is 0, the *ETX* of the other nodes is the *ETX* of its parent node plus the *ETX* of its parent link. The calculation of *ETX* is formulas (1) and (2). In formula (1), data_total represents the total packet delivered between two sensor nodes, and data_success represents the packet delivered successfully between two sensor nodes. In formula (2), EXT_{parent} presents *ETX* value of parent node, and $EXT_{linkparent}$ presents *ETX* value of parent link:

$$ETX = 10\ [\text{data\_total}/\text{data\_success} - 1] \quad (1)$$

$$EXT_{node} = EXT_{parent} + EXT_{linkparent} \quad (2)$$

Where EXT_{node} presents the *ETX* value of sensor node in wireless sensor network, when the nodes choose the path, they choose the path with the smallest *ETX* as the routing path. Formulas above show that when the sensor node chooses the next hop CTP only considers the packet transmission success rate, which is the reliability performance that we are concerned with.

For the requirements of the wearable wireless sensor network that is applied in the field of individual physiological monitoring, authors propose a routing selection algorithm based on the fuzzy logic to improve the CTP protocol. The basic idea of routing on fuzzy logic is calculating a reasonable value by fuzzy logic taking into account three parameters: reliability, time delay, and energy to replace the original *ETX* value.

The routing algorithm can be divided into three phases. The first phase is defining the input and output parameters, respectively, and choosing the membership functions which use the language set to express the parameters. Then, it is necessary to fuse the language information using fuzzy rules and get the evaluation results of candidate parent node. At last, it is necessary to defuse the evaluation results by center of gravity method and choose the best path.

The transmission model of the wireless networks and the coverage range mission region are shown in figure 6, where *A*, *B*, *C* and *D* are *A* neighbors which organize a neighbor node set.

Fuzzy logic algorithm includes three input and one output parameters. The first input parameter is a reliability $R(A, B)$ which calculates the probability of packets that are successfully transmitted between two sensor nodes A and B according to expression: $R(A,B)=n/m$, where *m* is the number packets to *B* from *A* with a certain time, and the number of packets *B* successfully received is *n*. The second input parameter is time delay *T* which calculates the average time delay that *B* successfully receives packets from *A*. Let the send time series is $\{T_1, T_2,..., T_{m-1}, T_m\}$ (the send time of *m* packet) and the receiving time series is $\{T^*_1, T^*_2,..., T^*_m\}$ (the receiving time of *n* packet), ignoring the lost package then $T(A,B) = \sum_i (T_i^* - T_i)$.

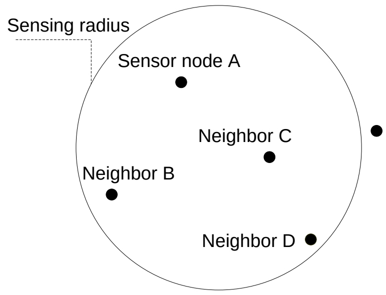

Fig. 6. The transmission model for the sensor networks

Third input parameter is energy parameter E which calculates the proportion of residual energy of one node accounted for the largest energy. Assume that E_r represents the residual energy of B and $E_{\max}$ represents the largest energy among the neighbor nodes then $E=E_r/E_{\max}$.

The fuzzy rules are composed of a series of fuzzy conditional statements in IF/THEN type. Part of the fuzzy rules are shown in Table.

Fuzzy rules

Rule	Reliability	Delay	Energy	Output
1	High	Small	Enough	Perfect
2	High	Small	General	Good
3	High	Small	Few	Acceptable
4	High	Medium	Enough	Good
5	High	Medium	General	Acceptable
6	High	Medium	Few	Unperfected
7	High	Large	Enough	Acceptable
8	High	Large	General	Unperfected
9	High	Large	Few	Bad

Center of gravity (COG) method may be used to defuzzify the fuzzy result. Since the fuzzy logic can reconcile conflicting objectives, this step can provide a quick ranking of multiple candidates (neighbor nodes). Each node maintains a routing table using the IF/THEN criterion. Forms of typical triangular membership functions of input and output variables are shown in Fig. 7–10: three for the input variables and six for output variable.

The presented analysis of the algorithm for choosing the optimal route based on fuzzy logic requires further execution of computer simulation and experimental verification taking into account the actual network topology and its comparison with the classical CTP routing protocol.

A Wireless sensor network is a special network that requires adaptive methods and techniques to meet the application requirements. Optimizing the energy consumption and enhancing the network lifetime while routing data from sensor nodes to the base station is the subject of extensive research works.

So the evaluation should be performed not only for energy efficient cluster-based routing protocol that uses a fuzzy logic module during the cluster-head election process but to increase the network lifetime. The objective of this research could be not to minimize the whole network consumption, but to balance the consumption over nodes to increase the network lifetime.

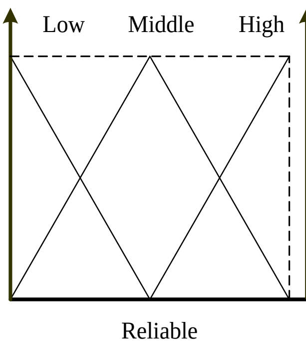

Fig. 7. The membership functions of R

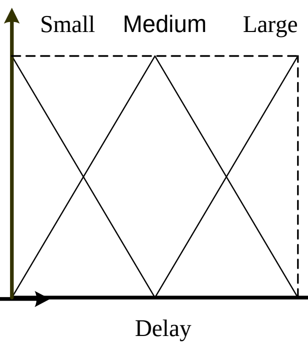

Fig. 8. The membership functions of T

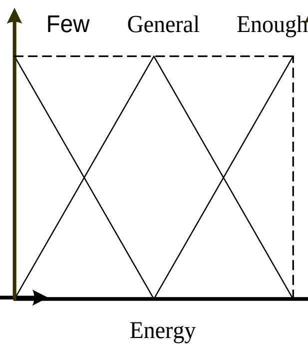

Fig. 9. The membership functions of E

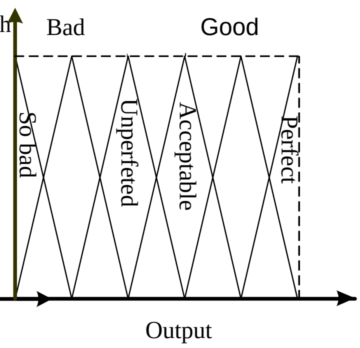

Fig. 10. The membership functions of output

Conclusion

The performed analysis of the use of the laws of thinking, invented by the creator, confirms their effectiveness for developing decision-making devices under uncertainty, although the construction of the surrounding world is carried out in accordance with the laws of clear logic. Virtually any control system can be replaced by a fuzzy logic control system with making decision based on a fuzzy inference system with or without a feedback loop. As result the theory of fuzzy logic is used in many applications, such as artificial intelligence, pattern recognition, control of unmanned military vehicles, and in knowledge-based systems such as weather forecasting, stock trading, traffic control, and medical diagnostics.

With regard to medicine, fuzzy logic is the basis for the development of such systems as the interpretation of medical data, the differentiation of the syndrome and the diagnosis of diseases, the optimal choice of treatment and real-time monitoring of patient data. Modern technologies based on fuzzy expert systems and wearable wireless body sensor networks have potential to tender a wide range of assistance to patients, medical personnel, and society through continuous monitoring in the ambulatory environment, early detection of abnormal conditions, supervised restoration and potential knowledge discovery through data mining of all gathered information.

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