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# **Neuro-fuzzy justification of the results obtained on the basis of GIS modeling**

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**ABSTRACT:** The results of neuro-fuzzy modeling based on the results of GIS modeling of the state of telecommunication systems on electromagnetic safety and the sequence of neuro-fuzzy modeling for making decisions on the parameters of the electromagnetic state of the territory in the ANFIS environment.

**KEY WORDS:** Neuro-fuzzy modeling, GIS modeling, electromagnetic safety, Fuzzy Logic Toolbox, ANFIS editor

## **I. INTRODUCTION**

Application of mathematical methods for data processing: changes in electromagnetic polarization on significant difficulties, primarily in measurements, based on electromagnetic voltages, field of view of functioning radio-emitting means in areas classified by operating frequency ranges [1].

However, in conditions of uncertainty of the source of field strength due to the influence of the terrain and the location of radio-emitting means, such as high-frequency radiators, directional radio communications (satellite radio communications, ground relay stations), navigation (air traffic, navigation, radio point), locators (air traffic, shipping, transport locators, air traffic control), etc., in the total amount of initial information, information of a fuzzy nature dominates, which is an experience and judgments of experienced specialists and experts with experience and a good knowledge of the subject area. The use of such information, presented in a verbal, linguistic form together with information of a numerical character in the practice of modeling and decision-making, in the practice of communication is poorly understood and relevant.

## **II. MAIN PART**

A promising approach for an adequate assessment of the electromagnetism in the areas of operation of radio-emitting technical means is the use of a fuzzy-logical approach, which makes it possible to directly use qualitative information reflecting the experience, knowledge and intuition of experts and experts.

Electromagnetic time series have a wide range of uncertainties, the main ones being:

- inherent uncertainties resulting from environmental changes;
- statistical uncertainties explained by non-observance of the basic rules for the formation of static aggregates;
- uncertainties associated with the use of inadequate modeling method or with the unreasonable use of simplified models.

The use of methods for processing interpolation-based data, on general trends of the time series, extrapolation, as well as unreasonable data reduction, without taking into account missing data, distort the original structure of the time series. Therefore, a promising method for processing data in such conditions is an approach based on a rational combination of a fuzzy-multiple approach and artificial neural networks, that is, hybrid neural networks that are effectively implemented in the Fuzzy Logic Toolbox (FLT) software environment, which help to recover the missing data without losing information about source time series. Today, the use of adaptive fuzzy systems and systems based on the used neural networks is one of the most popular approaches capable of learning. These systems work with time series, where a process of behavior is rearranged into a time series and then the behavior of the time series is predicted by a neural network. In fuzzy systems, relationships are represented explicitly in the form of IF - THEN rules. In neural networks,

relationships are represented implicitly in the form of coded network parameters. Therefore, neuro-fuzzy models combine the transparency of fuzzy systems with the ability of the neural network to learn.

Neuro-fuzzy modeling is implemented on the basis of the MATLAB system's Fuzzy Logic Toolbox package in the form of the ANFIS adaptive neural-fuzzy output system. The terms of the input linguistic variables are described by the standard membership functions of the MATLAB system, and the terms of the output variable are represented by a linear or constant membership function. In the FuzzyLogicToolbox package of the MATLAB system, hybrid networks are implemented in the form of the adaptive neuro-fuzzy inference systems ANFIS. At the same time, the development and research of hybrid networks is possible:

- in interactive mode with the help of a special graphical editor of adaptive networks, called ANFIS editor;
- in the command line mode by entering the names of the corresponding functions with the necessary arguments directly into the MATLAB system command window. Special functions are provided for working in the command line mode.

For neuro-fuzzy modeling in the ANFIS environment, based on the results of GIS modeling of the state of telecommunication systems on electromagnetic safety, a training sample is formed (Table 1 ):

Table 1. Educational data for building a hybrid network ANFIS

Elevation height	Antenna height	GIS-based results
10	15	0.1
15	30	1.1
30	50	4.5
40	60	4.5
45	70	4.5
60	80	4.5
70	90	4.5
80	100	0.4

The graphical interface of the ANFIS editor is called by the anfisedit function from the command line (Fig. 1).

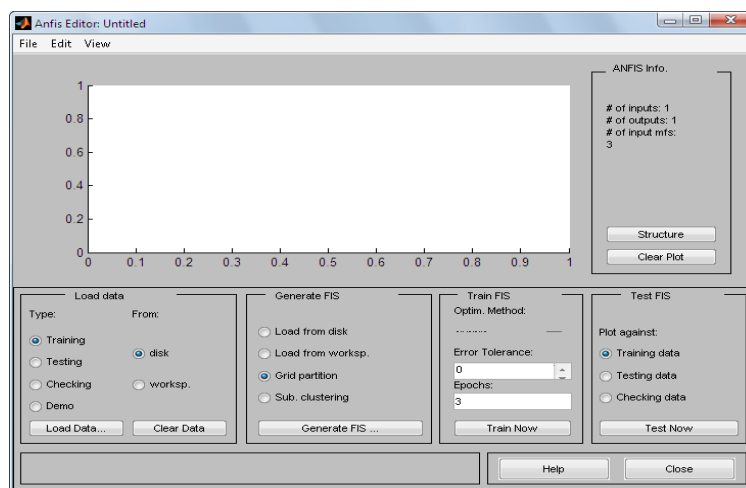


Fig.1. ANFIS Graphic Editor Interface, called anfisedit

The main menu of the ANFIS editor is quite simple and designed to work with a previously created system of fuzzy output. The main part of the graphical interface is occupied by the data visualization window, which is located below the main menu. For a newly created hybrid network, this window does not contain any data.

Downloadable source data can be one of the following types [3]:

- training data (Training) - mandatory data that is used to build a hybrid network;

- testing data - optional data that is used to test the constructed hybrid network in order to check the quality of operation of the constructed hybrid network;
- checking data (Checking) - optional data that is used to check the constructed hybrid network in order to ascertain the fact of network retraining;
- demo data (Demo) - allows you to download one of the demo examples of the hybrid network.

When creating a new FIS structure, you can independently split all input variables into their ranges (Gridpartition) or use the subtractive clustering procedure to pre-partition the values of the input variables into clusters of similar values (Sub. Clustering).

For this example, the fuzzy inference system contains one input variable with 3 terms, 11 fuzzy product rules, one output variable with 3 terms. The components of the FIS system are represented by nodes of the corresponding color. Before learning the hybrid network, you need to set the learning parameters, for which you should use the following group of options in the lower right part of the working window:

1. Choose a hybrid network learning method — back propagation (backprop) or hybrid (hybrid), which is a combination of the least squares method and the reverse gradient decreasing method.
2. Set the level of learning error (ErrorTolerance) - the default value is 0 (not recommended to be changed).
3. Set the number of learning cycles (Epochs) - the default value is 3 (it is recommended to increase and, for the considered example, set its value to 40).

To train the network, click the TrainNow button. In this case, the course of the learning process is illustrated in the visualization window in the form of a graph of the dependence of the error on the number of training cycles (Fig. 2).

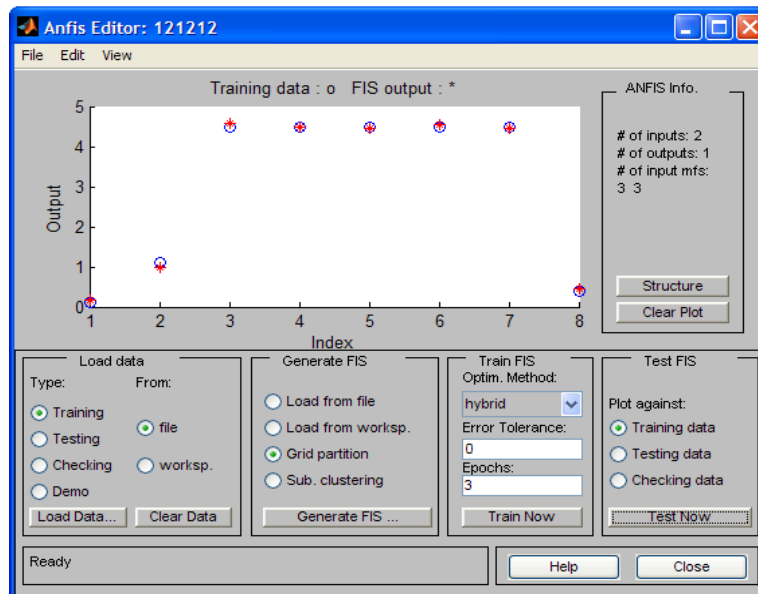


Fig.2 Training of neuro-fuzzy model

In this case, the upper graph shows the dependence of the verification error on the number of learning cycles, and the lower graph shows the dependence of the learning error on the number of learning cycles (the “\*” sign). Further configuration of the parameters of the constructed and trained hybrid network can be performed using the standard graphics tools of the Fuzzy Logic Toolbox package discussed earlier. For this purpose, it is recommended to save the created system of fuzzy output in an external file with the fis extension, after which you should load this file into the FIS Fuzzy Output Systems Editor.

To study the constructed model of the hybrid network, you can use the rule viewer (RuleViewer). To obtain the output variable of interest, you must specify a specific value for the input variable, similar to the general recommendations of fuzzy output systems. At the same time on the graph of the functions of the output variable will be indicated the desired value of the output variable (Fig. 3). Computational experiments can also be conducted on the basis of graphical models of fuzzy inference (Fig. 4).

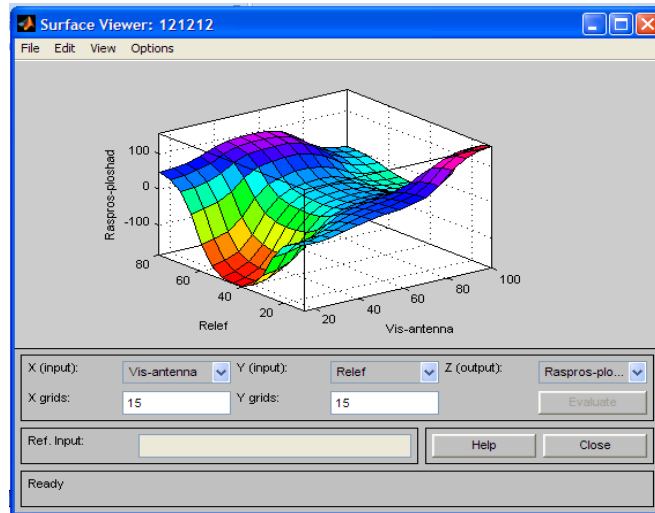


Fig.3. Graphic model of a fuzzy inference in the form of a graphic surface

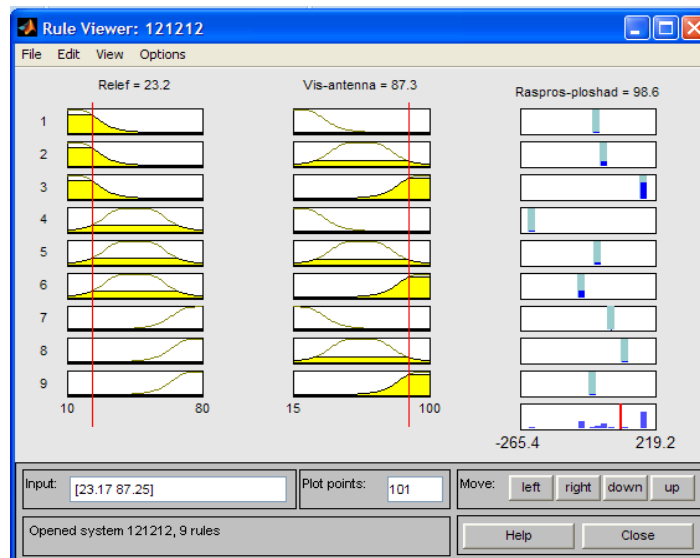


Fig.4. Graphical interface for viewing the rules of the generated fuzzy inference system

The results of computational experiments based on the neuro-fuzzy approach are presented in Table 2.

Table 2.

Results of computational experiments based on neuro-fuzzy approach

Elevation height	Antenna height	Expected results
10	20	<b>1,45</b>
15	33	<b>6.5</b>
30	50	<b>4.58</b>
40	60	<b>4.47</b>
55	56	<b>15</b>
45	70	<b>4.5</b>
60	78	<b>8,67</b>
70	87	<b>9</b>
80	90	<b>9.37</b>



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## III. CONCLUSION AND FUTURE WORK

In the case of insufficient information on the training data, the use of hybrid networks may be generally impractical because it is not possible to obtain an adequate fuzzy model, and therefore, an accurate prediction of the values of the output variable.

For these reasons, a preliminary analysis of all the capabilities of the fuzzy models used is needed to solve specific problems in a particular problem area. Such an analysis should be performed from a system point of view and taking into account all the current circumstances. Only a comprehensive and complete assessment of the problem situation will allow the development of an adequate model for solving a particular fuzzy control or decision making task.

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