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METHOD OF SOLVING INCORRECT TASKS FORMED BY CONSTRUCTION OF FUZZY MODELS ASSESSING THE WEAKLY FORMALLIZED PROCESSES

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Abstract: *The article examines the improvement of the method for obtaining a fuzzy and fuzzy-stable solution to incorrect problems arising in the construction of a model for estimating the state of weakly formalizable processes using various membership functions based on the theory of fuzzy sets. The proposed method makes it possible to construct a correct fuzzy model of weakly formalizable processes.*

Keywords: *fuzzy sets, fuzzy models, neural networks, membership function, decision making, incorrect task, sustainability, evaluation.*

Introduction

In the world special attention is paid to the improvement of intelligent computing technologies for solving problems of data mining. Theories of fuzzy sets and fuzzy logic are a prerequisite for processing a person with available information and possessing a decision-making mechanism in the face of inaccurate and incomplete information. At present, it is the development of artificial intelligence systems with the help of fuzzy logic estimation that is one of the urgent tasks. Soft Calculation, Soft Computing methods, including methods based on fuzzy sets theory, fuzzy logic and fuzzy arithmetic, a system of fuzzy inference rules and Z-numbers are widely used in countries such as the USA, England, Japan , Germany, Italy, France, Canada, Russia, Azerbaijan, Ukraine, etc., pays special attention to the implementation of systems to support the adoption of weakly structured solutions and Computational Intelligence - the deterioration of intelligent computing technologies [1-3].

The world is conducting scientific research aimed at improving the systems of artificial intelligence and developing decision support systems in weakly structured processes. In this regard, the construction of intelligent systems, the improvement of soft computing methods and tools, the development of evolutionary computational methods for processing data on evaluation, forecasting and risk management in weakly formalized systems, as well as the development of algorithms for solving fuzzy multicriteria optimization problems arising in the process of constructing fuzzy model.

In the Republic, in order to develop socio-economic spheres of the national economy, attention is paid to the introduction of intelligent computing technologies. In this sphere, in particular, on the basis of solving the problems of management, diagnosis, evaluation of the production process using the theory of fuzzy sets, significant results are achieved, highly effective intellectual systems for assessing the state of weakly formalized processes and making decisions based on the processing of fuzzy information are developed. In this connection, it is important to improve the methods for analyzing the states of weakly formalized processes and constructing intelligent decision-making systems with fuzzy initial data [3-5].

1. Statement of a problem

Solving the problem of intellectual analysis is characterized by a lack of essential information and data in a linguistic form. In such cases it is advisable to apply theories of fuzzy sets and Z-numbers.

In the process of constructing a fuzzy logic model for estimating and predicting the state of weakly formalized processes, in some cases there arises the problem of solving incorrect problems.

Let a sample of fuzzy experimental data be given (X_r, y_r) $r = \overline{1, M}$, where $X_r = (x_{r,1}, x_{r,2}, ..., x_{r,n})$ - the input vector in the r-th pair and y_r the corresponding output.

Let the model consisting of fuzzy inference rules, in general form, be constructed as follows [L.Zade, A.Rotstein, R.Aliyev]:

$$\bigcup_{p=1}^{k_j}\left(\bigcap_{i=1}^{n} x_i = a_{i,jp} - w_{jp} \text{ with weight}\right) \to$$
$$\to y_j = v_{j,0} + v_{j,1}x_1 + ... + v_{j,n}x_n + \tag{1}$$
$$+v_{j,n+1}x_1^2 + ... + v_{j,2n}x_n^2 + ... +$$
$$+v_{j,n+l-1}x_1^l + ... + v_{j,ln}x_n^l.$$

For l = 0, model (1) is a model of the singleton type. For l = 1 model (1) is a model of the Sugeno type.

In the process of building a model, it is required to find such values of the coefficients of fuzzy inference rules

$V = (v_{1,0}, v_{2,0}, ..., v_{m,0},\ v_{1,1}, v_{2,1}, ..., v_{m,1}, ..., v_{1,n} v_{2,n}, ...,$ $v_{m,n}, ..., v_{1,ln} v_{2,ln}, ..., v_{m,ln}),\ i = \overline{1,n},\ j = \overline{1,m}$ at which the minimum of the following expression is reached:

$$\sum_{r=\overline{1,M}} \left(y_r - y_r^f\right)^2 \to \min, \tag{2}$$

where y_r^f – output sample result in the r-th row of the base of fuzzy knowledge.

The solution of problem (2) corresponds to the solution of the following equation:

$$Y = A \cdot V, \tag{3}$$

here

$$A = \begin{bmatrix} \beta_{1,1}, ..., \beta_{1,m}, \quad x_{1,1} \cdot \beta_{1,1}, ..., x_{1,1} \cdot \beta_{1,m}, \quad ..., \\ x_{1,n} \cdot \beta_{1,1}, ..., x_{1,n} \cdot \beta_{1,m}, ..., \quad x^l{}_{1,1} \cdot \beta_{1,1}, ..., \\ x^l{}_{1,1} \cdot \beta_{1,m}, \quad ..., \quad x^l{}_{1,n} \cdot \beta_{1,1}, ..., x^l{}_{1,n} \cdot \beta_{1,m} \\ \vdots \\ \beta_{M,1}, ..., \beta_{M,m},\ x_{M,1} \cdot \beta_{1,1}, ..., x_{M,1} \cdot \beta_{1,m}, \\ ...,\ x_{M,n} \cdot \beta_{M,1}, ..., x_{M,n} \cdot \beta_{M,m}, ..., \quad x^l{}_{M,1} \cdot \beta_{1,1}, \\ ..., x^l{}_{M,1} \cdot \beta_{1,m},\ ...,\ x^l{}_{M,n} \cdot \beta_{M,1}, ..., x^l{}_{M,n} \cdot \beta_{M,m} \end{bmatrix} \tag{4}$$

$$\beta_{j,r} = \frac{\mu_{f_j}(X_r) \cdot f_j}{\sum_{k=1}^{m} \mu_{f_k}(X_r)} \text{ or } \beta_{j,r} = \frac{\mu_{f_j}(X_r) \cdot f_j}{\int_{x_-}^{x_+} \mu_{f_j}(x)dx},$$

$$f_j = v_{j,0} + v_{j,1}x_{r,1} + v_{j,2}x_{r,2} + ... + v_{j,n}x_{r,n}$$
$$+v_{j,n+1}x_{r,1}^2 + v_{j,n+2}x_{r,2}^2 + ... + v_{j,2n}x_{r,n}^2 + ...$$
$$+v_{j,n+l-1}x_{r,1}^l + v_{j,n+l}x_{r,2}^l + ... + v_{j,ln}x_{r,n}^l$$

conclusion of the j-rule; $\mu_{f_j}(x_r)$ - the degree of fulfillment of the conclusion of the j-th rule, corresponding to the experimental data $x_r \in X_r$:

$$\mu_{f_j}(X_r) = \mu_{j,1}(x_{r,1}) \cdot \mu_{j,1}(x_{r,2}) \cdot$$
$$\mu_{j,1}(x_{r,3}) \cdot ... \cdot \mu_{j,1}(x_{r,ln}) \vee$$
$$\vee \mu_{j,2}(x_{r,1}) \cdot \mu_{j,2}(x_{r,2}) \cdot$$
$$\mu_{j,2}(x_{r,3}) \cdot ... \cdot \mu_{j,2}(x_{r,ln}) \vee$$
$$.........................$$
$$\vee \mu_{j,k_j}(x_{r,1}) \cdot \mu_{j,k_j}(x_{r,2}) \cdot$$
$$\mu_{j,k_j}(x_{r,3}) \cdot ... \cdot \mu_{j,k_j}(x_{r,ln}).$$

For real problems, the number of configurable parameters is less than the sample size *m(n+1)<M*, so equation (3) does not have an exact solution. Then the solution of the system of equations $Y = A \cdot V$ reduces to the solution of the problem $A^T Y = A^T A \cdot V$.

2. The concept of the problem decision

- The possibility of obtaining fuzzy and fuzzy-stable solutions using various membership functions.

Statement *1*. The primary information given in the n-dimensional $X=R^n$ space and characterizing the following membership function is fuzzy-compact:

$$\mu(x) = \frac{1}{1 + t\|x\|^2}.$$

Proof. We will show that this primary information is fuzzy-compact.

Consider the set of α-level:

$$\forall \alpha \in (0,1],\ t > 1,\ \ A_\alpha(x) = \{x : \mu(x) \geq \alpha\} \Rightarrow$$

$$A_\alpha(x) = \left\{x : \frac{1}{1 + t\|x\|^2} \geq \alpha\right\} = \left\{x : 1 + t\|x\|^2 \leq \frac{1}{\alpha}\right\} =$$

$$\left\{x : \|x\|^2 \leq \frac{1-\alpha}{t\alpha}\right\} = \left\{x : \|x\| \leq \sqrt{\frac{1-\alpha}{t\alpha}}\right\} =$$

$$\{x : \|x\| < \varepsilon(\alpha)\},\ \varepsilon(\alpha) = \sqrt{\frac{1-\alpha}{t\alpha}}.$$

We get $\varepsilon(\alpha)=\sqrt{\frac{1-\alpha}{t\alpha}}<\infty$. Then A_α will be compact.

The statement is proved.

A fuzzy solution of the equation $Av=u$ is the primary information represented by a fuzzy set $\bigcup_\alpha \alpha A_\alpha$, which has the following properties:

- the operator A and the initial data u;
- $\forall\alpha\in(0,1],\ \mathrm{A}_\alpha=\{u:\mu_A(u)\geq\alpha\}$;

$\exists\varepsilon(\alpha)>0,\ \sup_{v\in \mathrm{A}_\alpha}\rho_v\left(A(v),A_\alpha\right)<\varepsilon(\alpha)<\infty$.

Here ρ_v – distance between sets $A(v)$ and A_α.

We search for a fuzzy solution of primary information with the membership function $\mu(v)=\dfrac{1}{1+t\|Av-u\|^2}$.

A continuous operator A and initial data are given.

$$\forall\alpha\in(0,1],\ t>1,\ A_\alpha(v)=\{v:\mu_A(v)\geq\alpha\}=$$

$$\left\{v:\frac{1}{1+t\|Av-u\|^2}\geq\alpha\right\}=\left\{v:\|Av-u\|\leq\sqrt{\frac{1-\alpha}{t\alpha}}=\varepsilon(\alpha)<\infty\right\}.$$

We can consider $\varepsilon(\alpha)$ in the form $\varepsilon(\alpha)=\sqrt{\frac{1-\alpha}{t\alpha}}<\infty$.

If the following conditions are satisfied, then the fuzzy solution is called stable:

- $\lim\limits_{\alpha\to\sup_{v\in V}\mu(v)}\varepsilon(\alpha)=0$;
- the operator A on $D(A_\alpha)$ is continuous.

Let us consider whether the above fuzzy solution is stable.

Since $\varepsilon(\alpha)=\sqrt{\frac{1-\alpha}{t\alpha}}$, then $\lim\limits_{\alpha\to1}\varepsilon(\alpha)=\lim\limits_{\alpha\to1}\left(\sqrt{\frac{1-\alpha}{ta}}\right)=0$ - the first condition is satisfied. The continuity of the operator A in $D(A_\alpha)$ follows from the statement of the problem. It is shown that the fuzzy solution is stable.

Fuzzy stable solutions allow us to construct approximate solutions.

Consider the case of constructing stable fuzzy solutions.

Let the operator $A:v\to U$ is a continuous operator in $v\in V$, then we can construct a stable fuzzy solution.

We take an arbitrary element $v\in V$. Let us prove that it is possible to construct a stable fuzzy solution of the primary information, expressed by the membership function $\mu(v)=\dfrac{1}{1+t\|Av-u\|^2}$.

Let $\forall\alpha\in(0,1],\ t>1,\ 0<Av-u<\infty$, $\varepsilon(\alpha)=\sqrt{\frac{1-\alpha}{t\alpha}}$.

Suppose that, $A_\alpha=O_{\varepsilon(\alpha)}(Av)$ ε is a circle of the set Av. One can construct a stable fuzzy solution of the form $\bigcup_\alpha \alpha A_\alpha$:

$$\lim_{\alpha\to1}\varepsilon(\alpha)=\lim_{\alpha\to1}\left(\sqrt{\frac{1-\alpha}{t\alpha}}\right)=0.$$

It was shown above that the primary information is stable and from continuity A the condition of fuzzy solution.

3. Realization of the concept

The Z-number is an ordered pair of fuzzy numbers, denoted as $Z=(A,B)$. The first component of A is the restriction to the values of the real indefinite variable X. The second component, B, represents the measure of the reliability of the first component.

Z-information is a fuzzy set with the membership function (μ_A,p_x), where $x\in X$.

A carrier of Z-information is an ordinary set of type

$$\sup pA=\left\{x:\mu\left(\frac{x}{k}\right)>0\right\}.$$

Here k – defuzzifying value of a generalized fuzzy number with respect to the mean integral representation. Let for the fuzzy number L-R of the form L^{-1} and R^{-1} are the inverse functions L and R, respectively. Then k is the defuzzification value of the generalized fuzzy number, based on the integral value of the weight mean h-power in the mean integral representation is

$$k=\frac{1}{2}\frac{\int_0^h\left[h\frac{L^{-1}(h)-R^{-1}(h)}{2}\right]dh}{\int_0^w hdh};$$

where $L(h)$- left membership function, $R(h)$- right membership function, h- degree is located between 0 and w, $0<w\leq1$.

Z-information is called compact if its carrier is compact on the base space X (that is, from any sequence we can select a convergent subsequence).

If any set level other than zero, is compact in the space X, the Z-information is called Z-compact, i.e. $\forall \alpha \in (0,1]$, $A_\alpha = \left\{ x : \mu\left(\frac{x}{k}\right) \geq \alpha \right\}$ – compact area in space.

Statement 2. Z-information, expressed by the following membership function, is Z-compact in $X=R^n$:

$$\mu(x) = e^{-t\left\|\frac{x}{k}\right\|^2}.$$

Proof. Let us prove that this Z-information is Z-compact.

Consider the set of α-degree:

$$\forall \alpha \in (0,1],\ t > 0,\ A_\alpha(x) = \left\{ x : \mu_A\left(\frac{x}{k}\right) \geq \alpha \right\} =$$

$$\left\{ x : \exp(-t\left\|\frac{x}{k}\right\|^2) \geq \alpha \right\} = \left\{ k : \|x\| \leq k\sqrt{-\frac{\ln \alpha}{t}} = \varepsilon(\alpha) < \infty \right\}.$$

The statement is proved.

The solution of the equation $Av = u,\ u \in U,\ v \in V$ obtained on the basis of Z-numbers is Z-information, given as a fuzzy set and having the following properties:

- the operator A and the initial data u;
- $\forall \alpha \in (0,1],\ A_\alpha = \left\{ x : \mu_A\left(\frac{x}{k}\right) \geq \alpha \right\}$ $\exists \varepsilon(\alpha) > 0$;
- $\sup\limits_{v \in A_\alpha} \rho_v\left(A(v), A_\alpha\right) < \varepsilon(\alpha) < \infty$; here ρ_v – distance between sets $A(v)$ and A_α.

If A is a continuous operator and u is given by the following formula, then the search problem v:

$$Av = u,\ u \in U,\ v \in V.$$

A solution obtained on the basis of Z-numbers is stable if the following conditions are satisfied:

- $\lim\limits_{\alpha \to \sup\limits_{x \in X} \mu\left(\frac{x}{k}\right)} \varepsilon(\alpha) = 0$;
- for $\forall \alpha \in (0,1]$ the operator A on $D(A_\alpha)$ is continuous.

Let's consider, whether the decision received on the basis of Z-numbers with membership function $\mu(v) = \exp\left(-\left(\frac{Av-u}{k}\right)^2\right)$, sustainable.

Shown, that $\varepsilon(\alpha) = k\sqrt{-\ln \alpha} < \infty$, and the first condition is satisfied, i.e. $\lim\limits_{\alpha \to 1} \varepsilon(\alpha) = \lim\limits_{\alpha \to 1}\left(k\sqrt{-\ln \alpha}\right) = 0$. The continuity of the operator A on $D(A_\alpha)$ follows from the conditions for setting the problem. Thus, it is shown that the solution obtained on the basis of Z-numbers is stable.

Conclusion

The method for determining incorrect problems arising in the construction of a fuzzy model is improved on the basis of checking the conditions for the correctness of the evaluation of the state of weakly formalized processes. This method serves to solve the problems of estimation and prediction.

An approach is developed for constructing a fuzzy-logical model for estimating, classifying and predicting the state of weakly formalized processes by converting Z-numbers to classical fuzzy numbers. This approach, unlike others, gives an opportunity to obtain a reliable result in decision-making within the framework of Z-information.

The method of obtaining a stable solution based on Z-numbers is improved. The method makes it possible to obtain a reliable result of classification and forecasting the state of weakly formalized processes.

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