Feature Extraction in Medical Image Applications using Fuzzy Logic

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Abstract. In this paper, we present the results to apply a fuzzy feature extraction method for medical imaging. The application is in the detection of cardiac insufficiency by using thorax image radiographies. From simulation results we observe that the proposed fuzzy method improves the feature extraction in comparison with a classical method.

Keywords: Fuzzy Feature Extraction, Cardiac Insufficiency.

1 Introduction

Digital image processing has been a useful tool to help doctors in diagnosis of several diseases. Digital chest radiographies have been studied and analyzed by image processing systems since two decades ago. The most common application of these image processing systems is the diagnosis of lung tumors. Chest radiographies are also used by doctors to diagnose several heart conditions, such as cardiac insufficiency.

The number of people suffering of cardiac insufficiency increases every year. The number of cases in Mexico increases 10% per year. In a paper in the "Revista Mexicana de Cardiología" shows that in Mexico there are about 750 thousand patients affected by cardiac insufficiency, this number increases about 10% per year, which means that there are 75 thousand new cases each year [1].

New alternative methods of diagnosis are needed to be developed in countries like México, so the non experts in cardiology can make a reliable diagnosis and start a preventive treatment to patients who suffer of cardiac insufficiency, until they are able to treat the condition with a cardiologist [2, 3].

The objective of this paper is to develop an algorithm to extract several features that can make a reliable diagnosis of cardiac insufficiency by analyzing thorax digital radiographies. The experimental results show that the proposed fuzzy method improves the feature extraction in comparison with a classical method.

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2 Detection of Cardiac Insufficiency

A cardiac insufficiency is defined as a clinic syndrome in which the anomalies in the heart structure and function cause the malfunction and incapacity of this organ to expel blood or refill with blood at the rate needed by other organs to function. There are several classifications of cardiac insufficiencies, here we present the must common classifications [2, 3]:

a) Right insufficiency. This insufficiency is allocated on the right side of the heart. This ventricle loses the function of pumping blood and it can be retained by other organs causing congestion.

b) Left insufficiency. It is allocated on the left side of the heart; the left side receives blood from the lungs and is in charge of pumping blood to the rest of the body. If the left side of the heart fails the rest of the body can not receive sufficient oxygen causing fatigue, and blood can be retained by the lungs.

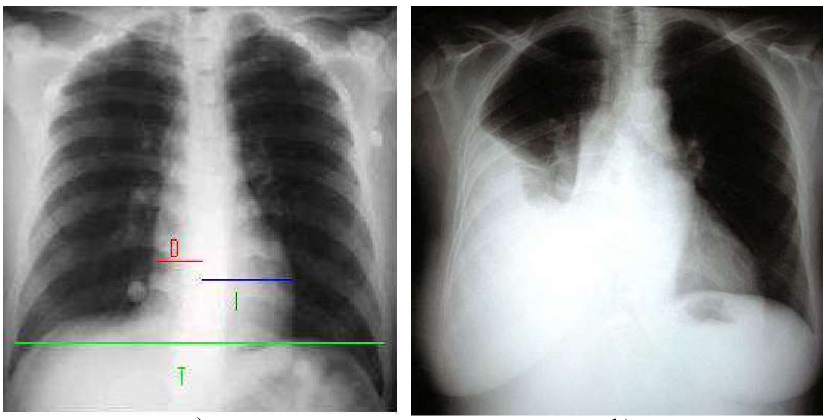
The first stage to give a reliable diagnose by analyzing thorax radiography is to evaluate if the radiography is well taken. A bad radiography can give us false information about the parameters that can be found to detect and diagnose the insufficiency. Listed below are some of the parameters and anomalies that are shown in a thorax radiography that can help us to diagnose a cardiac insufficiency.

Cardiomegaly refers to the abnormal growth of the heart. This condition is caused by the excessive work of the heart that it has to perform to function properly, just like a muscle; the heart increases its size and strength when it is forced continuously. Cardiomegaly can be identified by measuring of the cardiothoracic index (IC) [2],

$$IC = (D+I) / T \quad \textbf{(1)}$$

where "D" is the maximum distance between the mid line of the thorax and the right border of the heart, "I" is the maximum distance between the mid line of the thorax and the left border of the heart, and "T" is the maximum distance between the left and right borders of the thorax. According to Fig. 1a, if "IC" is greater than 0.5, this indicates cardiomegaly in most cases.

Pleural edema is an accumulation of fluid between the membrane covering the lungs and the thoracic cavity (see Figure 1b). This can be caused primarily by left cardiac insufficiencies; when the left side of the heart fails the blood is retained in the lungs, when there is too much blood retained this causes edema. When the edema is not severe can be seen as a decrease in the angle between the lung and the diaphragm.



a) b)

Fig. 1. Parameters and anomalies in a thorax radiography to diagnose a cardiac insufficiency. a) Measurement of Cardiothoracic index, b) Right pleural edema.

3 Proposed Method

The proposed method has three basic stages: pre-processing, segmentation and feature extraction [4, 5]:

a) Pre-processing: This process modifies the intensity of the pixels of an image to change the contrast between them; this is done to obtain a better image with the intensities needed in the proposed algorithm. We mention the methods to achieve this.

1. Adjustment. This method consists in the use of a threshold between intervals of intensities. The intensities between the limits are mapped into new intensity levels define in a curve that has been chosen before [6].
2. Histogram equalization. A histogram is a vector that contains the number of pixels that has the same level of intensity. Histogram equalization consists in increasing the dynamic range of an image and gives it a better contrast. The algorithm is given in the next steps [6],
   a. Calculate the image histogram.
   b. Calculate the cumulative distribution function vector (*cdf*), adding the value of *cdf(i)* with all the values before *i* where *i*=1,2,3,4,….*n*, and *n* is the number of grey levels in image.
   c. The general histogram equalization formula is:

$$h(v) = round\left\{\frac{cdf(v) - cdf_{\min}}{(M \times N) \times cdf_{\min}} \times (L-1)\right\} \quad \textbf{(2)}$$

where cdf_{min} is the minimum value of the cumulative distribution function, $M \times N$ gives the number image pixels, and L is the number of grey levels used in the image. This equation is used to obtain a new histogram with a wider dynamic range.

b) Segmentation: Segmentation refers to the process of partitioning a digital image into multiple segments. Segmentation algorithms used in this paper involve the edge detection and mathematical morphology [4]:

1. Edge detection. The edge detection is based on finding the areas in an image that have the maximum contrast. First level operators are approximations of the first order derivate of the image. The first order derivate shows a maximum where the intensity levels change quickly; this is the point where the maximum contrast is found.
   Canny algorithm. This is the most efficient first order algorithm of edge detection. Canny algorithm steps are as follows,
   - Gaussian Filter
   - Sobel operator. It consists of two matrices which are approximations of the first order derivative in vertical and horizontal directions,

$$Mx = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix} \qquad My = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \quad \textbf{(3)}$$

   - Non-max suppression. Eliminate the non maximum pixels in a window.

- Hysteresis threshold.

2. Mathematical morphology: Mathematical morphology processes images into shapes. To carry out transformations are structural elements consisting on matrices of 0´s and 1´s. The structural element can have any form needed by the program. There are two basic transformations: the dilation operator, (which grows or thickens some objects in a binary image), and the erosion operator (which shrinks or thins some objects in a binary image) [7].

c) Feature extraction: Feature extraction consists in extracting the characteristics needed by the program. Sometimes the characteristics are not easy to obtain from a segmented image, so it is useful to implement some fuzzy logic processing to achieve a reliable measurement of the feature [5].

1. Fuzzy logic: Fuzzy systems are useful to solve problems in which some data can have a level of uncertainty and imprecision [8,9]. These systems take decisions based on levels of membership between [0, 1] to a group, not like binary logic systems which only take levels of 1 or 0, meaning it belongs or not belongs. These systems deal with problems where the borders are not well defined in which a variable is part of a certain group, so this variable has a membership function that defines the level of membership of the variable to a certain group. The membership functions that represent the membership value of a pixel in the radiography to a part of the thorax are defined by eqs. (4), (5), and (6). Fig. 2 shows the membership functions. With these membership functions is feasible to create fuzzy rules that help us determine if the maximum distance (D and I defined before) found really belongs to the heart or belongs to another part of the body (like the diaphragm or the trachea). If the maximum measurement is not part of the heart, the program should take another measurement until it obtains the maximum measurement that is part of this.

$$trachea(p) = \begin{cases} 1, & if \quad p \le \overline{p}_T - \sigma_T \\ 1 - (p + \overline{p}_T - \sigma_T / 2\sigma_T), & if \quad \overline{p}_T - \sigma_T < p < \overline{p}_T + \sigma_T \\ 0, & otherwise \end{cases} \qquad \textbf{(4)}$$

$$heart(p) = \begin{cases} 1, & if \quad \overline{p}_T + \sigma_T \le p \le \overline{p}_D - \sigma_D \\ 1 - (p + \overline{p}_D - \sigma_D / 2\sigma_D), & if \quad \overline{p}_D - \sigma_D < p < \overline{p}_D + \sigma_D \\ (p - \overline{p}_T + \sigma_T / 2\sigma_T), & if \quad \overline{p}_T - \sigma_T < p < \overline{p}_T + \sigma_T \\ 0, & otherwise \end{cases} \qquad \textbf{(5)}$$

$$diaphragm(p) = \begin{cases} 1, & if \quad p \ge \overline{p}_D + \sigma_D \\ (p - \overline{p}_D + \sigma_D / 2\sigma_D), & if \quad \overline{p}_D - \sigma_D < p < \overline{p}_D + \sigma_D \\ 0, & otherwise \end{cases} \qquad \textbf{(6)}$$

where σ_D is the standard deviation of the diaphragm initial pixel, σ_T is the standard deviation of the trachea final pixel, p_D is the average of the diaphragm initial pixel and p_T is the average of the trachea final pixel.

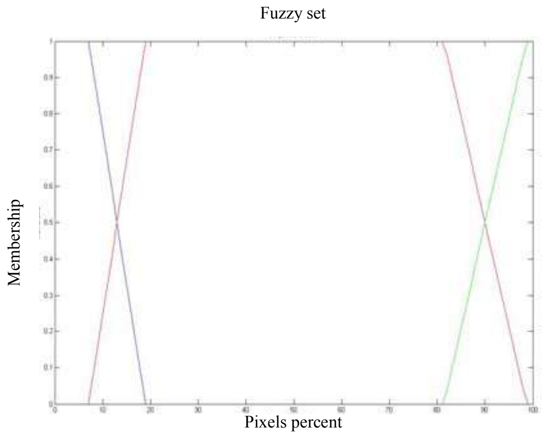


Fig. 2. Membership functions.

Another membership function is needed to evaluate if the maximum distance "D" and "I" found in the feature extraction is a correct measurement or not (if the measurement is part of the heart or part of another area like the diaphragm or trachea). The membership function *Similar*, indicates how much the maximum distance is similar to a maximum distance in the heart area (see Fig. 3). This fuzzy set will help to know if there is an abrupt growth of the measurements, meaning that the measurements pass from the heart area to the diaphragm area,

$$Similar = \begin{cases} -\frac{n}{10}+1, & if \quad 0 \le n \le 10 \\ 0, & otherwise \end{cases} \quad \textbf{(7)}$$

where n is the difference of pixels between the two measurements.

Using the *Similar* and *heart* membership functions the system is able to decide if the maximum distance is a measure of the heart or not. The fuzzy rule used to make the decision is presented as follows:

$$\text{IF } p \text{ IS } heart \text{ OR } n \text{ IS } Similar \text{ THEN } m \text{ IS correct} \quad \textbf{(8)}$$

where the OR connective used in the system is an algebraic sum of *Similar* and *heart*. The *heart* membership value is multiplied by 0.2 to lower the effect it has on the decision. In algebraic language this fuzzy rule is shown as,

$$correct(m) = \begin{cases} 1, & if\ m \ge 0.8 \\ 0, & otherwise \end{cases}, \quad \textbf{(9)}$$

where $m = \left(0.2 \cdot heart(p) + Similar(n)\right) - \left(0.2 \cdot heart(p) \cdot Similar(n)\right)$.

With this rule the system knows if the measurement is correct, if it is not correct, then a new measurement should be taken and the system has to evaluate if the new measurement is correct or not, until it founds a correct measurement.

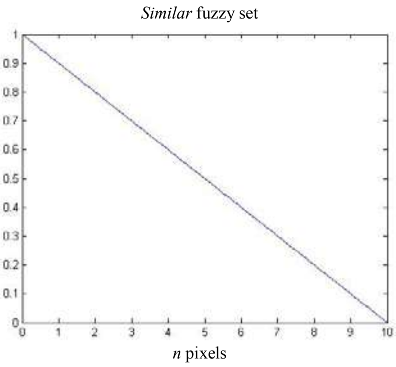
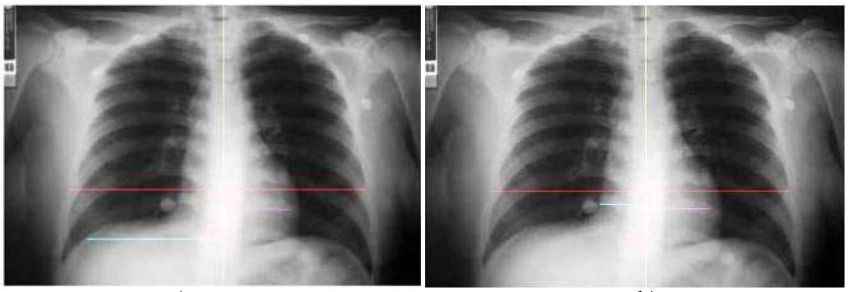


Fig. 3. Similar Membership function.

The problems found in the feature extraction of the heart size are solved using eq. (9) and the results are shown in Fig. 4, where the measurement obtained without implementing a fuzzy method (Fig. 4a) the right measurement of the heart is incorrect because it does not belong to the heart. After applying the fuzzy method (Fig. 4b) the system found the correct measurement of the right heart size.



a) b)

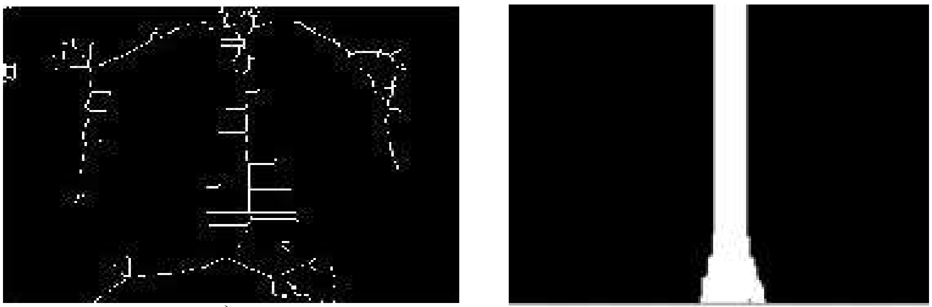
Fig. 4. Measurement of heart size: a) incorrect measurement, b) correct measurement.

4 Experimental Results

Several thorax radiographies where obtained from medical data bases. Here, the results to apply the mentioned algorithms to these images are presented. The features that are important in the thorax images are: size of the thorax, size of the heart, location of the mid line (trachea), distance between the mid line and the clavicles.

All the images were enhanced with the mentioned pre-processing algorithms (adjustment and histogram equalization) in order to obtain a similar contrast in all images according to the image that obtained the best results with the segmentation algorithms. Mathematical morphology algorithms were used to squeletize the pre-processed image. This process consists of several dilations and erosions; the new image is used to find the size of the thorax (see Fig. 5a). In order to find the mid line of the thorax, erosion is made with a rectangular structural element of size 5xm, where m is the vertical size of the image. The result of this erosion is shown in Fig. 5b.

In the images were used the edge detection algorithms. These new images (see Fig. 6) give us the necessary information to obtain the size of the heart ("D" and "I" defined previously).



a) b)

Fig. 5. Experimental results, a) Squeletize the image, b) Erosion.

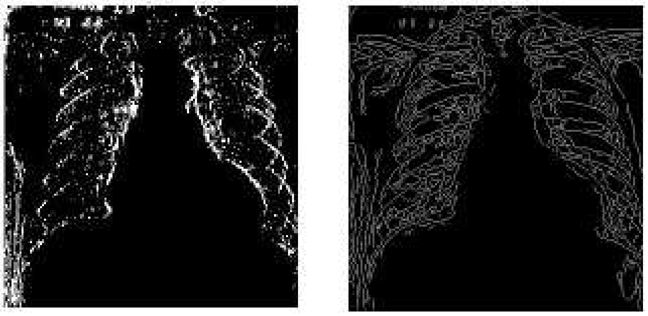


Fig. 6. Edge detection.

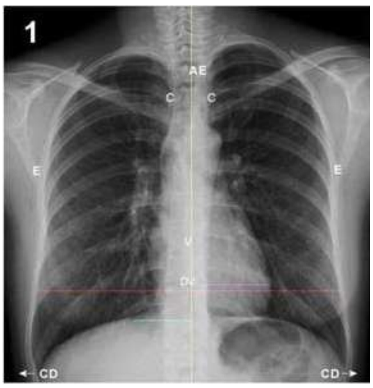


Fig. 7. Measurement of mid line and thorax size.

The measurements of the thorax size and mid line were achieved successfully. Fig. 7 shows the measurements.

Some problems were found to obtain the maximum size of the heart because there are an ambiguity regarding if the measurement is part of the heart, the trachea or the diaphragm. To solve this problem the implementation of a fuzzy system is needed. After making some measurements regarding the percentage of the image the heart belongs to, shown in the Table 1, some membership functions were created to represent if the maximum measurement belongs to the trachea, heart or diaphragm. In Table 1, (a), (b), and (c) are the number of vertical pixels in the image, start pixel of diaphragm, and percentage of pixels occupied by the diaphragm, respectively; (d) and (e) are the start pixel of heart, percentage of pixels occupied by the heart, respectively; (f), (g), (h), and (i) are the number of horizontal pixels in the image, the maximum distance found from the mid line of the thorax to a border found in the image, percentage of the distance, and mean distance in percentage, respectively.

Table 1. Measurements of image percents.

Image	a	b	c	d	e	f	g	h	i
1	205	161	21.46	25	66.34	226	43	19.02	11.94
2	418	401	4.06	103	71.29	599	69	11.51	8.68
3	170	154	9.41	20	78.82	341	46	13.48	8.5
4	181	-	0	29	83.97	326	40	12.26	9.2
5	175	143	18.28	20	70.28	303	39	12.87	9.57
6	247	226	8.5	34	77.73	394	50	12.69	8.88
7	135	127	5.92	13	84.44	218	31	14.22	10.09
8	321	-	0	71	77.88	640	138	21.56	13.9
9	194	153	21.13	27	64.94	300	59	19.66	10.66
10	289	236	18.33	23	73.70	432	105	24.30	16.89

Tables 2 and 3 present some experimental results in the case of use with and without fuzzy logic, respectively. The method used for comparison was using a fixed region in the image and take it as if this is the heart region, obtaining from this region the maximum distance as if this was the correct measurement of the heart size. The fuzzy method was implemented using the whole image and evaluating if the maximum distance found was the correct measurement of the heart. From these Tables, one can see that the proposed fuzzy method provides better results in terms of true positive and false negatives in comparison with the system without using fuzzy logic.

Table 2. Experimental results without fuzzy logic, where TP = true positive, FN = false negative, FP = false positive, and TN = true negative.

Image	IC Index by Program	Cardiomegaly by program	IC Index by manual measurement	Cardiomegaly by manual measurement	Difference
1	1.0000	Yes	0.45	No	FP
2	0.4182	No	0.3968	No	TN
3	0.6446	Yes	0.4020	No	FP
4	0.3533	No	0.3500	No	TN

5	0.6259	Yes	0.5957	Yes	TP
6	1.000	Yes	0.4320	No	FP
7	0.4471	No	0.4444	No	TN
8	0.7605	Yes	0.5714	Yes	TP
9	0.8855	Yes	0.5840	Yes	TP
10	0.3529	No	0.3500	No	TN
11	0.5369	Yes	0.3724	No	FP
12	0.6254	Yes	0.3917	No	FP
13	0.648	Yes	0.5526	Yes	TP
14	0.5787	Yes	0.3571	No	FP

Table 3. Experimental results with fuzzy logic.

Image	IC Index by Program	Cardiomegaly by program	IC Index by manual measurement	Cardiomegaly by manual measurement	Difference
1	0.4273	No	0.4500	No	TN
2	0.3798	No	0.3968	No	TN
3	0.396	No	0.4020	No	TN
4	0.3367	No	0.3500	No	TN
5	0.2937	No	0.5957	Yes	FN
6	0.3967	No	0.4320	No	TN
7	0.4087	No	0.4444	No	TN
8	0.5589	Yes	0.5714	Yes	TP
9	0.5954	Yes	0.5840	Yes	TP
10	0.3497	No	0.3500	No	TN
11	0.3833	No	0.3724	No	TN
12	0.3804	No	0.3917	No	TN
13	0.5302	Yes	0.5526	Yes	TP
14	0.414	No	0.3571	No	TN

To evaluate the performance of the proposed fuzzy method in terms of medical purposes, we compute the sensitivity and specificity. Sensitivity, is the probability that a medical test delivers a positive result when a group of patients with certain illness is under study, and specificity is the probability that a medical test delivers a negative result when a group of patients under study do not have certain illness,

$$Sn = TP / (TP + FN) \quad \textbf{(10)}$$

$$Sp = TN / (TN + FP) \quad \textbf{(11)}$$

where *Sn* is sensitivity, *TP* is the number of true positive that are correct, *FN* is the number of false negatives, that is, the negative results that are not correct, *Sp* is specificity, *TN* is the number of negative results that are correct and *FP* is the number of false positives, that is, the positive results that are not correct.

Table 4 shows the sensitivity, specificity, and error values obtained from the fuzzy method and the comparative method without fuzzy logic. We can observe that the specificity of the proposed method outperforms the comparative method. In the case of sensitivity, the proposed method has similar results in comparison with the comparative method.

Table 4. Comparative results in terms of sensitivity, specificity, and error values.

Method	Sensitivity	Specificity	Error
Comparative	75.00%	40%	42.85%
Fuzzy	75.00%	100%	7.14%

4 Conclusions

New diagnostic techniques are able to prevent and avoid deaths caused by cardiac insufficiencies. Analyzing thorax radiography by means of image processing is possible and can be used as an alternative diagnosis exam using the mentioned algorithms. This paper focus on finding cardiomegaly; but it is shown that there are other indicators that can be found in a thorax radiography that can help us make a better diagnosis. Fuzzy logic can be useful to achieve a good feature extraction of the radiographic image.

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References

1. Córdova Villalobos, J. A., Lee, G. M., Hernández Ávila, M., Aguilar Salinas, C. A, Barriguete-Meléndez, J. A., Kuri Morales, P., Lara Esqueda, A., Álvarez Lucas, C. H., Molina Cuevas, V., Barquera, S., Rosas Peralta, M., González Chávez, A.: Plan de Prevención Clínica de las Enfermedades Crónicas: sobrepeso, riesgo cardiovascular y diabetes mellitus 2007-2012 y Sistema de Indicadores de Diabetes en México. Comunicado de la secretaría de salud México. Revista Mexicana de Cardiología. Vol. 20, (1) pp. 42-45, (2009)
2. Giger D. K., MacMahon M., Nishikawa H., Schmidt R., Hoffmann R., Katsuragawa K., Sanada S., Behlen S., Sluis F. D.: Development of Digital Processing Techniques for Computer-Aided Diagnosis in Radiographic Images. In: The Third International Conference on Image Management and Communication in Patient Care. IMAC 93, pp. 110–115 (1993)
3. Jamroży M., Leyko T., Lewenstein K.: Early Detection of the Cardiac Insufficiency, Recent Advances in Mechatronics. Springer Berlin Heidelberg. pp. 407-411 (2010)
4. Bankman I.: Handbook of Medical Image Processing and Analysis. Vol. 1. Academic Press. Boston (2008)
5. Nixon M.: Feature Extraction & Image Processing. Academic Press. Boston (2008)

6. Gonzalez R.C.: Digital Image Processing using Matlab. Prentice Hall. New York (2003)
7. Ritter G.: Handbook of Computer Vision Algorithms in Image Algebra. CRC Press. Boca Raton-New York (2001)
8. Bezdek J.C.: Pattern Recognition with Fuzzy Objective Function Algorithms. Plenum Press. NewYork (1981)
9. Babuska R.: Fuzzy Modeling for Control. Kluwer Academic Publishers. Boston (1998)