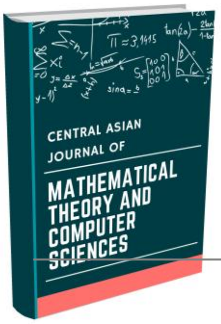

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DEVELOPMENT OF FUZZY REGRESSION HYBRID ALGORITHM

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Abstract

This article introduces a novel Fuzzy Regression Hybrid Algorithm, combining fuzzy logic and regression techniques to enhance predictive modeling. The algorithm adeptly handles uncertainty and non-linearity, offering a robust solution for complex data relationships. Through empirical analysis, the algorithm's effectiveness is demonstrated across various domains, showcasing its potential for accurate predictions and informed decision-making. The Fuzzy Regression Hybrid Algorithm emerges as a valuable tool for tackling real-world challenges and advancing the field of data-driven modeling.

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In the realm of predictive modeling, the fusion of fuzzy logic and regression techniques has gained prominence as a promising avenue to tackle the challenges posed by uncertain and non-linear data relationships. This article presents the culmination of this pursuit – the Development of a Fuzzy Regression Hybrid Algorithm. As data-driven decision-making continues to shape various domains, the need for accurate and adaptable models has grown exponentially. The integration of fuzzy logic's ability to handle uncertainty and regression's predictive power paves the way for a novel algorithm that seeks to provide an innovative solution to this demand. This article explores the conceptual foundations, methodology, and empirical evaluations that underpin the Fuzzy Regression Hybrid Algorithm's development, illustrating its potential to enhance predictive accuracy and inform decision-making across complex real-world scenarios. Through the amalgamation of two powerful methodologies, this algorithm emerges as a versatile tool poised to bridge the gap between intricate data relationships and practical applications.

$y = a_0 + a_1x_1 + a_2x_2 + \ldots + a_nx_n$- $y =$in the linear regression model, let a_i - estimation coefficients and x_i - input data be given in fuzzy form.

a_i – fuzzy numbers are given using the following parameters:

$a_i = (\underline{a}_i, \tilde{a}_i, \overline{a}_i)$,

$\tilde{a}_i$ - unclear thigh center;

$\underline{a}_i$ -fuzzy number lower limit;

$\overline{a}_i$ - fuzzy number upper limit.

x_i - input data should be provided using the following parameters:

$x_i = (\underline{x}_i, \tilde{x}_i, \overline{x}_i)$,

here:

$\tilde{x}_i$ - unclear thigh center;

$\underline{x}_i$ - fuzzy number lower limit;

$\overline{x}_i$ - fuzzy number upper limit.

In that case, u - fuzzy number parameters are determined as follows.

Ambiguous thigh center:

$$\tilde{y} = \sum_i \tilde{a}_i \tilde{x}_i .$$

The width of the left side of the fitness function:

$$\tilde{y} - \underline{y} = \sum_i |\tilde{a}_i|(\tilde{x}_i - \underline{x}_i) + c|\tilde{x}_i|.$$

The lower limit of the interval is equal to:

$$\underline{y} = -\sum_i |\tilde{a}_i|(\tilde{x}_i - \underline{x}_i) - c_i|\tilde{x}_i| + \tilde{a}_i\tilde{x}_i = \sum_i \tilde{a}_i\tilde{x}_i - |\tilde{a}_i|(\tilde{x}_i - \underline{x}_i) - c_i|\tilde{x}_i| .$$

The width of the right-hand side of the fitness function is:

$$\overline{y} - \tilde{y} = \sum_i |\tilde{a}_i|(\overline{x}_i - \tilde{x}_i) + c_i|\tilde{x}_i| .$$

The upper limit of the interval is:

$$\overline{y} = \sum_i |\tilde{a}_i|(\overline{x}_i - \tilde{x}_i) + c_i|\tilde{x}_i| + \tilde{a}_i\tilde{x}_i .$$

For the fuzzy logic model to be correct, the true values of u must belong to the optimal interval [103].

The main conditions imposed on the estimation interval model are $(\underline{a}_i, \tilde{a}_i, \overline{a}_i)$ to find parameters of fuzzy numbers such that the following are fulfilled.

a) the current y_k let the values lie in its evaluative interval;

b) let the sum of evaluative intervals be minimal.

The input data is $x_k = x_{ki}$ and y_k is a training sample; $k = \overline{1,m}$; *m is* the number of the examined sample.

Let's find the representation of the model given by the fitness function in triangular form:

a_i – be triangular in shape and given by the following three parameters:

$a_i = (\underline{a}_i, \tilde{a}_i, \overline{a}_i)$.

If the membership function is given in symmetric form

$\underline{a}_i = \tilde{a}_i - c_i$,

$\overline{a}_i = \tilde{a}_i + c_i$

then we can express it using 2 parameters.

Here $\tilde{a}_i$ is the unclear center of the thigh; c_i – vague number width, $c_i > 0$.

u fuzzy number parameters are expressed as follows, that is, the center of the interval:

$$\tilde{y} = \sum_i \tilde{a}_i \cdot \tilde{x}_i .$$

Deviation of the left part of the fitness function:

$$\overline{y} - \underline{y} = \sum_i |\tilde{a}_i| (\overline{x}_i - \underline{x}_i) + c_i |\tilde{x}_i|.$$

The lower limit of the interval is:

$$\underline{y} = -\left(\sum_i |\tilde{a}_i| (\tilde{x}_i - \underline{x}_i) + c_i |\tilde{x}_i| + \tilde{a}_i \tilde{x}_i \right) = \sum_i \tilde{a}_i \tilde{x}_i - |\tilde{a}_i| (\tilde{x}_i - \underline{x}_i) - c_i |\tilde{x}_i|.$$

The right side deviation of the fitness function is:

$$\overline{y} - \tilde{y} = \sum_i |\tilde{a}_i| (\overline{x}_i - \tilde{x}_i) + c_i |\tilde{x}_i|.$$

The upper limit of the interval is:

$$\overline{y} = \sum_i |\tilde{a}_i| (\overline{x}_i - \tilde{x}_i) + c_i |\tilde{x}_i| + \tilde{a}_i \tilde{x}_i .$$

For the fuzzy logic model to be correct

a) must belong to the interval in which the real values of *u are found.* This can be interpreted as follows:

$$\begin{cases} \sum_{i=1}^{n} \tilde{a}_i \tilde{x}_i - |\tilde{a}_i| (\tilde{x}_i - \underline{x}_i) - c_i |\tilde{x}_i| \le y_k, \\ \sum_{i=1}^{n} \tilde{a}_i \tilde{x}_i - |\tilde{a}_i| (\overline{x}_i - \tilde{x}_i) + c_i |\tilde{x}_i| \ge y_k. \end{cases}$$

b) Let the sum of estimation intervals be minimal.

These conditions can be solved by introducing a linear programming problem:

$$\begin{cases} \sum_{i=1}^{n} |\tilde{a}_i|(\overline{x}_i - \underline{x}_i) + 2c_i|\tilde{x}_i| \to \min, \\ \sum_{i=1}^{n} \tilde{a}_i\tilde{x}_i - |\tilde{a}_i|(\tilde{x}_i - \underline{x}_i) - c_i|\tilde{x}_i| \le y_k, \ \ k = \overline{1,m}, \\ \sum_{i=1}^{n} \tilde{a}_i\tilde{x}_i + |\tilde{a}_i|(\overline{x}_i - \tilde{x}_i) + c_i|\tilde{x}_i| \ge y_k. \end{cases}$$

Let us find the parameters of the model whose fitness function is Gaussian.

$$y = a_0 + a_1x_1 + a_2x_2 + ... + a_nx_n$$

in the linear fuzzy regression model a_i - is a Gaussian fuzzy number $(\tilde{a}_i, c_i)$ given by the parameter, where $\tilde{a}_i$ - is the center of the fuzzy number, c_i - describes the width of the interval, $c_i > 0$.

x_i - let the input data be a Gaussian fuzzy number. Let them have a membership function of the following form:

$$\mu(x) = \begin{cases} e^{-\frac{1}{2}\frac{(x-\tilde{a})^2}{c_1^2}}, & x \le a, \\ e^{-\frac{1}{2}\frac{(x-\tilde{a})^2}{c_2^2}}, & x > a. \end{cases}$$

Then such fuzzy numbers are determined by 3 parameters:

$(c_1, \tilde{a}, c_2)$,

here:

$\tilde{a}_i$ - unclear thigh center;

c_1 – left interval width;

c_2 – right side interval width;

In this case, the problem is formulated as follows: find such parameters of the coefficients $(\tilde{a}_i, c_i)$ a *and i* that the following conditions are fulfilled:

a) *y k in Eq let* the found interval αbelong to a degree not less than degree, $0 < \alpha < 1$;

b) αlet the width of the level interval be minimal.

αThe grade interval is equal to:

$$d_\alpha = y_2 - y_1.$$

it is 1 and *u 2* can be found from the following system [2,3]:

$$\begin{cases} \alpha = \exp\left(-\frac{1}{2}\frac{(y_2-\tilde{a})^2}{c_2^2}\right), \\ \alpha = \exp\left(-\frac{1}{2}\frac{(y_1-\tilde{a})^2}{c_1^2}\right). \end{cases}$$

From this:

$$y_2 = c_2\sqrt{-2\ln\alpha} + \tilde{a},$$

$$y_1 = c_1\sqrt{-2\ln\alpha} + \tilde{a},$$

$$d_\alpha = -2\ln\alpha(c_2 + c_1).$$

a) condition can be written in the following form:

$$\mu(y_k) \geq \alpha \Rightarrow \begin{cases} y_k \leq \tilde{a}_k + c_{2k}\sqrt{-2\ln\alpha}, \\ y_k \geq \tilde{a}_k - c_{1k}\sqrt{-2\ln\alpha}. \end{cases}$$

The problem can be written as follows:

$$\min\sum_{k=1}^{m} d_\alpha^k = \min\sum_{k=1}^{m}(c_{2k} + c_{1k})\sqrt{-2\ln\alpha},$$

$$\begin{cases} y_k \leq \tilde{a}_k + c_{2k}\sqrt{-2\ln\alpha}, \\ y_k \geq \tilde{a}_k - c_{1k}\sqrt{-2\ln\alpha}. \end{cases}$$

x_i variables $(\underline{x}_i, \tilde{x}_i, \overline{x}_i)$ can be given in the form, $\underline{x}_i$ – the lower limit of the fuzzy number, $\tilde{x}_i$ – the center of the fuzzy number, $\overline{x}_i$ – the upper limit of the fuzzy number.

Here:

$$\underline{x}_i = \tilde{x}_i - c_{1i},\ \overline{x}_i = \tilde{x}_i + c_{2i}.$$

Then *the* fuzzy number parameters are determined as follows:

it is the center of the fuzzy number interval:

$$\tilde{y} = \sum_i \tilde{a}_i\tilde{x}_i.$$

Deviation of the left side of the fitness function:

$$\tilde{y} - \underline{y} = \sum_i (\tilde{a}_i(\tilde{x}_i - \underline{x}_i) + c_i|\tilde{x}_i|).$$

The lower limit of the interval is:

$$\underline{y} = \sum_i (\tilde{a}_i\underline{x}_i - c_i|\tilde{x}_i|).$$

Deviation of the right-hand side of the fitness function:

$$\bar{y} - \tilde{y} = \sum_i (\tilde{a}_i(\bar{x}_i - \tilde{x}_i) + c_i |\tilde{x}_i|) = \sum_i \tilde{a}_i \bar{x}_i - \tilde{a}_i \tilde{x}_i + c|\tilde{x}_i|.$$

The upper limit of the interval is:

$$\bar{y} = \sum_i (\tilde{a}_i \bar{x}_i + c_i |\tilde{x}_i|).$$

In order to find the parameters of a model whose fitness functions are bell-shaped, it is necessary to solve the following linear programming problem:

$$\begin{cases} \sum_{k=1}^{m} (c_{1k} + c_{2k}) \sqrt{\dfrac{1-\alpha}{\alpha}} \to \min, \\ y_k \le \tilde{a}_k + c_{2k} \sqrt{\dfrac{1-\alpha}{\alpha}}, \\ y_k \ge \tilde{a}_k + c_{1k} \sqrt{\dfrac{1-\alpha}{\alpha}}. \end{cases}$$

$\tilde{a}_k$, c_{1k}, c_{2k} Once the parameters are found, the representation of the given fuzzy logic model is determined.

Effective results can be obtained if modern evolutionary algorithms are used in the process of finding the parameters of a fuzzy logic model.

The development of the Fuzzy Regression Hybrid Algorithm marks a significant advancement in predictive modeling. By seamlessly integrating fuzzy logic and regression, this algorithm addresses uncertainty and non-linearity, yielding accurate predictions across diverse domains. Empirical validation underscores its effectiveness, highlighting its potential to revolutionize decision-making and modeling. The Fuzzy Regression Hybrid Algorithm stands as a promising solution, bridging the gap between complex data relationships and practical applications, thereby advancing the landscape of data-driven methodologies.

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