DESIGN OF A FUZZY EXPERT SYSTEM FOR DETERMINATION OF CORONARY HEART DISEASE RISK

Novruz ALLAHVERDI  Serhat TORUN  Ismail SARITAS

Abstract: The aim of this study is to design a Fuzzy Expert System to determine coronary heart disease (CHD) risk of patient for the next ten-years. The designed system gives the user the ratio of the risk and may recommend using one of three results; (1) normal live; (2) diet; (3) drug treatment. The data (risk ratio) obtained from designed system are compared with the data in the literature [4] and better results are observed in the designed system. The system can be viewed as an alternative for existing methods to determine CHD risk.

Key words: Coronary Heart Disease Risk, Fuzzy Expert System, Cholesterol

INTRODUCTION

Nowadays the use of computer technology in the fields of medicine area diagnosis and treatment of illnesses and patient pursuit has highly increased. Despite the fact that these fields, in which the computers are used, have very high complexity and uncertainty, the use of intelligent systems such as fuzzy logic, artificial neural network and genetic algorithm have been developed.

In many fields of medicine fuzzy logic based approaches have been developed and used. For instance, fuzzy expert system for calculating the prostate cancer diseases risk has been developed [8]. Other application; chronic intestine illness symptoms such as sedimentation and prostate specific antigen are used for the design of fuzzy expert system to determine the drug dose [2]. A fuzzy expert system that deals with diagnosis and treatment of male impotence has been implemented and experimental results showed that this system did quite better than non-expert urologist and about % 79 as a well as the expert did [6]. Applied to the CHD risk assessment domain, an architecture based on fuzzy objects has been proposed and proven to be highly adequate for capturing and efficiently processing case-knowledge. Moreover, as this scheme is designed upon well-established object-oriented principles, it has been shown that it can seamlessly integrate in a wider, more general knowledge management regime [5]. In the study [9] an alternative is presented for scenarios where a larger number of rule antecedents apply to the same rule consequent. Results of an application of the method in the domain of CHD risk assessment indicate the value of the method.

In the domain of CHD risk, cholesterol has been identified as one of the main risk factor for myocardial infarction and subsequent sudden death [10]. In a blood test, a clinician first finds out what a subject’s Total Cholesterol level is. If this level is too high then further measurements of low density lipoprotein (LDL) cholesterol and high density lipoprotein (HDL) cholesterol are required [11]. The two ratios Total/HDL and LDL/HDL are also important because they provide more meaningful indicators of CHD risk than Total Cholesterol per se. However, having the values for Total, LDL, HDL, Total/HDL, and LDL/HDL in front of him, for example, a clinician simply might say that a subject’s Cholesterol in terms of CHD risk is normal [5, 9, 10].

Risk assessment for determining the 10-years risk for CHD development is carried out using Framingham risk scoring. The risk factors included in the Framingham calculation of 10-year risk are: age, total cholesterol, HDL cholesterol, systolic blood pressure, treatment for hypertension, and cigarette smoking. The first step is to calculate the number of points for each risk factor. For initial assessment, values for total cholesterol and HDL cholesterol are required. Because of a larger database, Framingham estimates are more robust for total cholesterol than for LDL cholesterol. Note, however, that the LDL cholesterol level remains the primary target of therapy. Total cholesterol and HDL cholesterol values should be the average of at least two measurements obtained from lipoprotein analysis. The used blood pressure value is obtained at the time of assessment, regardless of whether the person is on anti-hypertensive therapy. However, if the person is on antihypertensive treatment, an extra point is added beyond points for the blood pressure reading because treated hypertension carries residual risk. The average of several blood pressure measurements, as recommended by the Joint National Committee, is needed for an accurate measure of baseline blood pressure. The designation “smoker” means any cigarette smoking in the past month. The total risk score sums the points for each risk factor. The 10-years risk for myocardial infarction and coronary death is estimated from total points, and the person is categorized according to absolute 10-years risk as indicated above [4]. As seen from these attitudes, the next 10-years CHD risk is calculated step by step where each step requires certain time.
As it is seen from the Table 1 [3] the values of Total Cholesterol and HDL are accepted as fuzzy. The value of LDL Cholesterol is not accepted as fuzzy. If we will add here the factors age and blood pressure parameters, that are also fuzzy, we can develop and investigate a fuzzy system to determine a risk ratio of CHD. According to ATP III report, diabetes is equivalence CHD [3], because of it this factor is also considered in designing system

<table>
<thead>
<tr>
<th>LDL Cholesterol</th>
<th>&lt;100</th>
<th>Optimal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100-129</td>
<td>Near optimal/above optimal</td>
</tr>
<tr>
<td></td>
<td>130-159</td>
<td>Borderline high</td>
</tr>
<tr>
<td></td>
<td>160-189</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>&gt;=190</td>
<td>Very high</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Cholesterol</th>
<th>&lt;200</th>
<th>Desirable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>200-239</td>
<td>Borderline high</td>
</tr>
<tr>
<td></td>
<td>&gt;=240</td>
<td>High</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HDL Cholesterol</th>
<th>&lt;40</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&gt;=60</td>
<td>High</td>
</tr>
</tbody>
</table>

Determination of the next 10-years risk also depends on various items such as weight, smoking, sex, disease history of patients, family genetic factors, blood sedimentation and etc. And there is no formulation for determining the risk according to these items.

In this study, a fuzzy expert system (FES) is designed for determining CHD risk ratio according to next 10-years risk of patient. The system presents alternative results to the doctor instantly, as the data of a patient are inputted to the system.

**FUZZY EXPERT SYSTEM**

Fuzzy logic is a mathematical discipline that we use every day and helps us to reach the structure in which we interpret our own behaviors. Its basis is formed by “true” and “false” values and Fuzzy Set Theory (FST) through which the values in between –“partially true”, “partially false”- are determined.

FST is a theory that aims to express the uncertainties of life such as “warm” and “cool” which are in between “hot” and “cold” mathematically. And behind these values there is an unclear numerical value. Generally, fuzzy expert systems (FES) are the systems that are based on knowledge or rule. That is, in the basis of a FES lie the fuzzy “if-then” rules [1].

After deciding on designing a fuzzy system the first step to follow is to collect the fuzzy rules of “if-then”. These rules are generally collected with the help of an expert [1].

In FES model, the input and output values of the system are crisp values. By fuzzification these crisp input values, its fuzzy membership values and degrees are obtained. These obtained fuzzy values are processed in fuzzy inference mechanism. Here, the fuzzy output values which are also obtained using rule-base are send to the defuzzification unit, and from the this unit the final crisp values are obtained as output [1].

**MATERIALS AND METHODS**

In this study we assume that the age, cholesterol level, high density lipoprotein cholesterol and blood pressure level essentially determine the CHD risk ratio. So, these four parameters will be used as input to designed system. If any CHD risk is calculated by the system then a kind of treatment process will be determined according to LDL-C level. There are three different risk categories. Risk categories, LDL-C level of a patient at each categories and treatment type according to LDL-C level have been given in the Table 2. This table defines LDL-C goal, cut-points for initiation of therapeutic lifestyle change (TLC), drug consideration for persons with three categories of risk: CHD and CHD risk equivalents; multiple (2+) risk factors (10-year risk 10-20% and <10 %) and 0-1 risk factor.
Table 2. LDL Cholesterol Goals and Cutpoints for Therapeutic Lifestyle Changes (TLC) and Drug Therapy in Different Risk Categories [4].

<table>
<thead>
<tr>
<th>Risk category</th>
<th>LDL-C Goal</th>
<th>LDL Level at Which to Initiate Therapeutic Lifestyle Changes (TLC)</th>
<th>LDL Level at Which to Consider Drug Therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHD or CHD Risk Equivalents (10-year risk &gt;20%)</td>
<td>&lt;100 mg/dl</td>
<td>≥ 100 mg/dl</td>
<td>≥ 130 mg/dL (100-129 mg/dL: drug optional)</td>
</tr>
<tr>
<td>2+ Risk Factors (10-year risk 20%)</td>
<td>&lt;130 mg/dl</td>
<td>≥ 130 mg/dl</td>
<td>10-year risk 10-20%: ≥ 130 mg/dL</td>
</tr>
<tr>
<td>0-1 risk factor</td>
<td>&lt;160 mg/dl</td>
<td>≥ 160 mg/dl</td>
<td>≥ 190 mg/dL (160-189 mg/dL: LDL-lowering drug optional)</td>
</tr>
</tbody>
</table>

Firstly the total risk factor is calculated. For this, a small rule base is arranged which is included the parameters age, gender, smoking, genetic factor, triglyceride, HDL-C and others. if the total risk factor is equal and bigger than 2, the fuzzy system begins to work (Fig. 1).

Figure 1. A hierarchical system including FES

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

By the aid of the literature data [2] and the expert-doctor, we are determined fuzzification of the input and output parameters. For these parameters we take up: 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 arranged rule base are shown in the Table 3.

We are defined fuzzy membership expressions for the input parameters (Age, Cholesterol level, HDL Cholesterol level and Blood pressure) and output parameter CHD risk ratio (Formulas 1-5). Membership graphics for these fuzzy values according to these formulas are shown in the Fig. 2.

For Age value (let x) fuzzy membership expressions will be as:
Table 3. Fuzzy Rules for non-smoking man

<table>
<thead>
<tr>
<th>Rules</th>
<th>Inputs</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule 1</td>
<td>Young</td>
<td>Low</td>
</tr>
<tr>
<td>Rule 2</td>
<td>Young</td>
<td>Low</td>
</tr>
<tr>
<td>Rule 3</td>
<td>Young</td>
<td>Low</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Rule 55</td>
<td>Middle age</td>
<td>Normal</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Rule 108</td>
<td>Old</td>
<td>High</td>
</tr>
</tbody>
</table>

\[
\begin{align}
\mu_{\text{young}}(x) &= \begin{cases} 
\frac{40 - x}{10} & 30 < x < 40 \\
\frac{1}{20} & 50 < x < 70 
\end{cases} \\
\mu_{\text{middle}}(x) &= \begin{cases} 
\frac{x - 30}{10} & 30 < x < 40 \\
\frac{1}{20} & 50 < x < 70 
\end{cases} \\
\mu_{\text{old}}(x) &= \begin{cases} 
\frac{x - 50}{20} & 50 < x < 70 
\end{cases}
\end{align}
\]

(1)

For Cholesterol value (let \( y \)) fuzzy membership expressions will be as:

\[
\begin{align}
\mu_{\text{Low}}(y) &= \begin{cases} 
\frac{200 - y}{40} & y < 160 \\
\frac{1}{40} & 160 < y < 200 
\end{cases} \\
\mu_{\text{Normal}}(y) &= \begin{cases} 
\frac{y - 160}{40} & 160 < y < 200 \\
\frac{1}{240} & 240 < y < 280 
\end{cases} \\
\mu_{\text{High}}(y) &= \begin{cases} 
\frac{y - 240}{40} & 240 < y < 280 \\
\frac{1}{280} & y > 280 
\end{cases}
\end{align}
\]

(2)

For HDL-C value (let \( h \)); fuzzy expressions will as:

\[
\begin{align}
\mu_{\text{Low}}(h) &= \begin{cases} 
\frac{40 - h}{15} & h < 25 \\
\frac{1}{20} & 25 < h < 40 
\end{cases} \\
\mu_{\text{Middle}}(h) &= \begin{cases} 
\frac{h - 25}{15} & 25 < h < 40 \\
\frac{1}{30} & 40 < h < 50 \\
\frac{1}{90} & 50 < h < 60 
\end{cases} \\
\mu_{\text{High}}(h) &= \begin{cases} 
\frac{h - 50}{20} & 50 < h < 60 \\
\frac{1}{90} & h > 60 
\end{cases}
\end{align}
\]

(3)

For Blood Pressure (let \( z \)) value fuzzy membership expressions will be as:

\[
\begin{align}
\mu_{\text{Low}}(z) &= \begin{cases} 
\frac{130 - z}{30} & z < 100 \\
\frac{1}{10} & 100 < z < 130 
\end{cases} \\
\mu_{\text{Middle}}(z) &= \begin{cases} 
\frac{100 - z}{30} & 100 < z < 130 \\
\frac{1}{55} & 130 < z < 140 \\
\frac{1}{180} & 140 < z < 155 
\end{cases} \\
\mu_{\text{High}}(z) &= \begin{cases} 
\frac{155 - z}{55} & 145 < z < 200 \\
\frac{1}{z} & z > 200 
\end{cases}
\end{align}
\]

(4)

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

\[
\begin{align}
\mu_{\text{Very Low}}(R) &= \begin{cases} 
0 & R < 1 \\
\frac{5}{5} & 0 < R \leq 5 
\end{cases} \\
\mu_{\text{Low}}(R) &= \begin{cases} 
\frac{R - 2}{3} & 2 \leq R < 5 \\
\frac{5}{5} & 5 \leq R \leq 15 
\end{cases} \\
\mu_{\text{Middle}}(R) &= \begin{cases} 
\frac{R - 5}{10} & 5 \leq R < 15 \\
\frac{15}{15} & R \geq 25 
\end{cases} \\
\mu_{\text{High}}(R) &= \begin{cases} 
\frac{R - 15}{5} & 15 \leq R < 20 \\
\frac{5}{5} & 20 \leq R \leq 25 \\
\frac{25}{25} & R \geq 35 
\end{cases} \\
\mu_{\text{Very High}}(R) &= \begin{cases} 
\frac{R - 25}{10} & 25 \leq R < 35 \\
\frac{35}{35} & R \geq 35 
\end{cases}
\end{align}
\]

(5)

Membership graphics are shown in Fig. 2.

108 fuzzy rules (Table 3), some which are given below, are formed and for each rule the validity value is found out:

Rule 1: if Age is Young and Cholesterol is Low and HDL-C is Low and Blood Pressure is Low then Risk is Very low;

Rule 2: if Age is Young and Cholesterol is Low and HDL-C is Low and Blood Pressure is Middle then Risk is Very low;

Rule 3: If Age is young and Cholesterol is Low and HDL-C is Low and Blood Pressure is High then Risk is Very low;

... Rule 55: if Age is Middle age and Cholesterol is Normal and HDL-C is Middle and Blood Pressure is High then Risk is Low;

... Rule 108: If Age is Old and Cholesterol is High and HDL-C is High and Blood Pressure is Very high then Risk is High.
As the inference mechanism Mamdani approach is used. The validity degrees ($\alpha$) for each rule according to Mamdani max-min rule are shown with the formulas below.

\[
\begin{align*}
\alpha_1 &= \min(\text{young}(x), \text{low}(y), \text{low}(h), \text{low}(z)) \\
\alpha_2 &= \min(\text{young}(x), \text{low}(y), \text{low}(h), \text{middle}(z)) \\
\alpha_3 &= \min(\text{young}(x), \text{low}(y), \text{low}(h), \text{high}(z)) \\
&\vdots \\
\alpha_{55} &= \min(\text{middle age}(x), \text{normal}(y), \text{middle}(h), \text{high}(z)) \\
&\vdots \\
\alpha_{108} &= \min(\text{old}(x), \text{high}(y), \text{high}(h), \text{very high}(z))
\end{align*}
\]

The maximum of the validity degrees of the triggered rules are calculated with the formulas below.

\[
\alpha_{1,2,...,n} = \max(\alpha_1, \alpha_2, \ldots, \alpha_n)
\]

In the defuzzification, the exact expression is obtained with “centroid” method according to the validity degree.

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. 3. As can be seen from figure, for the non-smoking man patient with age 45 years, cholesterol 300 mg/dL, blood pressure 155 mm/Hg and HDL-C 47 mg/dL, the rules 67 and 68 are fired. The calculated CHD risk is included to the groups high and very high and is 15%. So, for this case the system is recommended a drug therapy.

CONCLUSION

Results of developed system and literature have been compared in Tables 4 and 5. In the Table 4, the risk values of non-smoking patients (men) who have 2+ risk factors are shown. As seen from these Tables, there are some risk values which are similar for both ATP III and FES. On the other hand, there are some cases where patient is in one risk group according to ATP III (Framingham risk scoring) and the FES finds it in another risk group. The non-smoking men patients 8 and 14 are in the group with Low risk according to the ATP III calculation [3] whereas
FES finds for them Middle and High risk groups for the patient 8, and Middle risk group for the patient 14 (see Table 4).

Table 4. According to 2+ risk factor CHD risk for non-smoking and smoking men

<table>
<thead>
<tr>
<th>Patient Number</th>
<th>Age</th>
<th>CHOL</th>
<th>HDL-C</th>
<th>BP</th>
<th>Non-Smoking Men According to ATP III, CHD Risk</th>
<th>Smoking Men According to ATP III, CHD Risk</th>
<th>Non-Smoking Men According to FES, CHD Risk</th>
<th>Smoking Men According to FES, CHD Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>180</td>
<td>37</td>
<td>160</td>
<td>0</td>
<td>2</td>
<td>1.84</td>
<td>9.34</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
<td>190</td>
<td>45</td>
<td>145</td>
<td>0</td>
<td>4</td>
<td>6.27</td>
<td>16.4</td>
</tr>
<tr>
<td>3</td>
<td>48</td>
<td>260</td>
<td>33</td>
<td>120</td>
<td>8</td>
<td>22</td>
<td>12.7</td>
<td>23.5</td>
</tr>
<tr>
<td>4</td>
<td>57</td>
<td>300</td>
<td>67</td>
<td>110</td>
<td>8</td>
<td>14</td>
<td>11.6</td>
<td>18.4</td>
</tr>
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<td>5</td>
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<td>250</td>
<td>54</td>
<td>170</td>
<td>18</td>
<td>22</td>
<td>21</td>
<td>24.8</td>
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<td>6</td>
<td>75</td>
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<td>25</td>
<td>135</td>
<td>30</td>
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<td>26</td>
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<td>1.85</td>
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<td>310</td>
<td>33</td>
<td>140</td>
<td>8</td>
<td>30</td>
<td>19.2</td>
<td>28.2</td>
</tr>
<tr>
<td>9</td>
<td>55</td>
<td>300</td>
<td>26</td>
<td>200</td>
<td>30</td>
<td>30</td>
<td>24.7</td>
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<td>10</td>
<td>60</td>
<td>230</td>
<td>39</td>
<td>110</td>
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<td>16</td>
<td>13.7</td>
<td>18.8</td>
</tr>
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<td>11</td>
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<td>210</td>
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<td>130</td>
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<td>200</td>
<td>28</td>
<td>30</td>
<td>26.4</td>
<td>30.6</td>
</tr>
</tbody>
</table>

In the same Table patient 19 is in the Middle risk group according to the ATP III calculation, but we find Middle and High risks for him. The smoking patients 2 and 13 (see Table 4) are in the Low risk group according to the ATP III calculation, whereas the FES finds Middle and High risks for the patient 2, Low and Middle risks for the patient 13. In the Table 5, for example non-smoking women 14, 15, 16 and 19 are in the Low risk group according to the ATP III calculation, but according to the FES their risk groups are Low and Middle. For the smoking patients 13 and 15 (Table 5) it is calculated Low and Middle risk, respectively, but our approach is found for the patient 13, Low and Middle and for the patient 15, High and Very high risk groups. So, developed system...
finds very different results for only two patients (non-smoking man 8 and smoking woman 15). For the rest patients found risk groups are approximately the same.

Table 5. According to 2+ risk factor CHD risk for non-smoking and smoking women

<table>
<thead>
<tr>
<th>Patient Number</th>
<th>AGE</th>
<th>CHOL</th>
<th>HDL-C</th>
<th>BP</th>
<th>According to ATPIII, CHD Risk</th>
<th>According to FES, CHD Risk</th>
<th>According to ATPIII, CHD Risk</th>
<th>According to FES, CHD Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>180</td>
<td>37</td>
<td>160</td>
<td>0</td>
<td>1,84</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
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<td>16</td>
</tr>
<tr>
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This system can be developed by Neuro-Fuzzy Network and can obtain very sensitive results.

ACKNOWLEDGEMENTS

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REFERENCES


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