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ASSURING RELIABILITY OF ALGORITHMIC PROCESSES BY SOFT-COMPUTING METHODS

The paper deals with the description of automatic system, developed by the author, for assuring reliability of algorithmic processes in uncertainty conditions. Soft-computing methods constitute theoretical basis of the system.

Key-words: *algorithmic process, reliability, modeling, optimization, soft computing, fuzzy numbers.*

Introduction

Due to the availability of the Internet, various kinds of scientific AEWP (automation equipped working places) and engineering CAD systems, duration of the "idea – research – industrial application" cycle has become three times shorter. The increased number of elements more complicated functioning algorithms and fast obsolescence of the systems has led to the situation when data accumulation for traditional reliability modeling will last considerably longer not only within the designing and testing stages, but also within the short life cycle of modern products. Such situations occur not only in the development of such dynamic products as software, but also in more inert fields, e. g. in semiconductor industry. The absence of the necessary information about elements reliability is explained by the following reasons:

- Availability of the unique components with new elements, design principles or operating conditions in the system being analyzed requires long, expensive experiments in order to determine their reliability, which nobody conducts in a full volume [2].
- With separate experimental data it is difficult to achieve statistical validity in finding characteristics of highly reliable components with failures probability of less than 10^{-7}, h^{-1}, that in airspace industry, for example, have been used since 1980s [3].
- For developing systems it is actually impossible to obtain experimental evaluation of reliability indicators because nobody will agree "to freeze' the system development for the sake of receiving statistical data [2].
- There is no valid information about the reliability of many new components. In the USSR such information was systemized by leading branch research institutes. Today, leading research institutes, that have survived, are unable to restore the interrupted information flows [4].
- Invalidity of statistical data about components reliability, caused by users' errors in defining the type of defect, time of its occurrence, operating conditions, etc. [3]. In the USSR errors in filling in the initial forms of failure account achieved 40% [4]. Much data from standard specifications were transferred to reference literature. Often those values were not calculated from the results of special investigations or observations in the course of operation, but were entered into standard specification with the purpose of not looking worse than foreign analogs [5];
- Even if data about reliability behavior are collected in real conditions. They lose their relevancy due to fast changes of software, equipment, personnel qualification, behavior stereotypes, operating conditions and purpose of the activities, etc.

In the theory of reliability of complex systems two essentially different approaches have been established [6]: (1) elemental S-approach with reliability models built on the basis of system structure and reliability behavior of its elements; (2) functional F-approach with reliability models built on the basis of structure of the functions, i. e. on the basis of the system functioning algorithms. S-approach corresponds to the classic theory of system reliability [7–9]. Its main indicators are probability of failure-free operation and availability factor. Probability and time characteristics of failures, i.e. random events of functionality loss, are used as initial data for modeling. F-approach comprises algorithms reliability theory [10 – 13], the theory of “man-machine” reliability [6, 14 – 18], the theory of reliability of labor and technological processes [19 – 21]. In F-approach probability is used as generalized indicator of reliability [6]. For applied problems the probability of achieving goal is used as a generalized indicator of probability [6]. For applied problems it is interpreted by such indicators as error-free operation, defect-free performance, validity, timeliness, etc.

As a rule, the most comprehensive description of system reliability can be achieved by combining S- and F-approaches. Methods of F-reliability description and assurance are well-developed both in theoretical and practical (engineering) aspects. Reliability according to F-approach is investigated to a considerably lesser degree. Therefore, it is logical to suppose that research work in terms of this approach will result in essential improvements of the reliability of complex systems.

The aim of this paper is representation of the automatic system, developed by the author, for assuring reliability of algorithmic processes (AP) – generalized research object in F-approach. Methodological conception of the system lies in the application of soft-computing idea to the solution of problems of reliability prediction and assurance in the initial data uncertainty conditions.

Algorithmic process as an object of reliability prediction and assurance

Functioning of different systems with discrete behavior is considered from a unified standpoint, presenting it in the form of AP, i.e. as occurring in time sequence of actions, operations or works, the completion of which provides achievement of the goal – obtaining information, product, documents, knowledge, etc. [13]. Typical representatives of AP include: computer networks functioning process, information processing and decision making processes, manufacturing processes, “man-machine” system operation process, engineering design, research work, educational process, activity algorithms, etc. The above-mentioned processes can be formalized by a certain algorithm with the following properties [22]:

- It consists of elementary operations forming a finite set.
- The system of algorithm operations is determinated.
- A discrete, pre-defined number of operations can be performed simultaneously.
- Transition from initial to the final state is performed within a finite number of operations.

Subsequently, we will consider AP that is represented in the form of a regular algorithm in algorithmic algebra system of V. Glushkov [23]. While designing AP, its analysis and synthesis according to reliability criteria are required. At the stage of reliability management, the ability of AP diagnostics and adaptation is necessary. In the process of AP analysis, synthesis, diagnostics and adaptation it is necessary to solve the problems of reliability modeling, optimization and identification (fig.1). *The modeling task* consists in the calculation of such AP indicators as error-free performance, timeliness, duration and cost on the basis of its structure and operations reliability characteristics. AP operations are divided into basic and auxiliary ones. It is impossible to achieve the goal without the completion of a certain basic operation. Auxiliary operations are introduced into AP in order to improve reliability. *The optimization task* consists in the synthesis of AP with the necessary or extremal values of reliability indicators.

Identification task lies in the following: proceeding from observation results, to create mathematical models that will connect the influence factors with reliability characteristics of operators and logic conditions. At the end of 1980s AP reliability research achieved its maximal efficiency. Disintegration of the USSR resulted in almost total interruption of research in this field and so no essential results have been received in reliability theory development in the course of the last 10 – 15 years.

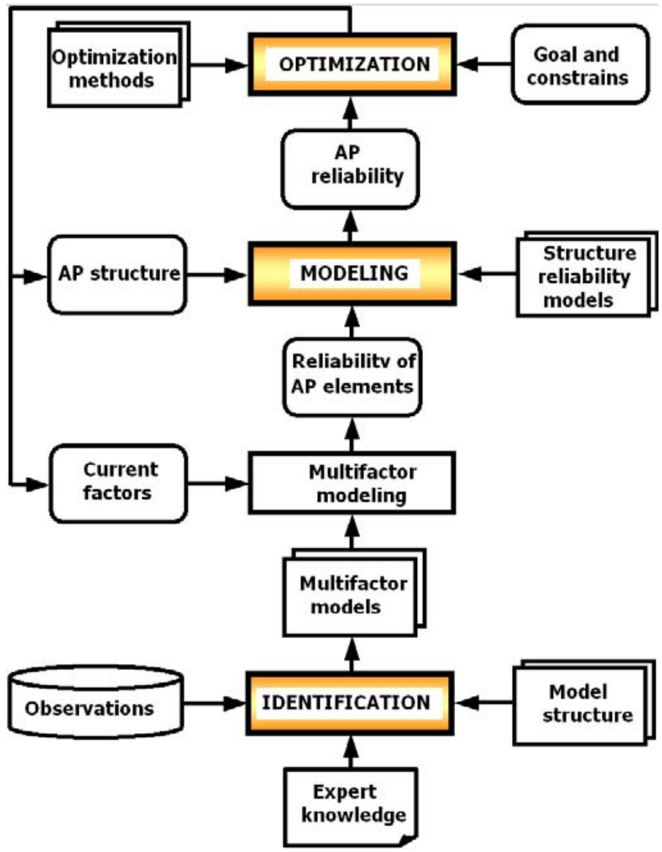

Fig. 1. Problems of AP reliability assurance

Application of soft-computing for assuring reliability in uncertainty conditions

During stagnation period in AP reliability theory information technologies were being developed – new efficient methods of data processing and knowledge representation appeared as well as methods for solving complicated problems of optimization and decision making in uncertainty conditions. One of the most prospective among them is the method of *soft-computing* – symbiosis of the approximation methods of knowledge representation and data processing for making rational decisions in the conditions of partial truth, inaccuracy, uncertainty and complexity of actual problems. The term of *"soft-computing"* was introduced by L. Zadeh at the beginning of 1990s [24]. Due to their softness, i.e. tolerance to partial truth, inaccuracy, uncertainty and complexity of actual problems, soft computing methods create convenient mechanisms for taking rational decisions without considerable research efforts [25]. Soft-computing technologies inherit the mechanisms of human intellectual activities and, therefore, they are transparent and understandable even to researchers without high mathematical qualification. From methodological point of view soft-computing is the combination of fuzzy logic, neural networks, genetic algorithms and other natural calculation methods, e.g. ant algorithms. These methods do not compete but complement one another. Such coalition of methods is a synergetic combination in the sense that combined application of the components is much more effective than their separate usage [25]. Such approach provides efficient solution of both known and new complicated scientific and applied problems in different fields.

Evidently, there is a growing contradiction between practical demands and assuring reliability of ever more complex systems, between the state of AP reliability theory development and capabilities of modern information technologies. Most methods of AP reliability modeling and optimization, created at the end of the XXth century, have lost their efficiency. Besides, nobody even tried to formalize some AP reliability problems at that time due to the absence of information technologies for their at least approximate solution. Therefore, there appeared a problem of AP reliability prediction and assurance in the conditions of the absence of valid numerical estimates of the element characteristics that are necessary for traditional modeling and optimization. This problem can be solved through the development of a new methodological approach to reliability theory on the basis of modern soft-computing information technologies. This approach will make it possible to solve both known and new problems of reliability evaluation and assurance. Research results, presented in publications [26 – 46], make the basis for soft-computing reliability assurance. Automatic system for AP reliability assurance, based on these results, is presented below.

Automatic system for AP reliability assurance

Automatic system for AP reliability assurance is implemented in MATLAB software. The system automates the most labor-consuming procedures of AP reliability identification, modeling and optimization. The system architecture is shown in fig.2. The following designations are used: "Kernel" – kernel of MATLAB software environment; "FLT" – Fuzzy Logic Toolbox; "StT" –Statistics Toolbox; "OptT" –Optimization Toolbox; "GAT" –Genetic Algorithms and Direct Search Toolbox; "EFLT" – Extended Fuzzy Logic Toolbox, created by the author.

Programs that automate calculations according to models and algorithms of fuzzy identification and decision-making are allocated to Extended Fuzzy Logic Toolbox package, because they are useful not only for assuring AP reliability in uncertainty conditions, but also in other fields of fuzzy-modeling. Components of Extended Fuzzy Logic Toolbox include 12 modules (table 1). Part of them is available on the site `http://matlab.exponenta.ru` through the authors' section "Fuzzy Logic Toolbox". Specific components of the automatic system are described in table 2.

In the automatic system data (`Value`) about error-free operation, durability, cost and other characteristics of AP elements reliability are represented by the structure with two fields (fig. 3a): `Crisp` – crisp numerical value and `Fuz` – fuzzy value. If AP reliability depends on the factors, than data structure will have 2 additional fields (fig. 3b): `Model` – the name of m-file, that realizes the model of multifactor reliability dependence and `Factors` – current values of factors. `Value.Factors` field is given by the structure from fig. 3a. `Value.Fuz` field is given by the structure from fig. 3b. Fuzzy value can be presented in the following way:

- by *l*-form of fuzzy number [13] in `Fuz.L_form` field;
- by α-form of fuzzy number [13] in `Fuz.A_form` field;
- by the set of elements and grades of membership in `Fuz.Mu_form` field;
- by parameter membership function in `Fuzzy.P_form` field.

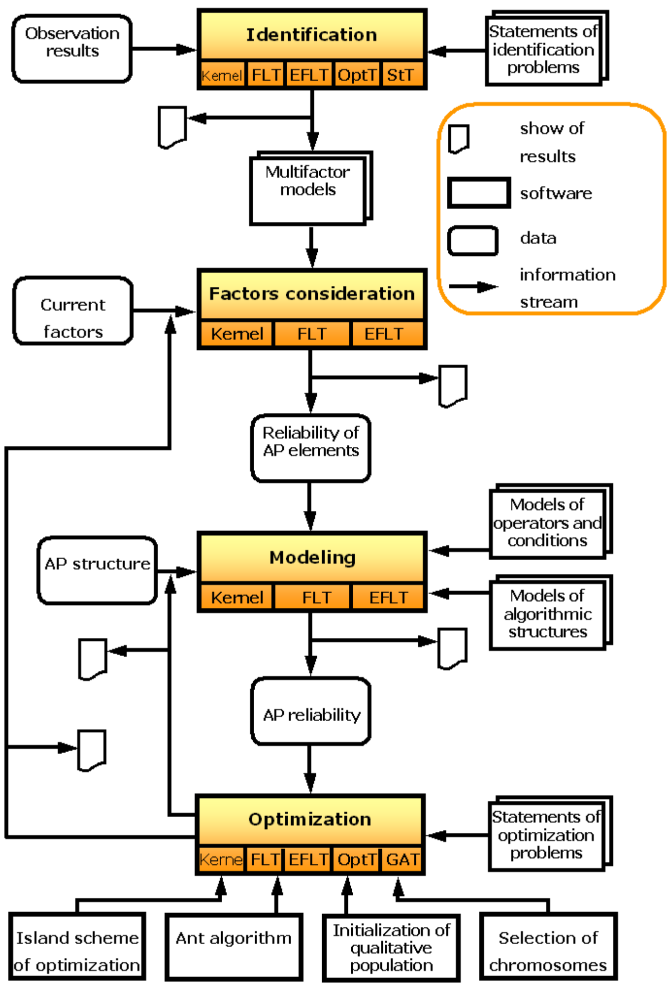

Fig. 2. Architecture of the automatic system for AP reliability assurance

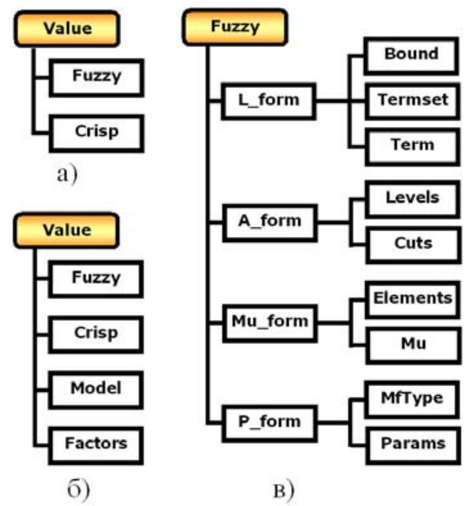

Fig.3. Data structures of the automatic system: a) general data structure; b) data structure for the description of multifactor dependence of AP elements reliability; c) fuzzy data structure

Table 1

Composition of Extended Fuzzy Logic Toolbox

Module name	Publications
Design of fuzzy classifiers	[28, 35, 43]
Design of hierarchical fuzzy models	[28, 35]
Training of Mamdani fuzzy model	[35, 38]
Protection of fuzzy model transparency in the process of training	[32, 38]
Fuzzy inference under fuzzy source data	[28, 29, 35]
Synthesis of fuzzy numbers on the results of fuzzy inference	[31, 37]
Inference using Sugeno knowledge base with fuzzy coefficients	[46]
Synthesis of membership functions through experimental data clustering	[31, 33]
Converter of fuzzy numbers	[35, 36, 41]
Regression fuzzy analysis	[30, 31]
Synthesis of fuzzy numbers of the II-type	[30]
Decision making in fuzzy conditions using Bellman – Zadeh approach	[34, 35, 36]

Table 2

Composition of specific modules of the developed automatic system

Module name	Module description	Publications
Statement of identification problems	Library containing the statements of the problems of operators reliability identification and AP logic conditions	[28–32, 35, 37–39, 43]
Multifactor modules	Library containing multifactor models of crisp and fuzzy reliability of the operators and AP logic conditions	[30, 31–35, 37–39, 43, 45]
Models of the operators and logic conditions	Library containing models of crisp and fuzzy reliability of the operators and AP logic conditions	[13, 36, 40–42]
Models of algorithmic structures	Library containing models of crisp and fuzzy reliability of algorithmic structures	[13, 36, 40–42]
Statement of optimization problems	Statement of the problems of crisp and fuzzy AP reliability optimization	[26, 36, 44]
Island optimization scheme	Realization of the interaction of genetic and ant algorithms according to the island scheme	[27, 36]
Ant algorithm	Realization of the ant algorithm of AP structural optimization	[36]
Initialization of the qualitative population	Initialization of the initial qualitative population of chromosomes for AP reliability optimization	[36, 44]
Selection of chromosomes	Chromosome selection for crisp and fuzzy optimization of AP reliability	[36, 44]

The remaining fields of `Fuz` structure have the following purposes:

`Fuz.L_form.Bound` – boundaries of the fuzzy number carrier;

`Fuz.L_form.Termset` – term-set of the linguistic variable;

`Fuz.L_form.Term` – current value of the linguistic variable;

`Fuz.A_form.Levels` – array of α-levels of a fuzzy number;

`Fuz.A_form.Cuts` – array of α-cuts of a fuzzy number;

`Fuz.Mu_form.Levels` – array of the universum elements;

`Fuz.Mu_form.Mu` – array of grades of the universum elements membership to a fuzzy number

`Fuz.P_form.MfType` – type of the parameter membership function;

`Fuz.P_form.Params` – vector of the membership function parameters.

In the automatic system AP structure is given by the list of reduction substitutions. Each row of this list has the following form:

<Type Out_name Element1 Element2 Element3 Element4>,

where Out_name is algorithmic structure identifier;

Element1, ..., Element4 – identifiers of the operators and logic conditions;

Type – type of the algorithmic structure.

E. g., AP $\{Z\,[A_1^{N_1} \underset{\omega_1}{,} A_2\ (\ E \vee R_1) \underset{\omega_2}{]}\,\}$ that is enlarged according to the following scheme

+,

will be given by the following list of m-functions:

```
A3=Multi_structure(A1, N1);
A4=AWR_structure(A2, ω1, R1);
A5=aParallel_structure(A3, A4);
A6=Cycle_structure(Z, A5, ω2).
```

Conclusions

The revealed problem of AP reliability assurance is connected with the absence of valid numerical estimates of operators characteristics and logic conditions. The expediency of this problem solution by the development of a new methodological approach to AP reliability theory is substantiated. This approach is based on the principles of soft-computing and is implemented in the form of the automatic system for AP reliability assurance in uncertainty conditions.

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