Recent Advances in Fuzzy Sets, Intuitionistic Fuzzy Sets, Generalized Nets and Related Topics
Volume II: Applications

Editors

Krassimir T. Atanassov
Władysław Homenda
Olgierd Hryniewicz
Janusz Kacprzyk
Maciej Krawczak
Zbigniew Nahorski
Eulalia Szmidt
Sławomir Zadrożny

SRI PAS IBS PAN

Recent Advances in Fuzzy Sets, Intuitionistic Fuzzy Sets, Generalized Nets and Related Topics
Volume II: Applications

Systems Research Institute
Polish Academy of Sciences

Recent Advances in Fuzzy Sets, Intuitionistic Fuzzy Sets, Generalized Nets and Related Topics
Volume II: Applications

Editors

Krassimir T. Atanassov
Władysław Homenda
Olgierd Hryniewicz
Janusz Kacprzyk
Maciej Krawczak
Zbigniew Nahorski
Eulalia Szmidt
Sławomir Zadrożny

IBS PAN SRI PAS

Systems Research Institute
Polish Academy of Sciences
Newelska 6, 01-447 Warsaw, Poland
www.ibspan.waw.pl

ISBN 9788389475367

Fuzzy controllers in evaluation of survival length in cancer patients

Elisabeth Rakus-Andersson, Hang Zettervall and Henrik Forssell
Blekinge Institute of Technology,
37179 Karlskrona, Sweden
Elisabeth.Andersson@bth.se, Hang.Zettervall@bth.se, Henrik.Forssell@bth.se

Abstract

Strict analytic formulas are the tools usually derived for determining the formal relationships between a sample of independent variables and a variable which they affect. If we cannot formalize the function tying the independent and dependent variables then we will utilize some control actions. Apart from crisp versions of control we often adopt their fuzzy variants developed by Mamdani and Assilian [10] or Sugeno [20, 21]. Fuzzy control algorithms are furnished with softer mechanisms, when comparing them to classical control. The algorithms are particularly adaptable to support medical systems, often handling uncertain premises and conclusions. From the medical point of view it would be desirable to prognosticate the survival length for patients suffering from gastric cancer. We thus formulate the objective of the current paper as the utilization of fuzzy control actions for the purpose of making the survival prognoses.

Keywords: Mamdani controller, Sugeno controller, control estimation of survival length.

1 Introduction

In the current paper we will study the control actions to support the approximation of the survival length. In the control models we wish to treat the survival length as a dependent variable, which is affected by some biological parameters. Strict analytic formulas are the tools usually derived for determining the formal relationships between a sample of independent variables and a variable which they affect.

If we cannot formalize the function tying the independent and dependent variables then we will utilize fuzzy control actions.

Recent Advances in Fuzzy Sets, Intuitionistic Fuzzy Sets, Generalized Nets and Related Topics. Volume II: Applications *(K.T. Atanassow, W.Homenda, O.Hryniewicz, J.Kacprzyk, M.Krawczak, Z.Nahorski, E. Szmidt, S. Zadrożny, Eds.), IBS PAN - SRI PAS, Warsaw, 2010.*

We consider the problem of prognosticating the survival length for patients who suffer from gastric cancer [23, 24].

Fuzzy set theory allows us to describe complex systems by using our knowledge and experience in transparent English-like rules. It does not need complex mathematical equations and system modeling that governs the relation between inputs and outputs.

Expert-knowledge designs together with assumptions of fuzzy set theory have given rise to the creation of fuzzy control and its technical applications, see e.g., [1, 2, 10, 13, 22]. Experience-based rules constitute the crucial part of fuzzy controllers, which have found many adherents to apply them in order to support solutions of complex systems not characterized by formally stated structures. Due to the possibility of making input and output variables verbally expressed, fuzzy control has also been tested in medicine [3, 7, 8].

The evaluation of survival length was already accomplished by statistical methods. In the first trials of survival approximation a survival curve from censored data was introduced [9]. The model was used in cancer patient examinations to estimate the length of living [12]. The Cox regression [4] of life length prediction was developed in such studies as logistic Cox regression [19]. The statistics-based models predicting the survival were compared by Everitt and Rabe-Hesketh [6] who found such model disadvantages as the lack of normal distribution or missing values among survival times.

In our study we compare the effects of two fuzzy controllers, namely, Mamdani and Sugeno to obtain a crisp value being a prediction of survival length. We make the survival length dependent on two clinical markers "*age*" and "*CRP-value*" due to the physicians' expertise. The choice of *CRP* and age, as representative markers of post-surgical survival in cancer diseases, has been suggested due to the latest investigations revealing associations of these indices with the progression of disease in many cancer types [5, 11].

2 The Mamdani controller in prediction of the survival length in elderly gastric patients

Fuzzy control model is applied in research to some relationships between a collection of independent variables and the dependent of them variable when we cannot mathematically formalize the functional connection among them. We are expected to evaluate the survival length in patients with diagnosis "*gastric cancer*". The period of survival is affected by two biological parameters X = "*age*" and Y = "*CRP-value*", which are selected as the most essential markers of making the prognosis. We cannot formally derive a function, which relates the independent variables X = "*age*" and Y = "*CRP-value*" to the dependent variable Z =

"*survival length*"; therefore we will adapt such fuzzy controller, which supports estimation of dependent values in spite of the lack of a formula concerning $z = f(x,y)$, $x \in X$, $y \in Y$, $z \in Z$.

2.1 Fuzzification of input and output variable entries

All variables will be differentiated into levels, which are expressed by lists of terms. The terms from the lists are represented by fuzzy numbers, restricted by the parametric *s*-functions lying over the variable domains $[x_{\min}, x_{\max}]$, $[y_{\min}, y_{\max}]$ and $[z_{\min}, z_{\max}]$ respectively.

In conformity with the physician's suggestions we introduce five levels of X, Y and Z as the collections

X = "*age*" = { X_0 = "*very young*", X_1 = "*young*", X_2 = "*middle-aged*", X_3 = "*old*", X_4 = "*very old"*}

Y = "*CRP-value*" = { Y_0 = "*very low"*, Y_1 = "*low*", Y_2 = "*medium*", Y_3 = "*high*", Y_4 = "*very high*"}

and

Z = "*survival length*" = { Z_0 = "*very short*", Z_1 = "*short*", Z_2 = "*middle-long*", Z_3 = "*long*", Z_4 = "*very long*"}.

To obtain a family of membership functions of fuzzy numbers standing for the terms of the respective lists we will modify the parametric s-class functions. For X_i, i = 0,...,4, we design [14-18]

$$\mu_{X_i}(x) = \begin{cases} left\mu_{X_i}(x), \\ right\mu_{X_i}(x), \end{cases} \tag{1}$$

Where

$$left\mu_{X_i}(x) = \begin{cases} 2\left(\frac{x-((x_{\min}-h_X)+h_X \cdot i)}{h_X}\right)^2 & \text{for } (x_{\min}-h_X)+h_X \cdot i \le x \le \left(x_{\min}-\frac{h_X}{2}\right)+h_X \cdot i, \\ 1-2\left(\frac{x-(x_{\min}+h_X \cdot i)}{h_X}\right)^2 & \text{for } \left(x_{\min}-\frac{h_X}{2}\right)+h_X \cdot i \le x \le (x_{\min})+h_X \cdot i, \end{cases} \tag{2}$$

and

$$right\mu_{X_i}(x) = \begin{cases} 1-2\left(\frac{x-(x_{\min}+h_X\cdot i)}{h_X}\right)^2 & \text{for } (x_{\min})+h_X\cdot i \le x \le \left(x_{\min}+\frac{h_X}{2}\right)+h_X\cdot i, \\ 2\left(\frac{x-((x_{\min}+h_X)+h_X\cdot i)}{h_X}\right)^2 & \text{for } \left(x_{\min}+\frac{h_X}{2}\right)+h_X\cdot i \le x \le (x_{\min}+h_X)+h_X\cdot i. \end{cases} \quad (3)$$

Formulas (2) and (3) depend on the minimal value $x_{\min}$, which starts the X-variable domain. The structures (2) and (3) are also affected by the value of a parameter h_X, which estimates the length between the beginnings of membership functions constructed for two adjacent terms of X. The h_X quantity is adjusted to the number of functions in the X-list and to the distance between the minimal and the maximal value of the X-variable domain.

The membership functions of Y_j, $j = 0,\ldots,4$, constructed for the accommodated values of parameters h_Y and $Y_{\min}$ to the conditions of Y, are yielded by

$$\mu_{Y_j}(y) = \begin{cases} left\mu_{Y_j}(y), \\ right\mu_{Y_j}(y), \end{cases} \quad (4)$$

For

$$left\mu_{Y_j}(y) = \begin{cases} 2\left(\frac{y-((y_{\min}-h_Y)+h_Y\cdot j)}{h_Y}\right)^2 & \text{for } (y_{\min}-h_Y)+h_Y\cdot j \le y \le \left(y_{\min}-\frac{h_y}{2}\right)+h_y\cdot j, \\ 1-2\left(\frac{y-(y_{\min}+h_Y\cdot j)}{h_Y}\right)^2 & \text{for } \left(y_{\min}-\frac{h_Y}{2}\right)+h_Y\cdot j \le y \le (y_{\min})+h_Y\cdot j, \end{cases} \quad (5)$$

And

$$right\mu_{Y_j}(y) = \begin{cases} 1-2\left(\frac{y-(y_{\min}+h_Y\cdot j)}{h_Y}\right)^2 & \text{for } (y_{\min})+h_Y\cdot j \le y \le \left(y_{\min}+\frac{h_Y}{2}\right)+h_Y\cdot j, \\ 2\left(\frac{y-((y_{\min}+h_Y)+h_Y\cdot j)}{h_Y}\right)^2 & \text{for } \left(y_{\min}+\frac{h_Y}{2}\right)+h_Y\cdot j \le y \le (y_{\min}+h_Y)+h_Y\cdot j. \end{cases} \quad (6)$$

Finally, the Z_k's functions, $k = 0,\ldots,4$, are derived as

$$\mu_{Z_k}(z) = \begin{cases} left\mu_{Z_k}(z), \\ middle\mu_{Z_k}(z), \\ right\mu_{Z_k}(z) \end{cases} \quad (7)$$

with

$$left\mu_{Z_k}(z)=$$

$$\begin{cases} 2\left(\frac{z-\left(z_{\min}-\frac{h_Z}{2}+h_Z\cdot k\right)}{\frac{h_Z}{2}}\right)^2 & \text{for} \quad z_{\min}-\frac{h_Z}{2}+h_Z\cdot k\le z\le z_{\min}-\frac{h_Z}{4}+h_Z\cdot k, \\ 1-2\left(\frac{z-\left(z_{\min}+h_Z\cdot k\right)}{\frac{h_Z}{2}}\right)^2 & \text{for} \quad z_{\min}-\frac{h_Z}{4}+h_Z\cdot k\le z\le z_{\min}+h_Z\cdot k, \end{cases} \tag{8}$$

the central part

$$middle\mu_{Z_k}(z)=1 \text{ for } z_{\min}+h_Z\cdot k\le z\le z_{\min}+\frac{h_Z}{2}+h_Z\cdot k, \tag{9}$$

And

$$right\mu_{Z_k}(z)=$$

$$\begin{cases} 1-2\left(\frac{z-\left(z_{\min}+\frac{h_Z}{2}+h_Z\cdot k\right)}{\frac{h_Z}{2}}\right)^2 & \text{for} \quad z_{\min}+\frac{h_Z}{2}+h_Z\cdot k\le z\le z_{\min}+\frac{3h_Z}{4}+h_Z\cdot k, \\ 2\left(\frac{z-\left(z_{\min}+h_Z+h_Z\cdot k\right)}{\frac{h_Z}{2}}\right)^2 & \text{for} \quad z_{\min}+\frac{3h_Z}{4}+h_Z\cdot k\le z\le z_{\min}+h_Z+h_Z\cdot k. \end{cases} \tag{10}$$

The parameter h_Z allows designing five numbers from Z over $[z_{\min}, z_{\max}]$.

We return to the variable X = "*age*", which is differentiated in five levels and restricted over the interval $[x_{\min}, x_{\max}]$ = [0, 100]. We thus state $x_{\min}=0$, $h_X=25$ and $i=0,\ldots,4$. For the terms of "*age*" we will obtain by (2) and (3) a family of the membership functions sketched in Fig. 1. The h_X value is specified to be equal to 25 since we wish to make a design in which X_0 has its peak in (0, 1) and the peak of X_4 should be moved to (100, 1). On the other hand five symmetric functions of fuzzy numbers have to find their placements over [0, 100] which, together with previously made assumptions, initiates $h_X = 25$.

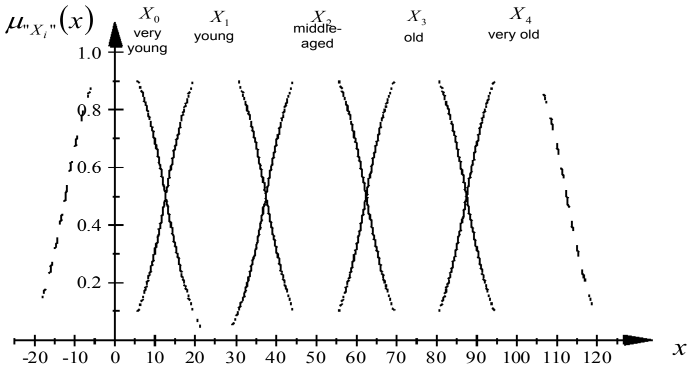

Figure 1: The membership functions for "*age*"

By inserting new parameters of $y_{\min}$ and h_Y in (5) and (6) we generate the membership functions for "*CRP-value*". We have stated Y as a collection of five levels over the interval [0, 50]. The design of installing five functions with the peak of Y_0 in (0, 1) and the peak of Y_4 in (50, 1) demands the selection of $h_Y = 15$. We plot the Y_j functions in Fig. 2 by setting in turn the different values of j in (5) and (6), where $j = 0,...,4$.

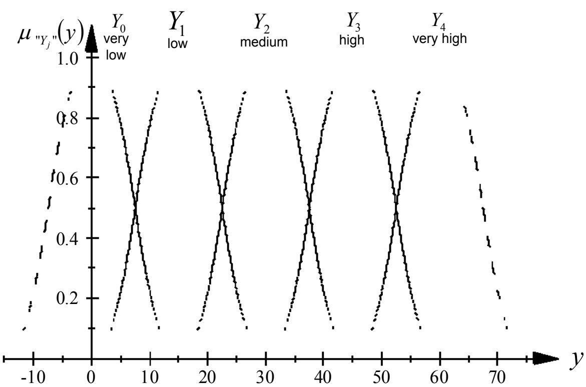

Figure 2: The membership functions for "*CRP-value*"

The output variable Z takes the values in the interval [0, 5]. We determine $h_Z = 1$ and set $k = 0,...,4$ in (8), (9) and (10) to initialize the functions depicted in Fig. 3.

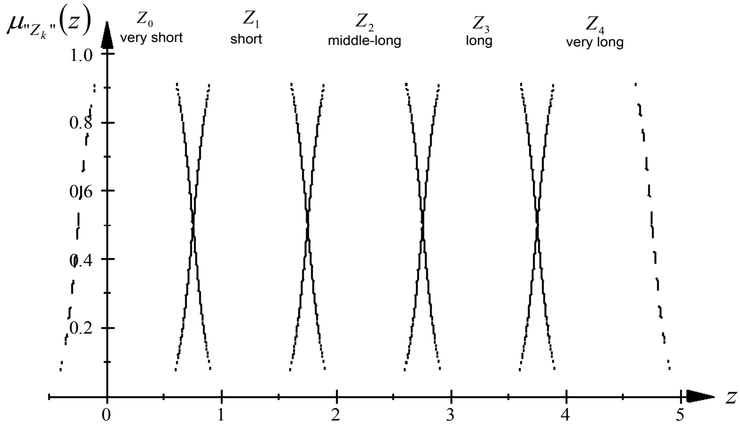

Figure 3: The membership functions for "*survival length*"

We emphasize the importance of the parametric design of functions. Instead of implementing fifteen formulas of the similar nature we have sampled all functions in three generic groups. Any time we can involve the desired function in necessary computations by setting its number in the proper formula concerning *X*, *Y* or *Z*. Moreover, the mathematical scenario of membership functions is established in the formal and elegant designs, which can be segments of a computer program for the reason of their nature letting the creation of loops.

2.2 The rule based processing part of surviving length model

After the fuzzification procedure we are able to create the rule bases, which link the states of the two input variables to the state of the output variable. We thus design a table in which the entries are filled with terms of "*survival length*". To express the states of the survival length as logically as possible, we have studied the behavior of variables on the basis of biological data samplings. The cells of the table are characterized by subintervals of domains of *X* and *Y*.

We first estimate the survival length median in the samplings of the data corresponding to considered cells. The median value was set as *z* in the membership functions of all fuzzy numbers listed in the *Z*-space. We select this fuzzy number Z_k as a representative of the cell, in which the membership degree of the median was largest. The technique of combining the human experience with data sets obtained for discrete samples to make conclusions for continuous samples is a modern branch of so-called "integration systems".

The estimations of survival length are collected in Table 1.

Table 1. Rule base of fuzzy controller estimating "*survival length*"

X_i/Y_j	very low	low	medium	high	very high
very young					
young					
middle-aged	middle long				
old	middle long	short	short	short	very short
very old	short	short	very short	very short	very short

Some entries in the table are empty, since the essential data was lacking for younger people. It rarely happens to find young patients with diagnosis "*gastric cancer*"; therefore we could not make any reliable conclusions concerning survival in this age group.

Suppose that we would like to make the survival prognosis for (x, y), $x \in X$, $y \in Y$ – with other words we want to evaluate $z = f(x, y)$ when assuming that the *f*-formula is not developed.

Furthermore, x belongs to the different fuzzy numbers X_i, i = 0,...,4, being the fuzzy subsets of X, with different membership degrees equalling $\mu_{X_i}(x)$. Element y associated to x is a member of some fuzzy numbers Y_j, j = 0,...,4, constituting the fuzzy subsets of Y with the membership degrees $\mu_{Y_j}(y)$.

By means of IF-THEN statements grounded on the basis of Table 1, we can determine the contents of rules by attaching the pair of input variable levels to a level of the output variable according to

$$\text{Rule } R_{(x,y):l} : \text{ If } x \text{ is } X_{i:l} \text{ and } y \text{ is } Y_{j:l}, \text{ then } z \text{ is } Z_{k:l}, \tag{11}$$

where l is the rule number. The expressions $X_{i:l}$, $Y_{j:l}$ and $Z_{k:l}$ denote the fuzzy numbers X_i, Y_j and Z_k assisting rule number l, which has been found for actual x and y.

To evaluate the influence of the input variables on the output consequences we need an estimate $\alpha_{(x,y):l}$ found by performing the minimum operation

$$\alpha_{(x,y):l} = \min\left(\mu_{X_i:l}(x), \mu_{Y_j:l}(y)\right) \tag{12}$$

for each $X_{i:l}$ and $Y_{j:l}$ concerning the choice of (x,y).

We use $\alpha_{(x,y):l}$ and the minimum operator to determine consequences of all rules $R_{(x,\, y):l}$ for the output. Fuzzy sets $R_{(x,y):l}^{conseq}$, stated in the output space Z, will have the membership functions

$$\mu_{R_{(x,y):l}}{}^{conseq}(z) = \min\left(\alpha_{(x,y):l}, \mu_{Z_k:l}(z)\right). \tag{13}$$

In the last step of the algorithm we aggregate the consequence sets $R_{(x,y):l}^{conseq}$ in one common set $conseq_{(x,y)}$ allocated in Z over a continuous interval $[z_0, z_n]$. To derive the membership function of $conseq_{(x,y)}$ we prove the action of the maximum operator in the form of

$$\mu_{conseq_{(x,y)}}(z) = \max_l\left(\mu_{R_{(x,y):l}}{}^{conseq}(z)\right). \tag{14}$$

2.3 Defuzzification of the output variable

In order to assign a crisp value z to the selected pair (x, y) we defuzzify the consequence fuzzy set (14) in Z. We will thus indicate the expected value of the survival length for a gastric cancer patient whose age x and *CRP*-value y have been examined.

As a defuzzification rule we adapt the centre of gravity method (COG). This model of computing is easy to perform and clearly interpretable. We expand COG as

$$z = f(x, y) = \frac{\int_{z_0}^{z_n} z \cdot \mu_{conseq_{(x,y)}}(z)dz}{\int_{z_0}^{z_n} \mu_{conseq_{(x,y)}}(z)dz} = \frac{\int_{z_0}^{z_1} z \cdot \mu_{conseq_{(x,y)}}(z)dz + \cdots + \int_{z_{n-1}}^{z_n} z \cdot \mu_{conseq_{(x,y)}}(z)dz}{\int_{z_0}^{z_1} \mu_{conseq_{(x,y)}}(z)dz + \cdots + \int_{z_{n-1}}^{z_n} \mu_{conseq_{(x,y)}}(z)dz} \tag{15}$$

with the inner borders $z_1,...,z_{n-1}$ being either z-coordinates of intersection points between adjacent branches of the $conseq_{(x,y)}$ membership function or characteristic support values of fuzzy numbers included in $conseq_{(x,y)}$.

2.4 The survival length prognosis for a selected patient

Suppose that we examine a 77-year-old patient, whose *CRP*-value is 16. His diagnosis is determined by a physician as "*gastric cancer*". We wish to estimate theoretically the expected value of his survival length by proving the algorithm sketched in previous sections. The information is confidential and used only by the physician.

Let $x = 77$ and $y = 16$. Age 77 belongs to fuzzy number X_3 = "*old*". Therefore, for i = 3, h_X = 0.25 and $x_{\min}$ = 0, we allocate x = 77 in the interval

$$(x_{\min}) + h_X \cdot i \le x \le \left(x_{\min} + \tfrac{h_X}{2}\right) + h_X \cdot i \leftrightarrow 0 + 25 \cdot 3 \le x \le \left(0 + \tfrac{25}{2}\right) + 25 \cdot 3 \leftrightarrow$$

$$75 \le x \le 87.5$$

with the membership degree

$$\mu_{X_3}(77) = \mu_{\text{"}old\text{"}}(77) = 1 - 2\left(\tfrac{77 - (x_{\min} + h_X \cdot i)}{h_X}\right)^2 = 1 - 2\left(\tfrac{77 - (0 + 25 \cdot 3)}{0.25}\right)^2 = 0.9872.$$

The same x = 77 is a member of another fuzzy number X_4 = "*very old*" with the membership degree of $\mu_{X_4}(77) = \mu_{\text{"}very\ old\text{"}}(77) = 0.0128$. The *CRP*-value 16 belongs to fuzzy number Y_1 = "*low*" with the membership degree $\mu_{Y_1}(16) = \mu_{\text{"}low\text{"}}(16) = 0.991$ and Y_2 = "*medium*" with the membership degree $\mu_{Y_2}(16) = \mu_{\text{"}medium\text{"}}(16) = 0.009$.

In accordance with (11) the rules, which connect the states of the input variables to the output variable levels, are established as:

$R_{(77,16):1}$: IF "*age*" is "*old*" and the "*CRP-value*" is "*low*", THEN "*survival length*" will be "*short*".

$R_{(77,16):2}$: IF "*age*" is "*old*" and "*CRP-value*" is "*medium*", THEN the survival length will be "*short*".

$R_{(77,16):3}$: IF "*age*" is "*very old*" and "*CRP-value*" is "*low*", THEN the survival length will be "*short*".

$R_{(77,16):4}$: IF "*age*" is "*very old*" and "*CRP-value*" is "*medium*", THEN the survival length will be "*very short*".

To evaluate the influences of the input variables on the output consequences due to (12), we estimate $\alpha_{(77,16):l}$, l = 1,...,4 as four quantities

$$\alpha_{(77,16):1} = \min\left(\mu_{X_3:1}(77), \mu_{Y_1:1}(16)\right) = \min\left(\mu_{\text{"}old\text{"}}(77), \mu_{\text{"}low\text{"}}(16)\right) = \min(0.9872, 0.991)$$

$$= 0.9872,$$

$$\alpha_{(77,16):2} = 0.009,$$

$$\alpha_{(77,16):3} = 0.0128$$

and $\alpha_{(77,16):4} = 0.009.$

In conformity with formula (13) we obtain the fuzzy subsets of the consequences. For instance, set $R_{(77,16):1}^{conseq}$ has a membership function

$$\mu_{"R_{(77,16):1}"}^{conseq}(z) = \min\left(\alpha_{(77,16):1}, \mu_{Z_1:1}(z)\right) = \min\left(0.9872, \mu_{Z_1:1}(z)\right) =$$
$$\min\left(0.9872, \mu_{"short"}(z)\right)$$

given by Fig. 4.

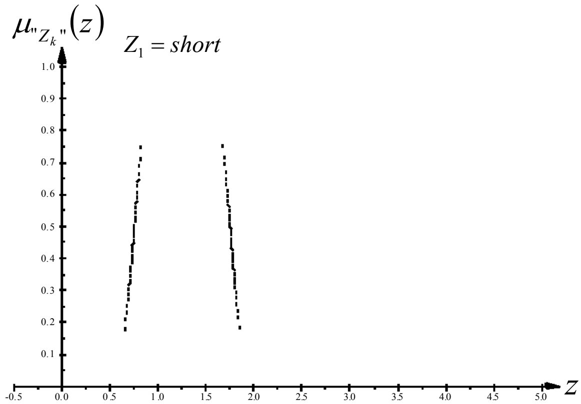

Figure 4: The fuzzy subset of consequence constructed due to $R_{(77,16):1}$

We repeat the action of (13) to find the consequence sets due to rules (11) for l = 2, 3, 4. When applying formula (14) we concatenate all $\mu_{"R_{(x,y):l}"}^{conseq}(z)$, l = 1,2,3,4, in order to determine a common consequence of rules (11) fitted for the pair (77, 16). The fuzzy subset of the universe Z will be thus yielded by its membership function $\mu_{conseq_{(77,16)}}(z) = \max\limits_{1 \le l \le 4}\left(\mu_{R_{(77,16):l}}^{conseq}(z)\right)$.

The fuzzy set $conseq_{(77,16)}$ is aggregated in Fig. 5.

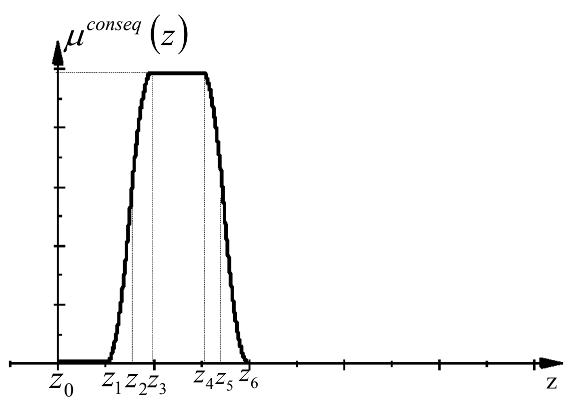

Figure 5: The consequence set $conseq_{(77,16)}$ in Z

Formula (15) constitutes a basis of an estimation of the survival length expected when assuming "*age*" = 77 and "*CRP-value*" = 16. Over interval $[z_0, z_6] = [0, 2]$, which contains characteristic points $z_0 = 0$, $z_1 = 0.533$, $z_2 = 0.75$, $z_3 = 0.96$, $z_4 = 1.54$, $z_5 = 1.75$ and $z_6 = 2$, we compute the z-prognosis

$$z = f(77,16)\frac{\int_0^{0.5335} 0.009z\,dz + \cdots + \int_{1.75}^{2} 2\left(\frac{z-2}{0.5}\right)^2 z\,dz}{\int_0^{0.5335} 0.009\,dz + \cdots + \int_{1.75}^{2} 2\left(\frac{z-2}{0.5}\right)^2 dz} = 1.05.$$

For the patient who is 77 years old and has the *CRP*-value equal to 16, the theoretical estimated survival length is about 1 year. The result converges to the physician's own judgment made on the basis of his medical reports. For each pair (x,y) we can arrange new computations due to the fuzzy control algorithm to estimate the patient's period of surviving in the case of suffering from gastric cancer.

In the next section we wish to confirm the magnitude of survival length approximation by testing the Sugeno controller.

3 Verification of survival length results by means of Sugeno controller

In the rules, constituting the crucial part of control processing, the levels of the independent variables have been tied to a selected level representing the dependent parameter. All levels have been further replaced by fuzzy numbers. The operations recommended by the Mamdani controller have been performed on membership functions of these fuzzy representatives of levels.

To shorten the action of the processing part in the Mamdani controller, Sugeno [20, 21] proposed another approach to the creation of rules, in which the dependent variable level will be determined by a functional connection of independent variables.

3.1 Adaptation of the processing part of the fuzzy controller to Sugeno-made assumptions

We still wish to evaluate the survival length in gastric cancer patients due to information about their age and *CRP*-value. In this new version of a fuzzy controller, called the Sugeno controller, we preserve the former results of the fuzzification of independent variables, i.e., we still keep alive the levels of variables X = *"age"* and Y = *"CRP-value"* with assisting membership functions (1), (2) and (3) for X, as well as (4), (5) and (6) for Y.

The dependent variable Z = "*survival length*" is not differentiated into levels anymore. Instead, for each combination of X- and Y-levels we derive a linear two-dimensional function of the general shape $f(x,y) = ax+by+c$. This procedure can only work in the case of possessing some data triplets (x,y,z), which come from the examinations carried out on patients belonging to the desired combinations of levels. We support our experience by engaging discrete point sets to predict the information, which can be obtained for continuous intervals of X and Y.

Example 1

The triplets ("*age*", "*CRP-value*", "*survival length*") = (x,y,z) belong to the set {(77, 18, 0.5),…,(81, 21, 0.9)}, in which x-values correspond to level X_3 = "*old*" and y-values are typical of Y_1 = "*low*". The dependent variable $z = f(x,y)$ has taken values between 0.1 and 0.8. The data is withdrawn from the patients' reports. Thus, for the couple of levels X_3 and Y_1 we find the functional dependency $z = f(x,y) = 0.13057x + 3.4256 \cdot 10^{-3} y - 9.4426$ shown in Fig. 6.

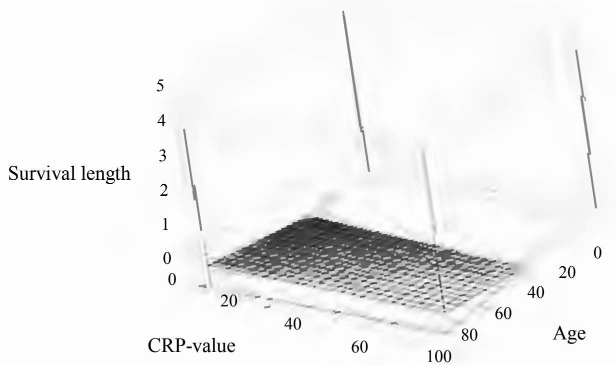

Figure 6: The example of the functional dependency between independent and dependent variables

In the IF-THEN rule (11) the Z-level indicates the character of dependency between levels of X and Y. In the Sugeno IF-THEN rule the function $z = f(x,y)$ is not assimilated to any level of variable Z from Section 2. We formulate a new pattern of (11) as

$$R_{(x,y):l} : \text{IF } x \text{ is } X_{i:l} \text{ and } y \text{ is } Y_{j:l}, \text{ THEN } z_{(x,y):l} \text{ is } z_k = f_k(x,y) \quad (16)$$

where l is the rule number, $X_{i:l}$ and $Y_{j:l}$ represent the fuzzy numbers X_i and Y_j, which are associated with the rule number l for the actual pair (x,y).

The formula

$$z_{(x,y):l} = z_k = f_k(x,y) = a_k x + b_k y + c_k \tag{17}$$

is a control function found for levels $X_{i:l}$ and $Y_{j:l}$. The quantities a_k, b_k and c_k are constants. The control functions have been constructed by the Maple computer program.

As we want to find the functional evaluations for all possible connections of levels, selected for independent variables due to Table 1, then the number of functions will equal 11. Hence, the index k, $k = 1,\ldots,11$, constitutes the function number with accordance to the next rule base table, introduced as Table 2.

Table 2. The functional rule base table for combinations of X- and Y-levels in estimations of survival length

X_i/Y_j	very low	low	medium	high	very high
very young					
young					
middle-aged	z_1				
old	z_2	z_3	z_4	z_5	z_6
very old	z_7	z_8	z_9	z_{10}	z_{11}

As before, we have left some empty cells in the table because of the lack of data for younger patients with diagnosis "gastric cancer".

Instead of the sophisticated procedure of looking for the final consequence set, characteristic of the Mamdani controller, we adopt the control function [20, 21]

$$z = f^{Sugeno}(x,y) = \frac{\sum_l \alpha_{(x,y):l} \cdot \left(z_{(x,y):l} = f_k(x,y) \right)}{\sum_l \alpha_{(x,y):l}}, k = 1,\ldots,11, \tag{18}$$

which directly delivers a crisp control value of the output variable "*survival length*".

To obtain the value of $\alpha_{(x,y):l}$, we need to perform the minimum operation for the membership degrees of $\mu_{X_i:l}(x)$ and $\mu_{Y_j:l}(y)$ according to (12).

3.2 Applications of the Sugeno fuzzy controller to estimation of the survival length in gastric cancer patients

We return to the case of the patient already presented in 2.4. By testing the Sugeno controller let us now evaluate the expected value of the survival length for a 77-year-old patient, whose *CRP*-value is 16.

We put x = 77 and y = 16. We have previously stated that age 77 belongs to the fuzzy number X_3 = "*old*" with membership degree $\mu_{X_3}(77) = 0.9872$.

Element x = 77 also is a member of X_4 = "*very old*" with the membership $\mu_{X_4}(77) = 0.0128$.

The *CRP*-value y = 16 is found in fuzzy number Y_1 = "*low*", where its membership equals $\mu_{Y_1}(16) = 0.991$. The same y = 16 takes place in Y_2 = "*medium*", but the membership degree is determined as $\mu_{Y_2}(16) = 0.009$.

The rules IF-THEN, which associate the input variables with the output variable are determined according to formula (16) and Table 2 as:

$R_{(77,16):1}$: IF x is X_3 and y is Y_1, THEN

$$z_{(77,16):1} = z_3 = f_3(x,y) = -4.3948 \cdot 10^{-2} x - 9.6411 \cdot 10^{-3} y + 4.3938,$$

$R_{(77,16):2}$: IF x is X_3 and y is Y_2, THEN

$$z_{(77,16):2} = z_4 = f_4(x,y) = -1.0077 \cdot 10^{-2} x - 2.7872 \cdot 10^{-2} y + 2.0658,$$

$R_{(77,16):3}$: IF x is X_4 and y is Y_1 THEN

$$z_{(77,16):3} = z_8 = f_8(x,y) = -6.2637 \cdot 10^{-2} x + 0.26035 y + 4.1361$$

and

$R_{(77,16):4}$: IF x is X_4 and y is Y_2 THEN

$$z_{(77,16):4} = z_9 = f_9(x,y) = -9.7739 \cdot 10^{-3} x + 3.3194 \cdot 10^{-4} y + 1.1162.$$

To estimate the value of $\alpha_{(x,y):l}$, we perform the minimum operation on each pair of values $\mu_{X_i:l}(x)$ and $\mu_{Y_j:l}(y)$. We refer to previously known results $\alpha_{(77,16):1} = 0.9872$, $\alpha_{(77,16):2} = 0.009$, $\alpha_{(77,16):3} = 0.0128$ and $\alpha_{(77,16):4} = 0.009$.

After substituting the values of $\alpha_{(x,y):l}, l = 1,\ldots,4$ and corresponding to them $z_{(x,y):l} = f_k(x,y)$, k = 3,4,8 and 9, in (18) we get

$$z = f^{Sugeno}(77,16) =$$
$$\frac{\alpha_{(77,16):1} \cdot f_3(77,16) + \alpha_{(77,16):2} \cdot f_4(77,16) + \alpha_{(77,16):3} \cdot f_8(77,16) + \alpha_{(77,16):4} \cdot f_9(77,16)}{\alpha_{(77,16):1} + \alpha_{(77,16):2} + \alpha_{(77,16):3} + \alpha_{(77,16):4}}$$
$$= \frac{0.9872 \cdot 0.8555 + 0.009 \cdot 0.84392 + \cdots + 0.009 \cdot 0.36892}{0.9872 + 0.0009 + \cdots + 0.009} \approx 0.88.$$

When comparing the results yielded by two controllers we make the conclusion about their convergence to the approximated survival value about one year. The deviation between quantities, related to survival length of the 77-year-old patient with *CRP* equaling 16, can be an effect of using the planar surface instead of an irregular one in the approximation of point sets in the Sugeno controller. We wish to formulate the following conclusion summing up the comparison of both controllers.

4 Conclusions

The fuzzy control systems are powerful methods, which mostly are applied to technologies controlling complex processes by means of human experience. In this work we have proved that the expected values of patients' survival lengths can be estimated even if the mathematical formalization involving independent and dependent variables is unknown.

When adapting Mamdani and Sugeno controllers to medical dependency assumptions we have supported the evaluation of the survival length, made so far by statistical tests.

By following the results of experiments, accomplished in the tests of controllers, we wish to sample the concluded remarks in the following way.

The algorithm of the Mamdani controller demands a large number of operations in the processing phase, but we can always construct logical rules IF-THEN, which are based on variable levels and assisted by fuzzy numbers. Even if the data from point sets is lacking it is still possible to make a trial of designing membership functions for all levels of variables by relying on the human expertise.

The Sugeno controller does not need so many operations in the processing stage. Nevertheless, its use is impossible in practice when we cannot be furnished with discrete data sets to accomplish the design of functions f_k. The choice of the method is thus dependent on the access to data.

The controllers encounter results coming from statistical experiments, and they do not need special assumptions like normal distributions of the dependent variables.

In the future experiments we want to construct the computer program to cover the rectangle $[x_{\min}, x_{\max}] \times [y_{\min}, y_{\max}]$ with a surface, which allows to read off the desired value of z for the pair (x, y). In that way we will solve the problem of the continuous evaluation of survival length as it has been recommended by our co-operating physicians. It will be desirable to introduce more independent variables to the model as well.

In the algorithm we have initially designed families of fuzzy numbers that are affected by parameters. The parameterization of membership function formulas constitutes an important stage in the computer programming of the systems.

In the end we emphasize that, unlike the traditional control methods, fuzzy control is the methodology, which deals with many real-life problems successfully. As the conventional control methods often are based on advanced mathematical models, such as differential equations sometimes impossible to solve, the method of fuzzy control is much more convenient to apply.

Acknowledgment

The authors thank the Blekinge Research Board for the grant funding the current research.

References

[1] Al-Odienat, A. I., Al-Lawama, A. A.: The Advantages of PID Fuzzy Controllers over the Conventional Types. *American Journal of Applied Sciences*, vol. 5, issue 6 (2008) 653–658

[2] Andrei, N.: Modern Control Theory: a Historical Perspective. Research Institute for Informatics, *Centre for Advanced Modelling and Optimization*, Romania, http://www.ici.ro/camo/neculai/history.pdf (2005)

[3] Chin-Te Chen, Win-Li Lin, Te-Son Kuo, Cheng-Yi Wang: Blood Pressure Regulation by Means of a Neuro-fuzzy Control System. *The 18th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Amsterdam (1996) 1725–1726

[4] Cox, D.: Regression Models and Life Tables. *J Roy Stat Soc B*, 4 (1972) 187–220.

[5] Do-Kyong Kim, Sung Yong Oh, Hyuk-Chan Kwon, Suee Lee, Kyung A Kwon, Byung Geun Kim, Seong-Geun Kim, Sung-Hyun Kim, Jin Seok Jang, Min Chan Kim, Kyeong Hee Kim, Jin-Yeong Han, Hyo-Jin Kim: Clinical Significances of Preoperative Serum Interleukin-6 and C-reactive

Protein Level in Operable Gastric Cancer. *BMC Cancer 2009*, 9 (2009) 155–156

[6] Everitt, B., Rabe-Hesketh, S.: Analyzing Medical Data Using S-PLUS, *Springer,* New York (2001)

[7] Hernández, C., Carollo, A., Tobar, C.: Fuzzy Control of Postoperative Pain. *Proceedings of the Annual International Conference of the IEEE* (1992) 2301–2303

[8] Isaka, S., Sebald, A. V.: An Adaptive Fuzzy Controller for Blood Pressure Regulation. *IEEE Engineering in Medicine & Biology Society – The 11th Annual International Conference* (1989) 1763–1764

[9] Kaplan, E., Meier, P.: Nonparametric Estimation from Incomplete Observations. *Journal American Statistical Association* 53 (1958) 457–481

[10] Mamdani, E. H., Assilian, S.: An Experiment in Linguistic Synthesis with a Fuzzy Logic Controller. *Int. J. Man-Machine Studies* 7 (1973) 1–13

[11] de Mello, J., Struthers, L., Turner, R., Cooper, E. H., Giles, G. R.: Multivariate Analyses as Aids to Diagnosis and Assessment of Prognosis in Gastrointestinal Cancer. *Br. J. Cancer*, 48 (1983) 341–348

[12] Newland, R. C., Dent, O. F., Lyttle, M. N., Chapuis, P. H., Bokey, E. L.: Pathologic Determinants of Survival Associated with Colorectal Cancer with Lymph Node Metastases. A Multivariate Analysis of 579 Patients. *Cancer* 73(8) (1994) 2076–2082

[13] Nguyen, H. T., Prasad, N. R., Walker, C. L., Walker, E. A.: A First Course in Fuzzy and Neural Control*, Chapman & Hall/CRC* (2002)

[14] Rakus-Andersson, E., Salomonsson, M., Zettervall, H.: Two-player Games with Fuzzy Entries of the Payoff Matrix. *Computational Intelligence in Decision and Control - Proceedings of FLINS 2008, Madrid 2008,* World Scientific (2008a) 593–598

[15] Rakus-Andersson, E., Salomonsson, M., Zettervall, H.: Ranking of Weighted Strategies in the Two-player Games with Fuzzy Entries of the Payoff Matrix. *Proceedings of the 8th International Conference on Hybrid Intelligent Systems*, Barcelona 2008, Eds: Fatos Xhafa, Francisco Herrera, Ajith Abraham et al., CDR by Universitat Polytecnica de Catalunya (2008b)

[16] Rakus-Andersson, E., Jain, L.: Computational Intelligence in Medical Decisions Making. *Recent Advances in Decision Making,* Rakus-Andersson, E., Yager, R. R., Jain, L., (Eds) in Series: Studies of Computational Intelligence, Berlin Heidelberg, Springer (2009a) 145–159

[17] Rakus-Andersson, E.: Approximate Reasoning in Surgical Decisions. *Proceedings of the International Fuzzy Systems Association World Congress – IFSA 2009*, Lisbon, Instituto Superior Technico (2009b) 225–230

[18] Rakus-Andersson, E., Zettervall, H., Erman, M.: Prioritization of Weighted Strategies in the Multi-player Games with Fuzzy Entries of the Payoff Matrix. *Int. J. of General Systems*, Vol, 39, Issue 3 (2010) 291–304

[19] Sargent, D. J.: Comparison of Artificial Networks with Other Statistical Approaches. *Cancer,* 91 (2001) 1636–1942

[20] Sugeno, M.: An Introductory Survey of Fuzzy Control. *Inf. Sci.* 36 (1985) 59–83

[21] Sugeno, M., Nishida, M.: Fuzzy Control of Model Car. *Fuzzy Sets and Systems* (1985) 103–113

[22] Sutton, R., Towill, D. R.: An Introduction to the Use of Fuzzy Sets in the Implementation of Control Algorithms. *IEEE Trans., UDC 510.54:62-519:629.12.014.5* (1985) paper no. 2208/ACS39.

[23] Zettervall, H., Rakus-Andersson, E., Forssell, H.: The Mamdani Controller in Prediction of the Survival Length in Elderly Gastric Patients. *Proceedings of Bioinformatics 2011*, Rome, (2011), 283–286

[24] Zettervall H. Fuzzy and Rough Theory in the Treatment of Elderly Gastric Cancer Patients, *Licentiate Dissertation*, Karlskrona, Sweden, 2011

The papers presented in this Volume 2 constitute a collection of contributions, both of a foundational and applied type, by both well-known experts and young researchers in various fields of broadly perceived intelligent systems.
It may be viewed as a result of fruitful discussions held during the Ninth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGN-2010) organized in Warsaw on October 8, 2010 by the Systems Research Institute, Polish Academy of Sciences, in Warsaw, Poland, Institute of Biophysics and Biomedical Engineering, Bulgarian Academy of Sciences in Sofia, Bulgaria, and WIT - Warsaw School of Information Technology in Warsaw, Poland, and co-organized by: the Matej Bel University, Banska Bystrica, Slovakia, Universidad Publica de Navarra, Pamplona, Spain, Universidade de Tras-Os-Montes e Alto Douro, Vila Real, Portugal, and the University of Westminster, Harrow, UK:

Http://www.ibspan.waw.pl/ifs2010

The consecutive International Workshops on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGNs) have been meant to provide a forum for the presentation of new results and for scientific discussion on new developments in foundations and applications of intuitionistic fuzzy sets and generalized nets pioneered by Professor Krassimir T. Atanassov. Other topics related to broadly perceived representation and processing of uncertain and imprecise information and intelligent systems have also been included. The Ninth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGN-2010) is a continuation of this undertaking, and provides many new ideas and results in the areas concerned.

We hope that a collection of main contributions presented at the Workshop, completed with many papers by leading experts who have not been able to participate, will provide a source of much needed information on recent trends in the topics considered.

ISBN-13 9788389475367
ISBN 838947536-7
9 788389 475367