Some Applications of Fuzzy Logic in Medical Area

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Abstract – This paper surveys the utilization of the fuzzy set and fuzzy control theory in the medicine area in general as well as on some concrete applications.

1. Introduction

The use of Artificial Intelligence Techniques (AITs) has now highly increased, especially, in the field of medicine such as diagnosis, treatment of illness, patient pursuit, prediction of disease risk and other medical fields. AITs offer the possibility to design such a system that allows building intelligent models for both predicting patients' response in treatment process and determining prediction of illness risk. Due to the fact that these fields, in which the computers are used, have very high complexity and especially uncertainty, the use of AITs such as fuzzy logic, artificial neural network, genetic algorithms, artificial immune systems and others have been developed by many researchers [1]. The proficiencies of AITs have been explored in almost every field of medicine. Artificial neural network was the most commonly used analytical tool whilst other artificial intelligent techniques such as fuzzy expert systems, evolutionary computation and hybrid intelligent systems have all been used in different clinical settings [2].

Fuzzy logic approach, rather than a certain or binary logic, uses a logic and decision mechanism which does not have certain boundaries like human logic. With this concept coined, one of its most common implementation was in fuzzy logic-based control mechanisms. Fuzzy logic control systems do not require complete model knowledge as in the other well known control systems such as proportional integral. For this purpose, many design methods have been derived. By making use of medicine expert's knowledge and experience uncertain sensual data fuzzy systems are being developed currently [3 - 6].

Fuzzy logic plays an important role in some medicine areas [7 -14]: To predict the response to treatment with citalopram in alcohol dependence [15]; To analyze diabetic neuropathy [16] and to detect early diabetic retinopathy [17]; To determine appropriate lithium dosage [18, 19]; To calculate volumes of brain tissue from magnetic resonance imaging (MRI) [20] and to analyze functional MRI data [21]; To characterize stroke subtypes and coexisting causes of ischemic stroke [22, 23]; To improve decision-making in radiation therapy [24]; To control hypertension during anesthesia [25]; To determine flexor-tendon repair techniques [26]; To detect breast cancer [27, 29], or prostate cancer [29, 41]; lung cancer [28], To assist the diagnosis of central nervous systems tumors (astrocytic tumors) [30]; To discriminate benign skin lesions from malignant melanomas [31]; To visualize nerve fibers in the human brain [32]; To represent quantitative estimates of drug use [33]; To study the auditory P50 component in schizophrenia [34].

Many other areas of application, to mention a few, are (a) to study fuzzy epidemics [35], (b) to make decisions in nursing [36], (c) to overcome electroacupuncture accommodation [37].

Fig. 1 indicates an exponential growth in the number of articles in medicine making use of fuzzy technology. The preliminary data we have for 2003 and further [38, 11] supports this tendency.

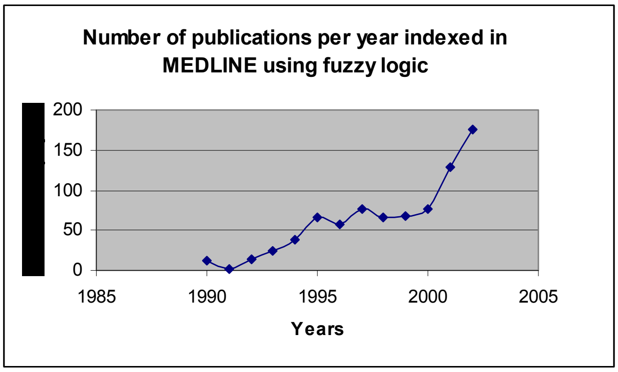

Fig. 1. Number of publications per year indexed in MEDLINE using fuzzy logic

Most of the medical knowledge available to a physician will always be fuzzy. When a person is given a medical examination, a wide variety of parameters, called symptoms in medical language, can be ascertained and measured. Due to the complexity of the human body, it is not possible to give a realistic limit for the number of established criteria. Because medical diagnostic investigations are very complex, it would be very difficult to cover this connection to describe this situation using crisp logical operations. The doctor who is faced with a patient has his/her own personal experience, knowledge from books, and mental ability. The doctor notes the patient's signs and symptoms, combines these with the patient's medical history, physical examination and laboratory findings, and then diagnoses the disease(s) [39, 40].

So, the goal of the fuzzy intelligent system is to imitate behavior of a doctor and give him consultation. In this paper, we showed some of our applications in different areas of medicine.

2. Some Applications

2.1. Applications for Determination of Disease Risk

There were designed two fuzzy expert systems (FES's) in this area: (1) It has been developed a rule-

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based FES that uses the laboratory and other data, and simulates an expert-doctor's behavior and can help the doctor to determine numerical value of the prostate cancer risk; (2) A hierarchical fuzzy expert system design for determining coronary heart disease's diagnosis according to the next 10 years risk of patient, and also treatment.

In the first study prostate specific antigen (PSA), age and prostate volume (PV) were used as system input parameters whereas prostate cancer risk (PCR) was used as output parameter. This system gives user a range of the risk of the cancer disease and facilitates the decision of the doctor if there is a need for the biopsy. The designed system was tested by the data taken from the literature and the clinical data. It was compared the diagnoses data of specialists of the every disease situation and literature data and it was seen that the system can be reliable for every situation [41].

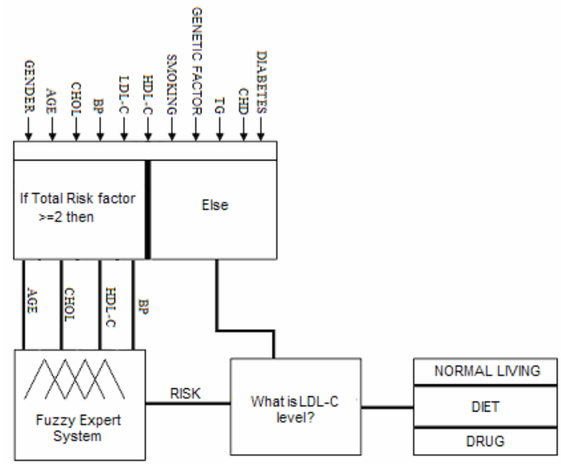

Fig. 2. A hierarchical system including FES

In the second study structure of FES is mix (hybrid). Fuzzy part of the system is as follows. Input values are age, cholesterol and blood pressure. Output value is risk. When the fuzzy part was constituted, patient's gender and being smoker were considered and four different groups have been formed regarding to these two criteria. These groups are; man-no smoking, man-smoking, women-no smoking and women-smoking. Thus, for each group, 36 rules were generated [42].

Firstly the total risk factor is calculated. To do this a small rule base that includes the parameters such as age, gender, smoking, genetic factor, triglyceride, HDL-C and others is arranged. If the total risk factor is equal or bigger than 2, then the fuzzy system begins to work (Fig. 2) [42].

After calculating 10-years risk by FES or if total risk factor is less than 2 then depending on LDL-C level the system will recommend three outputs (normal living, diet or drug treatment).

By the aid of the literature data [42] and the expert-doctor, there were determined fuzzification of the input and output parameters. For these parameters we determined: 3 fuzzy linguistic values (Young, Middle age and Old) for age; 3 fuzzy linguistic values (Low, Normal and High) for the Cholesterol level; 3 fuzzy linguistic values (Low, Middle and High) for the HDL Cholesterol level; 4 fuzzy linguistic values (Low, Middle High and Very high) for the Blood Pressure and 5 fuzzy linguistic values (Very low, Low, Middle, High and Very high) for CHD risk. As there are gender and smoking factors, which affect to the CHD risk of the patients, four different rule bases are arranged. In each of these rule bases, we have one hundred and eight rules. For example, if the patient is non-smoking then some rules of prepared rule base are shown in the Table 1 [42].

Table 1. Fuzzy Rules for non-smoking man

Rules	Inputs				Output
	Age	Cholesterol	HDL-C	Blood Pressure	Risk (%)
Rule 1	Young	Low	Low	Low	Very Low
Rule 2	Young	Low	Low	Middle	Very Low
…					
Rule 55	Middle Age	Normal	Middle	High	Low
…					
Rule 108	Old	High	High	Very High	High

We defined fuzzy membership expressions for the input parameters (Age, Cholesterol level, HDL Cholesterol level and Blood pressure) and output parameter that is CHD risk ratio. For example, fuzzy membership function for Blood Pressure is presented as formulas (1) and membership graphic for this fuzzy value according to the formulas (1) is shown in the Fig. 3 [42]. So, as example, for Blood Pressure value (let z) fuzzy membership expressions will be as (1):

$$\mu_{Low}(z)=\begin{cases}1 & z<100\\ \frac{(130-z)}{30} & 100\le z<130\end{cases}\quad \mu_{Middle}(z)=\begin{cases}\frac{(z\text{-}100)}{30} & 100\le z<130\\ 1 & 130\le z\le 140\\ \frac{(155-z)}{15} & 140\le z<155\end{cases}\quad \mu_{High}(z)=\begin{cases}\frac{(z\text{-}130)}{15} & 130\le z<145\\ 1 & 145\le z\le 180\\ \frac{(220-z)}{40} & 180\le z<220\end{cases}\quad \mu_{veryhigh}(z)=\begin{cases}\frac{(z\text{ - }145)}{55} & 145\le z<200\\ 1 & z\ge 200\end{cases} \tag{1}$$

For CHD Risk output value (let R) fuzzy membership expressions will be as (2):

$$\mu_{VeryLow}(R)=\begin{cases}0 & R<1\\ \frac{(5-R)}{5} & 0\le R<5\end{cases}\quad \mu_{Low}(R)=\begin{cases}\frac{(R-2)}{3} & 2\le R<5\\ \frac{(15-R)}{10} & 5\le R<15\end{cases}\quad \mu_{Middle}(R)=\begin{cases}\frac{(R-5)}{10} & 5\le R<15\\ \frac{(25-R)}{10} & 15\le R<25\end{cases}$$

$$\mu_{High}(R)=\begin{cases}\frac{(R-15)}{5} & 15\le R<20\\ \frac{(35-R)}{10} & 20\le R<35\end{cases}\quad \mu_{VeryHigh}(R)=\begin{cases}\frac{(R-25)}{10} & 25\le R<35\\ 1 & R\ge 35\end{cases} \tag{2}$$

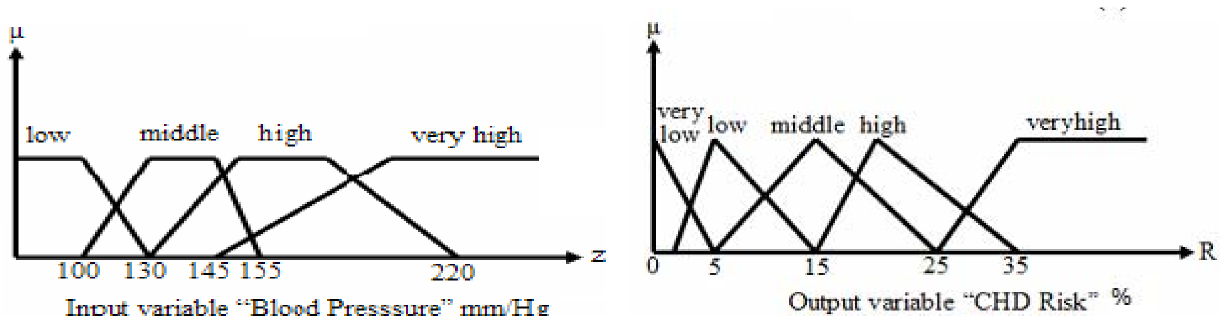

Fig. 3. Membership graphics for two fuzzy values

For the design of the system, Visual Basic is used as software package. For facilitation of entering the data of patients to the system, user-friendly interface is included in the design. A view of this interface is shown in Fig. 4. As can be seen from Fig. 4 [42], for the non smoking man patient with age 57 years, cholesterol 220 mg/dl, blood pressure 120 mm/Hg and HDL-C 38 mg/dl the calculated CHD risk is included to the groups low, middle and high and is % 13.75. So, for this case the system recommended a drug therapy.

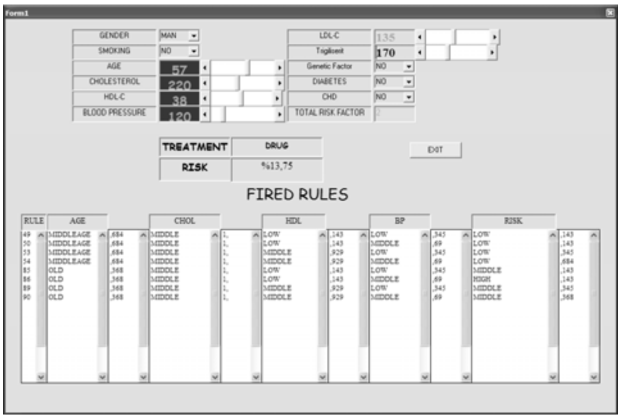

Fig. 4. Interface for the calculation of the CHD risk ratio

So, designed systems showed that such systems can be very useful for physicians for decision process.

2.2. Applications in medical control systems [4, 43]

It is known that fuzzy control (FC) systems are more economical and accurate, than tradition control systems. A designed FES provided the conditions necessary for operating room in surgery area. How an operating room can be controlled with FES and its advantages and disadvantages have also been researched. To show FES's advantage a prototype operating room was built and a suitable configuration was designed. In this system heat, humidity, oxygen and particle values were used as input parameters, and a fresh air entrance and fan circulation were chosen as output parameters. With the help of an expert, appropriate linguistic expressions and the membership functions of these expressions were defined. The sensors were classified and sensor information was transferred to computer by aid of a designed interface. The analyses of the results indicated that the controls performed with FES provide more economical, comfortable, reliable and consistent implementation than traditional systems. Thus, they are feasible in a real operating room. Accompanied by an expert, the air-condition systems of the operating rooms in Selcuk University Meram Faculty of Medicine were studied. The project was examined to see how FES can have positive contributions to the normal control systems (PID). In operating rooms where surgeries are performed important features including hygiene, heat, light, air and particles are so essential. These parameters are important for the health of the patients and the operator personnel, for the success of operation and for the prevention of possible complications during and after surgery. Some special conditions like maintaining the temperature in operating rooms at a certain level, reducing the particles in the room to the minimum level, maintaining the humidity level at the desired level and constantly maintaining the same level of fresh air are necessary and their control is required.

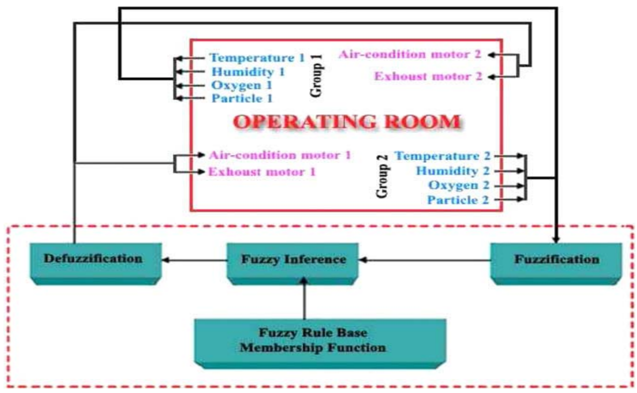

Fig. 5. The fuzzy control system model designed for the control system

Because of these reasons, to provide a better and comfortable environment, a different FC system has been designed which is different from other control systems (Fig. 5) [4, 43]. In order to determine the data (value) of the environment conditions that will be controlled, eight different sensors that exist in the operating room were used. These values are given in Celsius ($^{\circ}$C) for temperature, the humidity amount in the environment and oxygen level in percentage (%), and in pars per million (PPM) for particle number. Taking these four different values from two different places of the operating room

Adaptive Fuzzy Control (AFC) system was designed and two different sensor groups were used. In order to control AFC system, fresh air and exhaust fans were placed in two different places, and their fan circulations were designed as output parameters.

With the air-conditioning system, the operating room environment fresh air level, the heating and cooling of the air, and maintaining the humidity level at a desired level were all managed. There was an air-condition system for each sensor group, and after the assessment of input data by FES the heating/cooling and fan circulation were adjusted (Fig. 5). FC input and output values are defined in three language expressions- as low, normal and high.

Four parameters were chosen as input and the language expressions are fuzzified as Low, Medium and High.

For the output parameters, the fan motors circulation values are between 1000. . .4000 (Cr/Min). The heating and cooling values in air-conditioning system are between 15 and 28 °C. These parameters are also fuzzified as Low, Medium and High.

The system assesses the temperature, humidity, oxygen and the number of particles in the air and adjusts the speed of the fan and compressor motors and also the heating and cooling values of air-conditioner. For all the fuzzy inferences, Mamdani inference mechanism was preferred, since it is easy and better suited for the design of fuzzy system.

C# was used for the designed system and the user interface is shown in the Fig. 6. The data received from the sensors were transferred to PC with an RS232 serial port. These data were renewed every 30 s. The designed system was implemented in a prototype of operating room and the results were recorded. These results are also gathered with designed software. For this experiment, four people stayed in the prototype of the operating room for 80 minutes. The data that were gathered were all taken from the sensors and the air-condition system. The exhaust motor speeds were displayed and then saved to the FES computer.

2.3. Applications for Determination of Drug Dose

It is very important to determine the amount of the drug dose for patients and it depends on various items such as age, weight, sex, disease history of patients, blood segmentation and etc. There is no formulation for determining drug dose according to these items. In many fields of medicine from kidney diseases to diagnosis of cancer, from asthma to determination of dose of medicine, fuzzy logic based approaches have been developed and used.

One of our applications is determination of the drug dose by FES in treatment of chronic intestine inflammation [1, 41]. Symptoms of his illness such as sedimentation and prostate specific antigen are used to design of FES to determine the drug (salazopyrine) dose. Suitable drug dose for patients is obtained by using data of ten patients. The results of some patients are compared with the doses recommended to them by the physician. As a result, it has been seen that proposed system helped to shorten the treatment duration and minimize or remove the negative effects of determination of drug dose for helping physicians.

Fig. 6. The main page view of the program interface.

2.4. Some Other Applications

In some areas pure fuzzy logic method may have insufficient effects. In many medical applications soft computing methods give more productive results. As an example we can show rule extraction problem. Artificial Neural Network (ANN) usually reaches high classification accuracy, but the obtained results in most cases may be incomprehensible. This fact is causing a serious problem in medical data mining. The rules that are derived from ANN are needed to be formed to solve this problem and various methods have been improved to extract these rules. We have developed a method that uses ANN, fuzzy logic and Artificial Immune System algorithm to extract rules from trained hybrid neural network. The method was applied to medical datasets from University at California at Irvine machine learning repository. The datasets are Cleveland heart disease, hepatitis, breast cancer and EKG data. The proposed method achieved accuracy value 96.4 %, 96.8 %, 94.59 % and 92.31 % for Cleveland heart disease, hepatitis, ECG and breast cancer datasets respectively [44, 45]. It has been observed that these results are one of the best results comparing with results obtained from related previous studies.

3. CONCLUSION

In the study some applications of fuzzy logic method in medical area were described and presented. The fuzzy expert systems for determination of prostate cancer risk and coronary heart disease's risk were described. These systems aid to physicians in the decision processes. It was also presented a fuzzy control system for operating room to control air condition and other parameters. This system has more advantages than traditional control systems. Determination of drug dose is another application of fuzzy system and one of these systems was described here. Finally, we briefly refer to an application of hybrid fuzzy-neuro system in the extraction rule processes from neural networks.

Author and his collaborators believe that fuzzy logic, fuzzy control and hybrid systems will be widely used in medicine area in the near future.

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