Fuzzy control under uncertainty in machine building

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Abstract. This report addresses the aspects of decision-making problems during asset management in cases when there is an uncertainty of the situation that can be caused by complexity of an asset or insufficient information about it. In last decades, the fuzzy logic proposed by Lotfi Zadeh has been successfully used in such cases. This report also considers positive and negative aspects of this form of logic and proposes using fuzzy converse logic (antonyms-related), which is free from weaknesses of fuzzy-related concepts proposed by Zadeh. We outline the basic axioms of converse logic and its application for decision-making problems during asset management under uncertainty.

Development of methods and tools to control various objects and systems involving laws and principles of cybernetics results in that the scope of use is significantly extended. Today it is not a surprise that automation is being used for not only engineering process control (like metal cutting, welding, assembling, etc.), and civil planes, military aircrafts, and spacecraft, but for more complex objects and systems as well. Moreover, in the last decades we might notice that business entities had expressed interest to increase the integrity of decision-making process and search for the best solutions. This allows various companies to provide a competitive edge in the market. In this respect, you should analyze and search for control actions using the so-called social engineering systems where there are close relations between technical part required to achieve specific production goals and that social organization where those goals are accomplished [1].

The above-mentioned conditions have driven management professionals to search for new approaches and tools, on one hand, in order to ensure control of highly complex objects when it is really difficult to use precise quantitative methods for simulation of an object and control systems due to, let us say, lack of information that can be used to establish connectivity between arguments and functions without serious simplification of a simulation model [2]. On the other hand, a commitment to give form to control process of social engineering systems when they include a considerable amount of objects or elements when you experience lack of information or its inaccuracy when there is no clear understanding of cause and effect relations within the object in question. The most difficult thing is to control the so-called unique systems when you are not able to obtain information for “precise” mathematical representation.
Both the above-described cases relate to the class of tasks that must be solved under uncertainty [3]. In order to evaluate uncertainty we often use mathematical statistics apparatus that forms the basis of the theory of probability [4]. When using probabilistic simulation, factorization of the controlled object state is performed by probabilities of its being in one or another state at a certain point. In this case you should take into account that not the object itself has such a strong correlation of its state and time but the amount of its specific state in particular. Behavior of a required parameter is being studied and change over time is described using particular assumptions of familiar mathematical relationships (exponential, normal form, Weibull distribution, etc.).

However, methods of probabilistic simulation are good to solve tasks when you need to determine a set (class) of objects and to get mean estimates. Probabilistic characteristics are not that good for researchers to evaluate a specific controlled object. Time relationship gives this method some advantages for forecasting but the same relationship does not allow evaluating the state of an object at any given time [5]. In addition, you will be able to use this logic properly only if you have results statistics of similar controlled objects.

Conventionality of the theory of probability is now understood since it has been formed long before the tasks containing uncertainties have been recognized.

In the 1960s, the science recognized the fact that it needed to create methods of analysis, simulation, and control, which would not be based on classic two-valued logic but on continuous (fuzzy) logic. McNaughton [6] and Valery Rvachev [7] proposed that kind of approach.

Professor Igor Ryabinin in his works proposed a probabilistic logic approach to analyze systems and cognitive objects under uncertainty [8, 9], where methods of the theory of probability were combined with Boolean algebra logic. It was the author’s opinion that it would allow solving several tasks, primarily the evaluation tasks, for instance, when evaluating unique object reliability index. Obviously, the reason for the occurrence of this kind of approach is in that the same expression can be considered both as a statement (i.e. as Boolean algebra object) and as an event message (i.e. as object from the theory of probability). Some kind of inconsistency forming the basis for this approach requires to be explained and practically confirmed but is difficult to be ensured under conditions of unique objects control.

American professor Lotfi Zadeh proposed to use fuzzy logic for the purposes of control under uncertainty, which was eventually named after him [10, 11]. Zadeh laid down the principle of partial membership positing that x could be full element of set X, partial element or not an element of set X completely.

Zadeh developed the concepts of continuous logic and formalized them as a fuzzy logic that differs from Aristotelian logic, where x is either element of set X or is not an element. Aristotelian logic is described by a high level of rigor that attracted many mathematicians for years. However, it has one significant weakness – using this logic you cannot describe associative human thinking since it uses only two notions (“true” and “false”) and eliminates any intermediate concepts. At the same time, we use the entire range of notions in our everyday life. Apparently that the last case provides a fuller picture of the real state of things and better complies with associative thinking of a person who finds solutions thanks to it, without using any strong calculation and models but being only highly experienced and having an intuition. Meanwhile this person can control highly complex systems and objects successfully. In order to define control signals, Zadeh proposed to make up decision rules that use membership functions and classic logical operations. Simplicity of control action formalization, abandonment of functions, and procedures of mathematical and physical analysis are the advantages of fuzzy logic proposed by Zadeh, which lead to its extensive use for the control tasks of complex systems and objects, mostly in Japan [12]. The author of fuzzy logic himself stated that one of the reason for his interest in fuzzy logic was the thing that senior managers realized that in many cases you just did not need high accuracy and so the use of fuzzy logic was quite reasonable.
Giving credit to significance of classic two-valued logic, fuzzy logic and probabilistic logic analysis, we would like to focus on the fact that presence of logical operations in calculation models does not allow searching the best values of control functions.

The alternative to the above approaches is a logic of antonyms (converse logic), which is developed by Ya. Ya. Golota in the Saint Petersk Polytechnic University [13, 14]. Distinctive features of the logic of antonyms are having Boolean properties and possibility to specify numbers in the range \((0, +\infty)\). Such logic has all the advantages of fuzzy logic proposed by Zadeh but is able to solve the tasks that cannot be solved using fuzzy logic.

Logic of antonyms is reasonable to be used in the following cases:

1. Having the need to consider a large amount of parameters that stipulates great difficulties when using traditional methods;
2. Absence or lack of statistical materials for specific use of probabilistic methods;
3. Quantitative relationships between parameters cannot be either identified or difficult to formulate, but qualitative relationships are expressed quite well. Logic of antonyms, considering logical connectives between values in question, in this case allows obtaining quantitative estimates;
4. Need to consider the estimates of all elements of the system in question.

The antonyms logic considers simple and complex objects. The complex ones are based mostly on using three connectives (operators): \(\alpha, \beta, \gamma\). Objects of \(A\) and not \(A\) type (negation \(A\)) form antonymous pairs. Operators \(\beta\) and \(\gamma\) bind elements differently: the operator \(\gamma\) binds more tightly, than the operator \(\beta\). Tight binding means that an aggregate estimate vanishes simultaneously with vanishing one of the elements; loose binding means that vanishing one of the elements leads to the entire aggregate estimate is reduced but far from being vanished.

A certain non-negative number can be assigned to any object in question. Consistent use of logic rules allows identifying a number, which is assigned to complex objects by means of calculating the value of a certain multivariable function. In the converse logic, evaluation of an opposite event depends on evaluation of a direct event through a logarithm but is not a complement of a constant.

While analyzing a complex object \(C\), evaluation of a truth estimate of its state is performed depending on evaluation of its parts \(A\) and \(B\):

\[
H[C] = - \log_2 \left\{ 1 - (1 - 2^{-H[A]})(1 - 2^{-H[B]}) \right\},
\]

if there is a tight coupling \(\gamma\) between objects \(A\) and \(B\), and

\[
H[C] = H[A] + H[B],
\]

if there is a loose coupling \(\beta\) between objects \(A\) and \(B\).

Thus, consistently partitioning a complex object into constituents and establishing a binding between them, it is well enough to calculate the value of the complex object estimate as a function of evaluation of its constituents (for instance, signals from feedback sensors, information received from experts, etc.). It should be noted that the above expressions lack classic logical operations that provide an opportunity to solve tasks on searching the best solutions by using the Bellman’s principle of dynamic programming [15, 16], and using multivalued estimates (not two-valued) makes the analysis apparatus more adequate to the real world that allows obtaining more accurate estimates (Fig. 1).

The figure illustrates the potential scope of use of the analysis and control methods mentioned in the article, depending on completeness and depth of knowledge about the object in question.

Many examples of the converse logic used in real tasks (engineering system test processes control, social engineering system control – innovation projects, unique object reliability evaluation, etc.) showed the simplicity of practical use and more accurate findings as compared to other control methods [17-20].
**Figure 1.** Scope of potential use of mathematical simulation tools.

**References**

[1] Afonichkin A.I., Mikhalenko D.G. Upravlencheskie resheniia v ekonomicheskikh sistemakh upravlenia SPb Piter 2013 – 480p.

[2] Boiko I.A., Gurianov R.A. Matematicheskie modeli tekhnicheskikh sistem v usloviiakh neopredelennosti Molodoi uchenyi 2013 N6 p. 30-33.

[3] Upravlenie v usloviakh neopredelennosti. Pod red. A.E. Gorodetskogo SPb Izd. SPbGTU 2002, 398p.

[4] Pugachev V.S. Vvedenie v teoriu veroiatnostei – M. Nauka 1968 – 368p.

[5] Tisenko V.N. Agregirovannya modeli v sistemakh ispytanii slozhykh tekhnicheskikh obieekov -SPb Politekhnika 1998 -146p.

[6] Mak-Noton R. Teorema o beskonechnoznachnoi logike vyskazyvani Kiberneticheskii sb Vyp. 3 M. Izd. inostr lit. 1961 p.59-78

[7] Rvachev V.L. Geometricheskie prilozheniia algebry logiki Kiev Tekhnika 1967-96 p.

[8] Riabinin I.A. Nadezhnost i bezotkaznost strukturno-sloznykh sistem SPb Izd. S Peterb un-ta 2007 - 276 p.

[9] Riabinin I.A. Logiko-veroiatnostnoe ischislenie kak apparat issledovaniia nadezhnosti i bezopasnosti strukturno-sloznykh sistem Avtomatika i telemekhanika 7-2003 – pp.178-186

[10] Zadeh L.A. Furry Sets Information and Control N8 1965. - pp. 338 353

[11] Zade L A Poniatie lingvisticheskoi peremennoi i ego primenenii k priniatiu priblizhennykh reshenii M Mir 1976. – 165 p.

[12] Prikladnye nechetkie sistemy Perevod s iapon K.Asai, D.Vatada, S.Ivai i dr. pod red T.Terano, K.Asai, M.Sugeno – M. Mir -1993.

[13] Golota Ya.Ya Ob adekvatnosti logiki mirovozzrencheskim printsipam Sovremennaiia logiki problemy teorii istorii i primenenii v nauke. Tezisy dokladov nauchnoi konferentsii SPb SPbGU 1996 - p6-10

[14] Golota Ya.Ya., Tisenko V.N., Falkov D.S. Recognition of the Technical State of Objects in the Course of Complex Tests Applied Problems in Pattern Recognition and Image Analysis Systems Vol 8 No 3 1998 - p 403-405

[15] Bellman R. Dinamicheskoe programmirovanie M Izd. Inostrannaia literatura 1960 – 400p.

[16] K Hedli Dzh Nelineinoe i dinamicheskoe programmirovanie M Mir 1967 508 p.
[17] Nikolaeva V.M., Tisenko V.N., Cherniak V.S. Prognozirovanie perspektivnosti osvoeniia innovatsionnoi tekhnomii v proizvodstvе s ispolzovaniem TRIZ Innovatsii 2016 - pp.104-111.

[18] Golota Ya.Ya. O novom podkhode osnovannom na logike kontrarnykh otnoshenii k otsenke nadezhnosti Mezhdunarodnaiia konferentsiiia po miagkim vychislениiam i izmereniiiiam Sb. dokladov T.1. SPb: SPbGETU “LETI”. 2007. – pp.49-57.

[19] Drachev O.I. Tisenko V.N. Ob otsenke nadezhnosti edinichnykh obieektov V sb Sovremennye tendentsii v razvitiu nauki i tehnologii Trudy 4-oi nauchno-prakticheskoi konferentsii Belgorod 2015 – pp.151-154.

[20] Abliazov V.I. Tisenko V.N. Instrumentalnoe obespechenie interaktivnykh sistem V sb Sovremennoe obrazovanie professionalnaiia kompetentnosti prepodavatelei vuza garantiia obespecheniiia kachestva obrazovaniia Tomskii gosudarstvenniy universitet sistem upravleniia i radioelektroniki TUSUR. 2017. - pp.212-214.