Software Tools for the Implementation of Solutions to Management Problems based on Fuzzy Logic

Rana Hajiyeva [1] and Ughur Hajizada[2]

[1] Department of Information Technologies, School of Advanced Technologies and Innovation Engineering, Western Caspian University, 17 A, Ahmad Rajabli Street, III Parallel, AZ1072 Baku, Azerbaijan

[2] Department of Computer Science, Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS), University of Twente, Enschede, The Netherlands

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Abstract: As artificial intelligence primarily processes incoming data, its scope is limited. Therefore, the interaction of artificial intelligence and humans is used to expand the scope of application. Such a partnership allows for solving complex problems and obtaining accurate results. Such problems are currently solved thanks to the experience and intuition of prominent specialists. However, in technical fields, there is a risk of making a serious mistake if the initial conditions and assumptions are not carefully studied. For example, unexpected failures in security systems, unreasonable results in information systems, unbalanced automation systems, and so on all arise because project conditions differ significantly from real conditions. For technical purposes, fuzzy logic is considered in a broad sense. Fuzzy set theory allows solving complex technical problems, such as technical diagnostic problems. Thus, fuzzy relationships allow the establishment of approximate relationships between causes and effects based on expert assessments. Expert assessments of the current technical condition of electrical equipment, carried out on the basis of fuzzy causal relationships of symptoms and defects, can increase the reliability of determining the causes of defects.

Keywords: Artificial intelligence, diagnostic systems, deterministic knowledge, fuzzy set, adaptive fuzzy model

1. Introduction

The generalization of expert assessments allows for increasing the reliability of the diagnosis of the technical condition of the facilities of the power grid complex. Modern diagnostic systems, which are necessary to analyze the symptoms of faults in the electrical network, must be based on current or expert information about the location and causes of faults, while monitoring the current technical condition and the deviation limits of certain technical characteristics. Recently, various new effective approaches have been developed based on artificial intelligence methods, namely expert systems, fuzzy logic, image recognition through artificial neural networks, and fuzzy relationships [1].

2. Application of Diagnostic Systems

The field of application of diagnostic systems includes monitoring the operation of electrical devices of the power grid complex, monitoring trends and monitoring instruments in complex automated production, and controlling the quality of electrical energy. The choice of the most appropriate strategy for diagnostic examination is determined by knowledge of the specific characteristics of the process to be monitored. The most effective solution for assessing the current technical situation can be considered artificial intelligence methods. If deterministic knowledge is not sufficient or mathematical modeling requires a high cost or does not have sufficient accuracy, it is advisable to use methods based on modeling the operator's knowledge. This can be done using logical inference strategies such as expert systems, fuzzy logic output systems, or artificial neural networks. This allows determining the technical condition of the facility based on fuzzy, inaccurate, and incomplete knowledge. Currently, systems for diagnosing and monitoring the technical condition of high-voltage electrical equipment are expert automated systems in "advisory" mode. There are two directions for solving the following problems: determining the technical condition of electrical equipment in order to detect defects and malfunctions; selecting optimal control effects on electrical equipment of the power grid complex in order to increase the reliability of the facility's operation and extend its service life.

Thus, information about the normal and abnormal operation of the process can be used to detect malfunctions. As a result of the application of fuzzy logic methods, knowledge about the process, which exists in the form of observations and verbal descriptions, can be used in the classification of processes. For this purpose, linguistic variables are used, expressed as weighting coefficients for values between "true" and "false". This is achieved by introducing the concept of a “membership function”. Membership functions should accurately describe the state of the system being diagnosed.
Thus, it is shown that fuzzy set theory and fuzzy logic represent a promising scientific direction in technical diagnostics, allowing experts to create a formalized fuzzy mathematical model of cause-and-effect relationships by formulating their knowledge in the form of verbal assessments and linguistic variables [2], [3].

3. Fuzzy Logic Packages

Currently, the global market for commercial software products for working with fuzzy logic is actively developing. It provides over 100 software packages that use fuzzy logic to one degree or another. Several software companies are leaders in this field. Their tools are aimed at applying fuzzy logic to as many areas and applications as possible. These include the CubiCalc package from Hyper Logic, FuzzyTECH (Inform Software), FIDE (Ap-tronix), extension packages for MATLAB: Fuzzy Logic Toolbox (included with MATLAB) and FlexTool for MATLAB from Cynap Sys, as well as the JFS package (developed by Jan Mortensen), and others. Most of the software packages listed have a full-featured user interface and advanced data import/export tools.

Fuzzy logic packages can be divided into the following groups according to their capabilities.

1. A program that generates code for microcontrollers that run on fuzzy algorithms. Typically, the code is generated in basic assembly language.
2. Packages that allow you to create expert systems based on fuzzy logic. In other words, fuzzy rules and membership functions are defined by subject matter experts. All packages allow the researcher to choose the type of membership functions (triangular, trapezoidal, Gaussian, etc.), the fuzzy output mechanism (Mamdani, Sugeno, Tsukamoto, Larsen), and the compilation and clarification method. Working with the package is facilitated by graphical representations of fuzzy models, response surfaces, and mnemonics of other dependencies.
3. Packages that allow you to build dependency approximators and classification systems based on adaptive fuzzy inference models.

The first group includes FuzzyTECH and FIDE tools. Software packages from the last two groups are of primary interest when modeling complex systems.

Most of the software listed above allows you to create fuzzy expert systems. The price of some programs can reach several thousand dollars in standard delivery. And only a few of them allow you to adaptively configure the structure and parameters of the fuzzy model.

Thus, during the analysis, no programs focused solely on working with adaptive fuzzy systems were identified. Among the packages reviewed, FuzzyTECH and the Fuzzy Logic Toolbox for MATLAB Extension have the most versatility [4]. Let us focus only on the features of the adaptive configuration capabilities of the fuzzy knowledge base in these packages [5], [6].

FuzzyTECH implements some methods for structural adaptation of a fuzzy model or methods for generating fuzzy “If-Then” rules. One of them is that first, a complete base of fuzzy rules is formed, and each of them is initially given a random importance coefficient. Then, one of four learning methods is selected (RealMethod, RandomMethod, Batch_Learn, Batch_Random), during which time the importance coefficients are refined. If the significance coefficient is close to zero, it is suggested that the rule be deleted, but the final choice remains with the researcher.

It should be noted that assigning importance coefficients to rules contradicts the ideology of fuzzy systems, which assumes that all rules have equal weight. This approach is closer to hybrid neuro-fuzzy systems, where the weight coefficients of neurons play the role of the importance coefficients of fuzzy rules.

The second method available in FuzzyTECH uses a genetic algorithm to optimize the number of terms for each system variable using general forms of membership functions and a symmetric fuzzy partition [3]. The disadvantage of this method is the large size of the problem, which increases exponentially with the number of system variables. Furthermore, the problem of optimizing the number of terms is less significant than the problem of generating a set of rules from experimental data.

The Fuzzy Logic Toolbox for MATLAB has more advanced capabilities than FuzzyTECH for estimating nonlinear dependencies with adaptive fuzzy models [7]. A necessary advantage is that the MATLAB mathematical environment is popular in the CIS, and there is sufficient documentation and information sources on its use. The main functions and algorithms in the Fuzzy Logic Toolbox extension are implemented for the Sugeno inference engine (TSK). It is possible to work with both descriptive and approximate rules in the TSK form.

The development of a fuzzy model is carried out in two stages. In the first stage, the creation of rules and finding the boundaries of terms is carried out based on the subtractive clustering method. The second stage uses AN-FIS (Adaptive Network-based Fuzzy Inference System) technology [8], an iterative procedure for constructing membership functions using the backpropagation method. This package does not provide training for Mamdani models.

Using the additional Optimization Toolbox package, it is possible to implement adaptive adjustment of Mamdani membership functions, but the fuzzy rules must be defined independently. There is also no possibility to use evolutionary computations and genetic algorithms in the methods of tuning adaptive fuzzy models in the fuzzy logic toolbox. This feature is available in another MATLAB extension package, CynapSys's FlexTool package. This is the only widely recognized commercial package that offers full genetic tuning of all parts of a fuzzy model [9].

An adaptive fuzzy model has the ability to adapt to a specific fuzzification method, so the criterion for choosing one or another method should be its lowest computational complexity. To train a model on experimental data, you can choose from three types of genetic algorithms - standard GA, micro-GA, and steady state GA.

The last two are modifications of the standard GA and are described in detail in [4].

The disadvantages of the FlexTool package include:

1. The high price to which you need to add the price of the MATLAB environment, then the total cost of the package will be 2.5-4.5 thousand dollars, depending on the delivery option.
2. Lack of documentation in Russian for the FlexTool package.

3. The methods used in the FlexTool package for training a fuzzy model using a genetic algorithm are not described in the system reference book.

A review of well-known software packages for fuzzy modeling demonstrated that most of them are focused on building fuzzy expert systems; only one package uses genetic algorithms to create a fuzzy model, when the parameters of the member functions and rules are set by the expert [10], [11].

4. Conclusion

1. The features of the manifestation of information uncertainty in the course of natural and technological processes and the methodological means of studying the issues of managing these processes in such conditions are explained [12].

It has been determined that four levels of uncertainty are distinguished:

- low level that does not affect the main stages of the process of preparing and implementing a management decision.
- medium level, requiring reconsideration of some stages of development and implementation of the decision.
- high level, involving the development of new procedures.
- an ultra-high level that does not allow for the assessment and adequate interpretation of information related to the emerging situation.

  Ultra-high levels of uncertainty lead to ineffective decisions because poorly structured, difficult-to-understand, and unreliable information make it difficult to make effective decisions. Taking into account uncertainty levels allows for their use to be presented analytically [13], [14].

When a technologist or dispatcher encounters uncertainty in the decision-making process, they act in different ways:

- Often, one ignores the existence of conscious (or unconscious) uncertainty and uses deterministic models.
- Selects the type of uncertainty from the perspective of most importance and uses the appropriate theory. Currently developed decision-making methods only help to choose the best of many possible decisions under a certain level of uncertainty.
- It conducts more systems research or obtains information through supervision (adaptation and training) or management.

In management theory, several main types of uncertainties are distinguished: parametric uncertainty, non-parametric uncertainty, undecidable uncertainty, nonlinear uncertainty, uncertainty of external conditions, and uncertainty of the goal.

When solving some practical problems, it is necessary to eliminate the uncertainty in the initial data or to take into account the presence of uncertainty in this data. In such cases, the rigorous mathematical formulation of practical problems creates the need to use models that take into account the uncertain nature of the information, since in real situations, complete information about the conditions for solving the problem is rarely available. Solving such problems is currently considered one of the issues of significant theoretical and practical importance. The application of various research methods and computational tools allows obtaining solutions that take into account the uncertainty of the initial data and make judgments about the processes under study that have real characteristics [15].

To perform the fuzzy logic-based research process, the Fuzzy Logic Toolbox package is used in the MATLAB environment. In interactive mode, the user can solve various difficult problems by using the capabilities of the package to perform fuzzy logic-based research. This software environment also allows for the development of a neuro-fuzzy model and the generation of appropriate results.

2. Controlling gas transportation processes is considered one of the most pressing technological problems. A reliable solution to these problems is determined, first of all, by the precise identification of the factors

influencing these processes and the level of their consideration in the relevant behavioral models. In this regard, a methodology is proposed for estimating hydraulic pressure losses during gas movement in a gas pipeline, within the framework of uncertain knowledge of the values of the pipeline operating parameters (hydraulic friction coefficient and pipeline diameter), depending on the flow characteristics and the influence of influencing factors. The proposed methodology can be used to assess hydraulic pressure losses that may arise during gas transportation through main pipelines due to the influence of various factors, using uncertain information about changes in the gas flow regime, as well as the diameter of the pipeline, so that the assessment results obtained in this way can allow for the necessary efficiency in taking measures to regulate the technological regime of compressor stations.

3. Taking into account the uncertainty of information, a volumetric method of estimating gas field reserves has been introduced. With the presented method, it is possible to calculate the gas volume based on the fuzzy known values of the calculation parameters included in the formula: gasification, porosity, layer thickness, and gasification area.

Author Contributions

Nurlan Karimli conducted the literature search and drafted the manuscript. Assoc. Prof. Rana Hajiyeva. supervised the study, provided critical guidance on content and structure, and reviewed the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

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