Object Information Models of Complicated Systems in Control Problems

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Abstract

Methodology for mathematical and information modeling of complicated systems is developed. A complicated system is considered as a system with a complex nature of interaction between elements. The difference between complicated systems and "large" systems is shown. Complicated systems are studied as control objects. Methodology for mathematical modeling of complicated systems is based on combining of fuzzy logic and classical mathematics. Such combining makes it possible to exclude the participation of experts in the process of the development of the decision support systems. This allows you to avoid the difficulties associated with expert evaluations in organizing decision-making under uncertainty. Methodology for information modeling of complicated systems is based on the method of object-oriented analysis (Shlaer-Mellor method). Particular attention is paid to recommendations for the selection of the object attributes for objects that model complicated systems in the information models. Every value of every object attribute (except identifiers of the object) varies from zero to one as the value of a fuzzy variable. There is an example of developing an information model based on the proposed methodology. This is information model of the potentially detonative object. Information structure diagram for the complex potentially detonative object is composed for general case. Information structure diagrams for different kinds of the potentially detonative object are built in general terms. The proposed methodology is adequate for modern technological processes. It is used successfully for enlargement and improvement of DSS for explosion-proof of the grain processing enterprises of different types. Original software for real time control of risky situations is created.

Keywords

Object-oriented analysis, complicated system, mathematical modeling, fuzzy logic, information model, object attributes, decision-making

1. Introduction

Object-oriented analysis (OOA) [1,2] assumes that software system is initially split up into domains. Every domain corresponds to a certain subject area. Each domain is independent of the each other. Domain charts are used to depict domains and their relationships. Some domains are rather "large" and complicated. These domains have to be broken down into subsystems for analyzing.

Every "all-in-one" domain or subsystem of the complicated domain must be analyzed in three steps [2]:

1. Information modeling
2. State modeling
3. Process modeling

These steps are separate but integrated parts for OOA.

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Information modeling is aimed at identification of objects, which make up a system for (object-oriented) analysis.

Every object (class) corresponds to a set of the real world things. All instances of the object (elements of the set):

- have the same characteristics (that can be abstracted as attributes [1,2]);
- subject to the same set of rules and laws.

There are identifiers among attributes, i.e. attributes which values identify each individual instance of an object uniquely.

There are different ways for representation of an object. It can be presented either graphically or in tabular form [1,2]. For the information model of a subsystem or domain, three products must be developed [2]:

- Information structure diagram (entity-relationship diagram);
- Descriptions of objects and attributes;
- Descriptions of relationships.

It is rather simple to choose attributes for objects that correspond to such real world things which may be described as “simple systems”. But it is not so easy to choose attributes for objects that describe so-called “complicated systems”. It should be borne in mind that (from the practical point of view) values of the object attributes should be calculated relatively easily, and the attributes themselves should describe the state of the object quite accurately.

The aim of this research is to develop recommendations for the selection of attributes for objects that model complicated systems in information models.

2. Mathematical and information modeling of complicated systems

Considering the problem of mathematical and information modeling of complicated systems, one should initially define what a complicated system is.

The system is considered as an ordered set of structurally interconnected and functionally interacting elements.

At first glance, it is natural to consider a system consisting of large number of elements as a complicated system (according to the principle: the greater the number of elements, the more complicated the system is). But this point of view is obviously not correct. Indeed, a system can consist of a large number of similar (identical) elements interacting with each other on the basis of well-known and simple principles (laws). Such systems are usually pretty easily described by statistical laws. For example, an ideal gas [3], considered as a physical system, can in no way be considered a complicated system.

An ideal gas is a theoretical gas composed of many randomly moving point particles that are not subject to interparticle interactions [3]. So the ideal gas consists of large number of similar elements. The thermodynamic properties of an ideal gas can be described by the equation of state that is known as Clapeyron equation or the ideal gas law [4]. From this equation it is evident that the state of an ideal gas is completely determined by the values of only two thermodynamic parameters (e.g., pressure and temperature). It should be noted that the ideal gas law can be considered as a consequence of the Boltzmann equation (the basic equation of the molecular kinetic theory of gases), obtained statistically.

Thus, not every "large" system, i.e. a system consisting of a large number of elements, is a complicated system. Although, naturally, a complicated system can be a " large" system.

A complicated system should be considered as a system with a complex nature of interaction between elements and, as a rule, with dissimilar elements.

A complex nature of interaction between elements suggests two different possibilities:

- Mathematical equations describing this interaction can not be solved either analytically or numerically (at least, the solution of these equations by known numerical methods cannot be carried out in an acceptable time);
- The interaction between elements of the system cannot be described at all by the equations of classical mathematics due to the difficulties of formalization.

Systems are studied primarily as control objects. Every system interacts with the external environment (other systems or objects) and are characterized by input and output parameters.

Effective control of systems (control objects) in most cases requires the construction of an adequate mathematical and information models of these systems. This is especially true for control process based on the principle of the compensation of perturbations.

From the standpoint of the control theory, it does not matter what the complexity of the interaction of the system elements consists in (which, in fact, allows to consider the system itself as a complicated system).

For mathematical modeling of a control object, which is a complicated system, it is necessary to apply the theory of probability or fuzzy logic. This study considers the second possibility.

2.1. Mathematical modeling of complicated systems using fuzzy logic

Let us consider complicated system as control object, which is determined by n parameters $p_1, p_2, \ldots, p_n$. These parameters are controlled parameters of this object. A specific set of these parameters defines the object state at the moment.

To construct a mathematical model of the control object means to write down the parameters $p_1, p_2, \ldots, p_n$ that fully determine the state of the object as functions of the other parameters $m_1, m_2, \ldots, m_k$ that determine (from the point of view of the control problem) the state of the control object environment. Parameters $m_1, m_2, \ldots, m_k$ assumed to be known as functions of time *t*.

Thus there are *n* functions from *k* variables

$$pi = pi(m1, m2, \ldots, mk)\ (i = 1, \ldots, n), \qquad (1)$$

where $m_1, m_2, \ldots, m_k$ are functions of time *t*.

So *n* functions p_i $(i=1,\ldots,n)$ are composite functions from time *t*:

$$p_i(m_1(t), m_2(t), \ldots, m_k(t)) = p_i(t) (i=1,\ldots,n). \qquad (2)$$

The main problem of this approach is that for complicated systems it is almost impossible to define functions (1) and, as a consequence, to define functions (2). It's almost impossible even if the functions $m_j(t)$ $(j=1,\ldots,k)$ are accurately defined. This impossibility is usually connected with a very complicated nature of physical (mechanical, chemical) models of the control object itself (if it is a technical or technological object) and the processes in which this object participates. These processes reflect, among other things, the interaction of the object with the environment.

It should also be noted that the parameters $p_1, p_2, \ldots, p_n$ may not be independent.

As a matter of fact, in some cases it is not possible to ascertain the presence or absence of the corresponding relations between these parameters. In addition, in a number of cases it makes sense to consider the obviously interdependent parameters of an object in order to organize effective control of this object.

Thus there are *q* $(q<n)$ functions from *n* variables

$$r_i = r_i(p_1, p_2, \ldots, p_n)\ (i=1,\ldots,q), \qquad (3)$$

but this fact is not essential.

The proposed methodology of developing of mathematical model for a complicated system includes the following items.

- Finding of simplified mathematical relations between p_i $(i=1,\ldots,n)$ and m_j $(j=1,\ldots,k)$, i.e. construction of functions $p_i = f_i(m_1, m_2, \ldots, m_k)$ $(i=1,\ldots,n)$. As a result, the values of the parameters p_i are found only approximately. Solving of this problem is the most difficult part of the proposed method realization. It requires deep knowledge of the technical/technological process, mathematics and special sciences (mechanics, physics and/or chemistry).
- Finding of intervals $[p_i^{\min}, p_i^{\max}]$ for possible changes of p_i $(i=1,\ldots,n)$. $p_i^{\min}$ is minimum value of p_i for the technical/technological process as a whole. Accordingly, $p_i^{\max}$ is maximum value of p_i for the technological process as a whole. As a rule, $p_i^{\min}$ and $p_i^{\max}$ are determined by production regulations and technical propeties and capabilities of equipment.
- Replacement of every value p_i by the corresponding interval $[p_i^*, p_i^{**}]$ $(i=1,\ldots,n)$, where the inequalities $p_i^* < p_i^{**}$, $p_i^* < p_i^{\max}$ and $p_i^{\min} < p_i^{**}$ take place, but the inequality $p_i^{\min} < p_i^* < p_i^{**} < p_i^{\max}$ is not always correct. Usually the length of the interval $[p_i^*, p_i^{**}]$ is much less than the length of the interval $[p_i^{\min}, p_i^{\max}]$, i.e. $p_i^{**} - p_i^* << p_i^{\max} - p_i^{\min}$ $(i=1,\ldots,n)$. The nature of intervals $[p_i^*, p_i^{**}]$ is defined by methods for determination of p_i $(i=1,\ldots,n)$. Value p_i can be determined by measurements (if possible) or by calculations for functions $f_i(m_1, m_2, \ldots, m_k)$ $(i=1,\ldots,n)$. In the first case the interval $[p_i^*, p_i^{**}]$ displays the measurement error, in the second case this interval displays either calculations errors or model biases (or, may be, a combination of these two kinds of errors).
- Shift away from "clear"("accurate") values $p_1, p_2, \ldots, p_n$ towards fuzzy values $P_1, P_2, \ldots, P_n$ (fuzzification). This fuzzification is based on the intervals $[p_i^{\min}, p_i^{\max}]$ and the corresponding intervals $[p_i^*, p_i^{**}]$ $(i=1,\ldots,n)$. Exactly from the point of view of fuzzification the cases when $p_i^* \leq p_i^{\min}$ or $p_i^{\max} \leq p_i^{**}$ are very important. The last step of this fuzzification may be shift away from fuzzy values to linguistic variables (it may be done for the convenience of the decisionmaker, but sometimes it is not necessary to do it). The essential principle of the described above

fuzzification lies in fuzzifying all input values into fuzzy membership functions by using formulae obtained by methods of classical mathematics (or by using experimental data). Mathematical equations for mechanical, physical or chemical processes are considered only as approximate estimates. These equations have approximate solutions $p_i = f_i(m_1, m_2, \dots, m_k)$ $(i=1,\dots,n)$ and form basis for inequalities. Those inequalities, in their turn, form the base for constructions of corresponding fuzzy membership functions [5,6]. The supposition of the approximate character of mathematical equations for complicated processes (mechanical, physical, chemical, etc.) is fully justified because of the errors of appropriate theories and inaccuracy of the input data (obtained, as a rule, from different experiments which are almost always not accurate). This way of the definition for fuzzy membership functions makes it possible to avoid bringing experts (evaluators) in and (as a result) to avoid all problems and weaknesses connected with evaluators and their interaction and cooperation with decision-makers.

Such methodology for mathematical modeling of complicated systems is based on combining of fuzzy logic with classical mathematics.

This methodology is very useful for solving some problems of the explosion-proof [5] (especially for the grain processing enterprises and chemical plants) [6].

2.2. Information modeling of complicated systems

The first stage for the development of an information model of every system is its structuring. The architecture of complicated system consists of some components (subsystems) and of the hierarchical relationships between these components. Every subsystem is also complicated system. As a matter of fact, hierarchy is the first feature of a system, since only systems with a hierarchical structure can be in principle investigated.

Every component (subsystem) is assotiated with an object in terms of OOA. This object must have attributes [2].

The selection of the attributes (except identifiers) for such object is reduced to a simple procedure of mnemonic naming of fuzzy variables P_1, P_2, …, P_n. The methodology for determining these variables is described above. So value of every attribute of the object (again except identifiers) varies from 0 to 1 as the value of a fuzzy variable.

The paper [7] provides an example of building an information model based on the methodology described above for potentially detonative object (PDO). Arbitrary potentially detonative object is considered from the point of view of the system analysis as the complex hierarchical (complicated) system. This system is structurized, elementary potentially detonative objects are indicated. All kinds of these objects are described with their attributes and relationships. Information structure diagram [2] for complex PDO is composed for general case. Information structure diagrams for different kinds of PDO are also built in general terms.

3. Conclusions

Proposed methodology for mathematical and information modeling of complicated systems is very useful for developing of decision support systems (DSS) for automated control system (ACS) when the control object is complicated system.

Thus the developing of DSS is based on combining of two decision-making models: the model of choice under uncertainty (based on fuzzy logic) and the classical model (based on classical mathematics including classical numerical methods). Such combining makes it possible to exclude the participation of evaluators (experts) in the process of the DSS development. This is rather important since the difficulties associated with expert evaluations in organizing decision-making under uncertainty are well known [8,9].

This methodology is fully adequate for modern technological processes and technical systems. It is used successfully for enlargement and improvement of DSS for explosion-proof of the grain processing enterprises of different types.

Decision support systems for explosion-proof of the grain processing enterprises of different types (elevators, flour milling plants, compound feed plants) are enlarged and improved by consistent using of described above items. Original software for real time control of risky situations is created.

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