International Journal of
Intelligent Systems and Applications in Engineering

ISSN:2147-6799 www.ijisae.org Original Research Paper

A fuzzy approach for determination of prostate cancer

I. Saritas,*[a] N. Allahverdi [b] and U. Sert [c]

Received 20th February 2013, Accepted 28th February 2013

Abstract: *Goal of this study is a design of a fuzzy expert system, its application aspects in the medicine area and its introduction for calculation of numeric value of prostate cancer risk. For this aim it was used prostate specific antigen (PSA), age and prostate volume (PV) as system input parameters and prostate cancer risk (PCR) as output. 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 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 available for every situation. It is observed that this system is rapid because it needs minimum calculation, economical, without any risk than traditional diagnostic systems, has also a high reliability than the other system and can be used as assistant system for physicians. Having used in the hospital this system was tested as decision support system and the approach used in this study can be used in difference studies and analyses, because the system is transparent and explainable to a user.*

Keywords: *Fuzzy logic, fuzzy expert system, prostate cancer, prostate specific antigen, prostate cancer risk.*

1. Introduction

In recent years, the methods of Artificial Intelligence have largely been used in the different areas including the medical applications. In the medicine area, many expert systems (ESs) were designed. ONCOCIN and ONCO-HELP are the ESs for diagnosis of the general cancer diseases (Allahverdi, 2002; Allahverdi & Yaldiz, 1998). For example, ONCO-HELP is a multimedia knowledge-based decision support system for individual tumour entities. It makes individual and prognosis-oriented treatment of patient's tumour possible (if corresponding predictor's respective prognostic factors are known). Through registration of individual patient data over tumour type, histology, metastatic type, metastasis localization and amount, as well as corresponding laboratory parameters together with a corresponding knowledge based on a patient individual prognosis-score can be determined. Using this score, a therapy concept is drafted. ONCO-HELP evaluates this concept by using therapy controls with regards to tumour progression/regression and side effects of the therapy. Consequently, a concept modification or a different therapy is proposed (Allahverdi & Yaldiz, 1998).

Computing technology and artificial intelligence are interdisciplinary research fields in computational science and it was proved that very respective area for application of these technologies has been the medicine diagnosis the last 20-25 years.

Various techniques in these areas such as ESs, neural networks, fuzzy logic, genetic algorithms, Bayesian statistics, chaos theory, etc, have been developed and applied to solve many challenging tasks in medicine and engineering design. There are some publications in the area prostate cancer prognosis or diagnosis by aid of soft computing methods (Abboad et al., 2001; Boegla et al., 2002; Lorenz et al., 2007; Nguyen et al., 2001; Ronco et al., 1999; Seker et al, 2003; Kaiser Permanente, 2007). In the study (Seker et al., 2003) a fuzzy logic based method for prognostic decision making in breast and prostate cancers is developed. In the study (Lorenz et al., 2007) five different trainable neuro-fuzzy classification algorithms based on different approaches to organize and classify biological data sets by the construction of a fuzzy interference system were investigated. The best classifier based on a mountain clustering algorithm reached recognition rates above 86 % in comparison to the Bayes classifier 79 % and the KNN classifier 78%. These results suggest that neuro-fuzzy algorithms have the potential to improve common classification methods significantly for the use in ultrasonic tissue characterization.

As seen from analysis of these studies, it is not quite possible to diagnose of prostate cancer fully based on only ultrasonography and image processing. In the prostate cancer disease except laboratory analysis of blood with aim to define the prostate specific antigen (PSA) and rectal definition of a prostate volume, here man's age plays great role. Recent modification of the PSA test is based on the observation that as man's age, the amount of PSA in the blood can normally rises without the presence of a prostate cancer. Thus, doctors can use what is referred to as an age-specific PSA, especially to evaluate borderline values. In the age-specific PSA, the normal values are adjusted for the age of the patient. Accordingly, the age-specific normal ranges are 0 to 2.5 *ng/ml* for men in their 40s, 0 to 3.5 *ng/ml* in their 50s, 0 to 4.5 *ng/ml* in their 60s, and 0 to 6.5 *ng/ml* for men 70 and over. Therefore, as an example, a PSA value of 4 *ng/ml* would be considered borderline for men in their 30s and 40s, but could be normal for men in their 50s, 60s, and 70s (Medicine Net, 2007).

[a] *Faculty of Technology, Selcuk University Campus,Konya,Turkey.*
Tel: +90 332 2233354; E-mail:isaritas@selcuk.edu.tr
[b] *Faculty of Technology, Selcuk University Campus,Konya,Turkey.*
Tel: +90 332 2233329; E-mail:noval@selcuk.edu.tr
[c] *Meram Medicine Faculty,Necmettin Erbakan University,Konya,Turkey.*
Tel: +90 332 2233329; E-mail:unalsert@hotmail.com
** Corresponding Author*

As shown from these data the borders of the age-PSA estimations are fuzzy. If one will add here the prostate volumes data, the fuzziness is seen clearly.

As known when the prostate cancer can be diagnosed earlier, the patient can be completely treated. If there is a biopsy for diagnosing, the cancer may spread to the other vital organs (Metlin et al., 1991; Saritas et al, 2003). For this reason the biopsy method is undesirable.

We have developed a rule-based fuzzy expert system (FES) that uses the laboratory and other data, and simulate an expert-doctor's behaviour and can be help doctor to determine of numerical value of the prostate cancer risk.

Prostate specific antigen (PSA), prostate volume (PV) and age of the patient are being used as laboratory data. Provided that using these data and getting help from an expert doctor the fuzzy rules which define the necessity of biopsy and the risk factor were developed. The designed system gives the user the patient's possibility ratio of the prostate cancer. The system was developed by aid of the Matlab 7.0. Comparison between the results of the developed FES and the data of 4641 patients from the literature (Brawer et al., 1999) showed that the FES gives close results. Additionally, the FES is rapid, economical, when compared to traditional diagnostic systems it has no risk and has also a high reliability and can be used as learning system for medical students, because the system is transparent and explainable to a user.

The paper is organized as bellow: In the second section, material and used methods are described. Then in the third section the developed system is discussed and a conclusion is given in the next section.

2. Materials and Methods

To develop the expert system in this study the laboratory data for the developed system were taken from the literature (Brawer et al., 1999] and (Seker et al., 2003). For the design process prostate specific antigen (PSA=A), age (B) and prostate volume (PV=C) are used as input parameters and prostate cancer risk (PCR=D) is used as output. For fuzzification of these factors the linguistic variables very small, small, middle, high, very high, very low, low and etc. were used. For the inference mechanism the Mamdani max-min inference was used. The system was developed by aid of the Matlab 7.0 fuzzy tool-box.

2.1. Fuzzy Expert System

An expert system (ES) can be viewed as fuzzy expert system (FES) if its rules are included fuzziness and parameters used by this ES can be fuzzy or can be fuzzification. Regardless the designed system it uses the amount of prostate specific antigen (PSA) in the blood of the patient, age and prostate volume (PV) of this patient for the system input parameters as crisp parameters, they are fuzzified when they input to the system. The same time prostate cancer risk (PCR) parameter viewed as output is fuzzy and because of this it has to be defuzzified. Thus in such a system with the fuzzy rules base and fuzzy inference mechanism there must be included to the system parts of fuzzification and defuzzification. General structure of the developed respective ES is shown in the Fig.1.

Amount of PSA (*ng/ml*), age (*years*) and PV (*ml*) were used as input parameters and range of PCR (*%*) was treated as output parameter in the designed system. Thus in this situation the system will have a structure as seen in Fig. 2.

Crisp values of three input parameters applied to the system input in during of the system work. As input parameters apply to the input, the system provides a firing of rule or rules in the fuzzy rules base which is/are suitable on respective fuzzy values of parameters. Then the fuzzy value(s) of PCR is (are) obtained using of Mamdani inference approach. Next, crisp value of PCR is obtained using a certain defuzzification method. The fuzzification part determines how fuzzy values are suitable to the crisp values of input parameters.

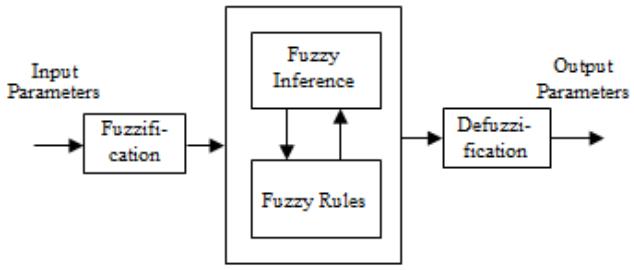


Figure 1. The Structure of FES

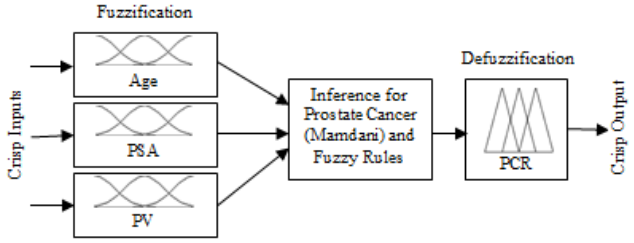


Figure 2. The Structure of the FES for Determination Prostate Cancer Risk

2.2. Fuzzification of Input and Output Parameters

In general the triangle membership function is one of the acceptable and simple methods to fuzzification of parameters applied in a fuzzy system. Therefore the triangle fuzzification method is used for the input and output parameters in the designed system. It was determined how many linguistic values will be used to present each parameter by aid of expert-doctor. These values are:

For PSA: Very Low (VL), Low (L), Middle (M), High (H) and Very High (VH);

For age: Very Young (VY), Young (Y), Middle Age (MA) and Old (O);

For prostate volume: Small (S), Middle (M), Big (B) and Very Big (VB);

For prostate cancer risk: Very Low (VL), Low (L), Middle (M), High (H) and Very High (VH).

So, these parameters are fuzzified and their membership functions are given literature (Saritas et al., 2003).

2.3. Forming of Fuzzy Rules Base and Defuzzification

Parts of the developed fuzzy rules are shown in the Table 1. Total of 80 rules are formed by aid of the expert-doctor and according to the literature data (Brawer et al., 1999). For example, Rule 1 and Rule 77 can be interpreted as follows:

Rule 1: If Age=Very Young and PSA=Very Low and PV=Very Small, then PCR=Very Low, i.e. if the patient's PSA is very low and patient is very young and patient's PV is very small, then patient's prostate cancer risk is very low.

Rule 77: If Age=Old and PSA=Very High and PV=Very Small, then PCR=Very High, i.e. if the patient's PSA is very high and patient is old and patient's PV is very small, then patient's

prostate cancer risk is high.

Table 1. Fuzzy rules (Saritas et al.,2003)

		Age		PSA		PV		PCR
1	If	VY	and	VL	and	S	then	VL
2	If	VY	and	VL	and	M	then	VL
3	If	VY	and	VL	and	B	then	VL
...		...		...		...		...
77	If	O	and	VH	and	S	then	VH
78	If	O	and	VH	and	M	then	VH
79	If	O	and	VH	and	B	then	VH
80	If	O	and	VH	and	VB	then	VH

The other rules can be interpreted by similar way. In this stage, true degrees (α) of the rules are determined for the each rule by aid of the min and then by taking max between firing rules. For example, for PSA=40 *ng/ml*, Age=55 *years*, PV=230 *ml* the rules 60 and 80 will be fired and we will obtain:

α_{60} = min(Very High PSA, Middle Age, Very Big PV)

α_{60} = min(1, 0.67, 1)=0.67

α_{80} = min(Very High PSA, Old Age, Very Big PV)

α_{80} = min(1, 0.33, 1)= 0.33

From Mamdani max-min inference we will obtain the membership function of our system as max(α_{60}, α_{80})=0.67. Then we can calculate the crisp output value. The crisp value of the PCR is calculated by the method centroid defuzzifier by the Eq.1.

$$\frac{\int D \quad le(D)dD}{\int \mu \quad le(D)dD} \qquad (1)$$

As also seen from the Fig. 3, obtained from the Matlab software, the value of PCR=78.4. This means that the patient has the prostate cancer with a possibility 78.4 %. Because this is a quite high percentage, doctor has to decide a biopsy.

3. Application aspects

The designed new system was used to the data of 119 patients in Ankara University Medicine Faculty in 2005 year. The comparing results of this system and real clinical data of the patients are shown in the Table 2. The results of the prediction of the cancer risk by the ratio of FPSA (Free PSA)/PSA, by online risk calculator (Cancer risk calculator, 2007) (Fig. 4 and 5) and the designed FES are given in this table. In the column of the "Results of Biopsy" the results are presented as "negative" and "positive", in the column of "FPSA/PSA" calculated by this division risk ratio is shown, in the columns online risk calculator and FES, calculated risk prediction ratio are presented by %.

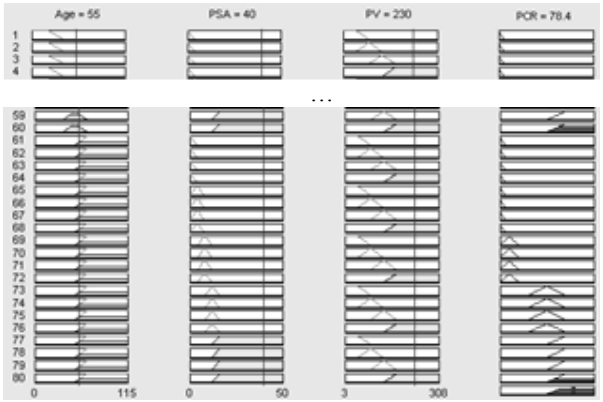


Figure 3. Calculation of the value PCR for the values PSA=40 *ng/ml*, Age=55, PV=230 *ml*

Table 2. Results of the biopsy, FPSA/PSA, risk ratios of online calculator and FES

Number of Patients	Input Variables of FES and Online Calculator			FPSA	Result of Biopsy	Risk ratio FPSA/PSA		Risk ratio of online calculator	Output Variable of FES
	Old	PSA	PV			FPSA/PSA	Predict		Risk ratio
1	44	7.60	38.00	0.80	Negative	0.11	Yes	12	10
2	51	6.76	15.00	0.28	Positive	0.04	Yes	5	9
3	51	44.00	83.00	14.00	Positive	0.32	No	61	80
4	53	4.50	39.00	0.85	Negative	0.19	No	13	6
5	53	5.83	25.00	0.40	Negative	0.07	Yes	7	8
6	53	8.34	25.00	0.62	Negative	0.07	Yes	10	20
7	54	5.62	28.00	0.84	Negative	0.15	Yes	13	8
8	54	17.30	90.00	4.75	Negative	0.27	No	38	79
9	54	17.30	45.00	1.54	Positive	0.09	Yes	19	79
10	55	10.51	54.00	2.36	Negative	0.22	No	26	40
11	56	8.90	26.00	3.04	Negative	0.34	No	30	30
12	56	9.05	39.00	0.77	Positive	0.09	Yes	12	31
13	56	16.00	146.00	1.35	Negative	0.08	Yes	18	78
14	57	12.56	52.00	8.27	Negative	0.66	No	50	58
15	58	4.48	67.50	0.72	Negative	0.16	No	11	6
16	58	4.62	48.00	0.51	Negative	0.11	Yes	9	7
17	58	5.20	58.00	1.22	Negative	0.23	No	16	8
18	58	16.39	27.00	15.09	Negative	0.92	No	62	78
19	59	0.28	168.00	0.12	Negative	0.43	No	3	2
20	59	8.36	55.00	0.63	Positive	0.08	Yes	10	30
21	59	18.20	77.00	3.23	Negative	0.18	No	31	78
22	59	19.48	79.00	4.87	Positive	0.25	No	39	78
23	59	22.51	42.00	1.58	Negative	0.07	Yes	20	78
24	59	22.65	66.00	2.45	Negative	0.11	Yes	26	80
25	60	6.58	65.00	0.97	Negative	0.15	Yes	14	9
26	60	10.60	30.00	1.78	Positive	0.17	No	21	40
27	60	11.45	46.00	2.23	Negative	0.19	No	25	45
28	60	14.79	38.00	1.02	Positive	0.07	Yes	62	72
29	60	15.51	35.00	3.26	Negative	0.21	No	31	80

30	61	4.60	37.00	0.50	Negative	0.11	Yes	8	6
31	61	10.33	62.00	2.62	Negative	0.25	No	27	37
32	61	10.36	35.00	2.05	Negative	0.20	No	23	39
33	61	10.59	56.00	1.80	Positive	0.17	No	21	40
34	61	18.30	62.00	1.28	Positive	0.07	Yes	66	79
35	62	6.12	52.00	1.48	Negative	0.24	No	19	9
36	62	6.20	25.00	0.27	Positive	0.04	Yes	44	9
37	62	8.37	43.00	0.94	Negative	0.11	Yes	14	21
38	62	8.79	45.00	0.96	Positive	0.11	Yes	14	27
39	62	20.00	53.00	1.04	Positive	0.05	Yes	68	79
40	62	51.74	29.00	3.52	Positive	0.07	Yes	33	79
41	63	8.80	31.00	1.98	Positive	0.23	No	23	27
42	64	5.70	36.00	1.70	Negative	0.30	No	21	8
43	64	6.96	45.00	0.64	Negative	0.09	Yes	10	10
44	64	8.00	40.00	0.60	Positive	0.08	Yes	49	10
45	64	11.08	26.00	1.12	Negative	0.10	Yes	15	43
46	64	16.28	21.00	1.13	Positive	0.07	Yes	16	80
47	65	4.39	30.00	0.95	Negative	0.22	No	14	5
48	65	5.15	47.00	0.81	Negative	0.16	No	12	8
49	65	7.61	23.00	0.44	Positive	0.06	Yes	48	10
50	65	7.82	75.00	1.78	Negative	0.23	No	21	10
51	65	8.33	32.00	1.21	Positive	0.15	Yes	50	20
52	66	4.38	33.00	1.03	Negative	0.24	No	15	5
53	66	6.72	61.00	0.93	Positive	0.14	Yes	13	9
54	66	7.65	89.00	1.81	Negative	0.24	No	22	10
55	66	9.00	74.00	1.70	Positive	0.19	No	21	29
56	66	9.86	49.00	2.35	Negative	0.24	No	26	36
57	67	4.39	28.00	0.04	Negative	0.01	Yes	2	5
58	67	5.65	24.00	0.58	Positive	0.10	Yes	42	8
59	67	6.24	65.00	1.37	Negative	0.22	No	18	9
60	67	8.20	36.00	1.67	Positive	0.20	No	20	27
61	67	9.68	41.00	0.72	Positive	0.07	Yes	53	35
62	67	15.93	69.00	0.97	Positive	0.06	Yes	63	79
63	67	28.00	47.00	4.20	Positive	0.15	No	36	80
64	68	5.09	47.00	0.12	Negative	0.02	Yes	3	8
65	68	5.51	45.00	0.62	Negative	0.11	Yes	10	8
66	68	7.20	33.00	0.26	Positive	0.04	Yes	47	10
67	68	9.25	91.00	0.33	Positive	0.04	Yes	52	32
68	68	12.10	61.00	1.95	Negative	0.16	No	23	50
69	68	23.70	109.00	2.38	Positive	0.10	Yes	26	80
70	68	140.00	117.00	20.00	Positive	0.14	Yes	68	80
71	68	140.00	54.00	4.60	Positive	0.03	Yes	38	80
72	69	8.80	34.00	0.79	Positive	0.09	Yes	12	27
73	69	11.06	38.00	3.30	Negative	0.30	No	31	43
74	69	15.31	74.00	4.68	Positive	0.31	No	38	75
75	69	61.00	46.00	6.06	Negative	0.10	Yes	43	80
76	69	70.56	45.00	4.25	Positive	0.06	Yes	36	80
77	69	146.00	29.00	10.70	Positive	0.07	Yes	54	80
78	70	5.39	120.00	1.03	Negative	0.19	No	15	8
79	70	5.39	42.00	0.69	Negative	0.13	Yes	11	8
80	70	13.00	40.00	2.01	Negative	0.15	No	23	60
81	70	13.95	119.00	1.92	Negative	0.14	Yes	22	67
82	70	19.20	44.00	1.94	Positive	0.10	Yes	23	80
83	70	21.94	29.00	1.56	Positive	0.07	Yes	19	80
84	70	27.70	63.00	2.49	Negative	0.09	Yes	26	80
85	71	6.08	48.00	1.30	Positive	0.21	No	43	9
86	71	12.64	50.00	1.01	Positive	0.08	Yes	59	57
87	71	22.00	57.00	2.64	Positive	0.12	Yes	27	80
88	72	6.64	32.00	1.82	Negative	0.27	No	22	9
89	72	13.31	33.00	0.51	Positive	0.04	Yes	60	63
90	72	13.31	33.00	0.50	Positive	0.04	Yes	60	63
91	72	20.00	48.00	1.58	Positive	0.08	Yes	20	80
92	72	46.00	36.00	4.92	Positive	0.11	Yes	39	80
93	72	77.00	48.00	6.40	Positive	0.08	Yes	44	80
94	73	4.65	41.00	1.95	Negative	0.42	No	23	6
95	73	7.25	19.00	0.40	Negative	0.06	Yes	47	10
96	73	7.60	74.00	2.38	Positive	0.31	No	26	10
97	73	19.00	90.00	1.30	Positive	0.07	Yes	67	80
98	73	29.52	91.00	2.90	Negative	0.10	Yes	29	80
99	73	47.40	87.00	7.53	Positive	0.16	No	48	80
100	74	12.52	27.00	1.48	Negative	0.12	Yes	19	56
101	74	150.00	54.00	25.00	Positive	0.17	No	72	80
102	75	4.61	16.00	0.81	Positive	0.18	No	12	6
103	75	10.00	34.00	0.76	Positive	0.08	Yes	12	37
104	76	9.81	56.00	3.67	Negative	0.37	No	33	36
105	76	13.61	61.00	2.71	Positive	0.20	No	28	65
106	76	13.83	54.00	2.76	Positive	0.20	No	28	67
107	76	21.00	86.00	1.14	Positive	0.05	Yes	69	80
108	77	10.00	60.00	0.60	Positive	0.06	Yes	10	37

109	77	12.05	28.00	3.26	Positive	0.27	No	31	51
110	77	56.00	51.00	4.11	Positive	0.07	Yes	36	80
111	78	4.50	180.00	0.92	Negative	0.20	No	13	6
112	78	26.10	46.00	2.25	Negative	0.09	Yes	25	80
113	78	26.13	235.00	2.16	Negative	0.08	Yes	24	80
114	78	31.60	57.00	2.80	Negative	0.09	Yes	28	80
115	79	17.10	41.00	1.30	Negative	0.08	Yes	17	80
116	80	69.51	28.00	20.00	Positive	0.29	No	68	80
117	81	4.50	28.00	0.97	Positive	0.22	No	14	6
118	81	68.36	52.00	24.11	Positive	0.35	No	71	80
119	88	10.40	32.00	0.78	Positive	0.08	Yes	12	39

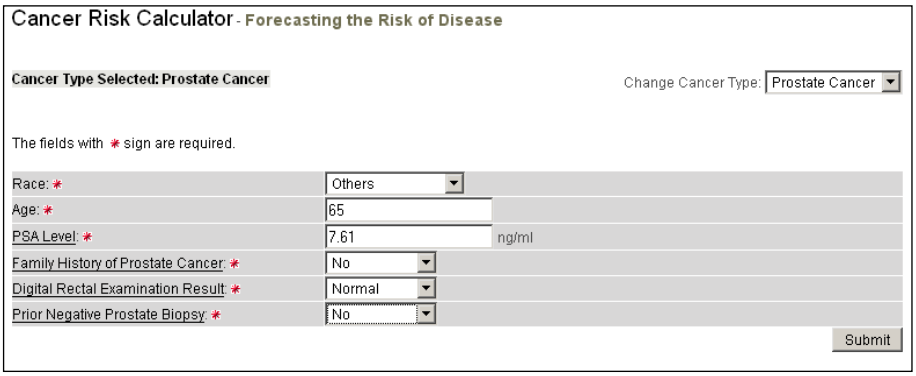


Figure 4. Online risk calculator page.

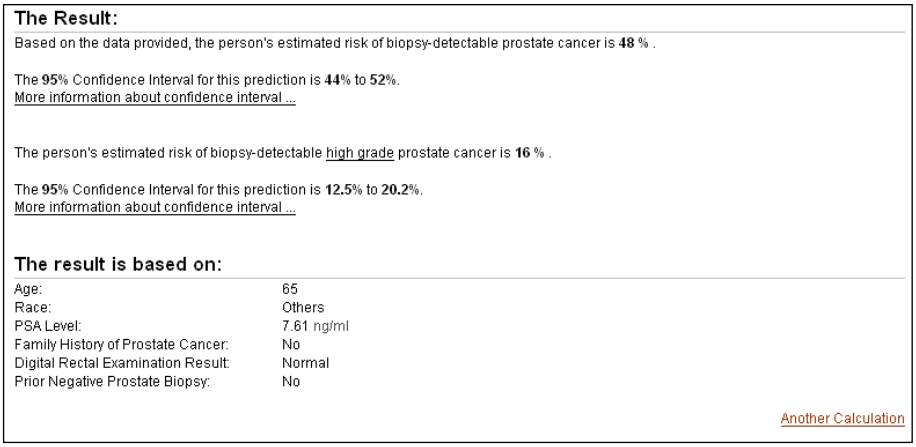


Figure 5. Online risk calculator results page.

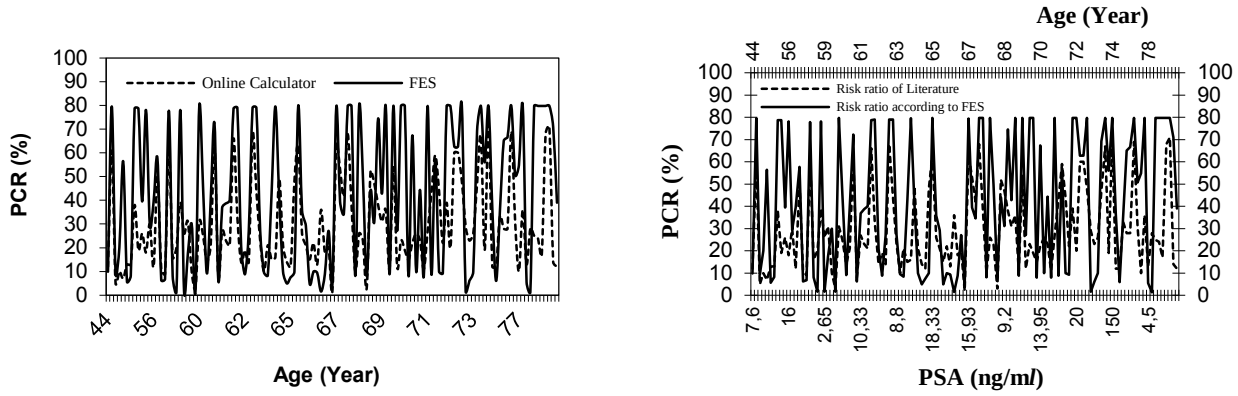
4. Discussion and conclusion

For discussion we analysed the results of biopsy of 119 patients with the results of the other methods (see Table 2). These analyses show that the true orientation ratio for 119 patients to doctor gives the methods: 60.50% FPSA/PSA, 62.18% online calculator method and 64.71% FES (Table 3). Besides, it is seen that for 56 patients from 119 patients, the using methods have different predictions and thus they have different orientation rations to the doctors. When we analysed only these patients we have seen that true bigger risk orientation ratio is fond by the FES method 75%. So, we can say that the FES method provides higher success ratio level to determine PCR than the other two methods, which have PCR ratios only 39.29% (FPSA/PSA) and 57.14% (online calculator).

The PCR ratio value's graphics are shown in the Fig. 6 and 7. In the Fig. 6.a, correlation graphic of PCR results according to age parameter of the patients calculated by the methods online calculator and FES are given. In the next graphic (Fig. 6.b) the correlation values of PCR according to the literature data and data calculated by FES are shown. In this graphic both age and PSA values are taken into account. In the Fig. 7.a, correlation graphic of PCR results according to PSA value of the patients calculated by the methods online calculator and FES are given. In the next graphic (Fig. 7.b) the correlation values of PCR according to the literature data and data calculated by FES are shown. In this graphic both age and PSA values are taken into account. From these graphics we can see that as age and PSA values are bigger, the FES predicts more correct forecasting.

Table 3. The Results of True Prediction

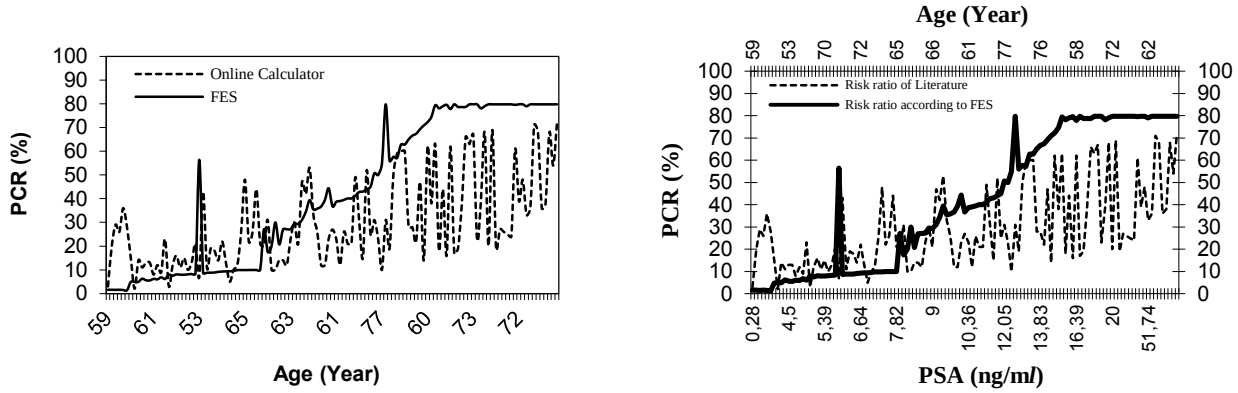
	FPSA/PSA	Online Calculator	FES
True prediction ratio of all patients (for 119 patients) (%)	60.50	62.18	64.71
True prediction ratio of the patients with different results (for 56 patients) (%)	39.29	57.14	75.00



a. PCR-Age

b. PCR-PSA-Age

Figure 6. Correlation graphic of PCR results according to ordered Age



a. PCR-Age

b. PCR-PSA

Figure 7. Graphic of PCR according to ordered PSA

Thus, the paper describes a design method and application aspects of a fuzzy expert system to define of the possibility of the determination of the prostate cancer risk, which can be used by the expert-doctors for treatment and by the students for learning scopes. The system does not answer if there is a cancer disease in the patient, but it gives a percentage of the possibility of the prostate cancer and helps the doctor to decide a biopsy or not.

This system can be developed further with increasing the knowledge rules from one side and with adding the neural network to the system from the other side. Besides, family genetic factor of a patient may be took into account. In this case the fuzzy rules have to be modified.

References

Abbod MF., von Keyserlingk DG., Linkens DA., Mahfouf M (2001). Survey of Utilization of Fuzzy Technology in Medicine and Healthcare. Fuzzy Sets and Systems. 120:331–349.

Allahverdi N (2001). Expert Systems: An Application of Artificial Intelligence. Nobel Press. Ankara. 1-248.

Allahverdi N., Yaldiz S (1998). Expert System Applications in Medicine and Example of Design of a Pre-Diagnosis Expert System. Proc. Second Turkish-German Joint Computer Application Days. 175-192.

Allahverdi N., Torun S., Saritas I (2007). Design of a Fuzzy Expert System for Determination of Coronary Heart Disease risk. International Conference on Computer Systems and Technologies-CompSysTech'07, June 2007, Rousse, Bulgaria. II.A: 14.1-14.8.

Boegla K., Adlassniga KP., Hayashic Y., Rothenfluhd TE., Leiticha H (2002). Knowledge Acquisition in the Fuzzy Knowledge Representation Framework of a Medical Consultation System. Artificial Intelligence in Medicine. 676: 1–26.

Brawer MK, Kirby R (1999). Prostate Specific Antigen. In: Brawer MK, Kirby R, eds. Prostate Specific Antigen. 2nd ed. Health Press. 1-96.

Cancer Risk Calculator (2012). Forecasting the risk of disease, http://www.compass. fhcrc.org/edrnnci/bin/calculator/.

Kaiser Permanente (2006). Healty manager, http://www.kaiser permanente. org /medicine/.

Lorenz A., Blum M., Ermert H., Senge T (2007). Comparison of Different Neuro-Fuzzy Classification Systems for the Detection of Prostate Cancer in Ultrasonic Images. Proc. IEEE Ultrasonics Symposium 2007. 1201-1204.

Medicine Net (2010). Prostate Cancer. Medical Editors:William C. Shiel Jr., MD, FACP, FACR and Dennis Lee, MD, http://www.medicinenet.com/prostate_cancer/.

Metlin C., Lee F., Drago J et all (1991). The American Cancer Society National Prostate Cancer Detection, Project: Findings

on the Detection of Early Prostate Cancer in 2425 men. Cancer. 67:2949-2958.

Nguyen H.P., Krenovich V (2001). Fuzzy Logic and its Applications in Medicine. International Journal of Medical Informatics, 62:165–173.

Ronco A.L., Fernandez R (1999). Improving Ultrasonographic Diagnosis of Prostate Cancer with Neural Networks. Ultrasound in Med. & Biol. 25(5):729–733.

Saritas I., Allahverdi N., Sert IU (2003). A Fuzzy Expert System Design for Diagnosis of Prostate Cancer, International Conference on Computer Systems and Technologies - CompSysTech'03. Sofia-Bulgaria. 345 – 351.

Seker H., Odeyato M., Petrovic D., Naguib RNG (2003). A Fuzzy Logic Based Method for Prognostic Decision Making in Breast and Prostate Cancers. IEEE Trans. on Information Technology in Biomedicine. 7(2):114-120.