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## COGNITIVE APPROACH TO THE FORMATION OF A ROBOTIC SYSTEM IN EDUCATION

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### Abstract

The article deals with the features of modeling systems for managing educational processes using robot assistants based on a cognitive approach. The main objective of the study is the use of hybrid human-machine intelligence in the education system. The authors propose a new version of the use of fuzzy cognitive maps and the capabilities of the corresponding software systems to solve a number of practical problems using examples of automated learning. Within the framework of the cognitive approach, which allows to take into account the various linguistic features of people, it is possible to use appropriate fuzzy cognitive maps that allow you to determine cause-and-effect networks that reflect the subjective view of researchers about the system in the form of a set of semantic categories called factors or concepts.

The study shows that taking into account the NON-factors that take place in the educational process, as well as the possibilities of their application for the formation of individual learning trajectories in the context of the use of human-machine intelligence, it is possible to obtain fundamentally new opportunities for training personnel.

The authors propose a fuzzy cognitive model of strategic management with the participation of a robotic system, identify the main concepts for its construction and analysis. The parameters of the cognitive map are identified using the principles of intelligent generation of the best alternatives based on the modified method of pair comparisons. The study is aimed at employees of educational institutions responsible for the digitalization of education and teachers.

**Keywords:** education management, weakly structured system, ergotechnical system, cognitive approach, fuzzy cognitive map.

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## КОГНИТИВНЫЙ ПОДХОД К ФОРМИРОВАНИЮ РОБОТОТЕХНИЧЕСКОЙ СИСТЕМЫ В ОБРАЗОВАНИИ

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### Аннотация

В статье рассматриваются особенности моделирования систем управления образовательными процессами с применением роботов-ассистентов на основе когнитивного подхода. Основной задачей исследования являются вопросы использования гибридного человеко-машинного интеллекта в системе образования. Авторами предложен новый вариант применения нечетких когнитивных карт и возможностей соответствующих программных систем для решения ряда практических задач на примерах автоматизированного обучения. В рамках когнитивного подхода, который позволяет учитывать различные языковые особенности людей, возможно использование соответствующих нечетких когнитивных карт, которые позволяют определять причинно-следственные сети, отражающие субъективное представление исследователей о системе в виде множества семантических категорий, называемых факторами или концептами.

В исследовании показано, что при учете НЕ-факторов, имеющих место в образовательном процессе, а также возможностей их применения для формирования индивидуальных траекторий обучения в условиях применения человеко-машинного интеллекта можно получать принципиально новые возможности для подготовки кадров.

Авторами предложена нечеткая когнитивная модель стратегического управления с участием робототехнической системы, выявлены основные концепты для ее построения и анализа. Выполнена идентификация параметров когнитивной карты с применением принципов интеллектуальной генерации лучших альтернатив, основанной на модифицированном методе парных

сравнений. Исследование ориентировано на сотрудников учебных заведений, отвечающих за цифровизацию образования, и на преподавателей.

**Ключевые слова:** управление образованием, слабоструктурированная система, эрготехническая система, когнитивный подход, нечеткая когнитивная карта.

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## 1. Introduction

In recent years, in the context of global digitalization, the decision-making process increasingly involves the use of hybrid human-machine intelligence, characterized by a close relationship between a human and a robot. A special role in this process is played by the system of training future personnel, where higher education issues play a special role. At the same time, the cognitive approach has already been used in various areas of research, when new branches of sciences were formed, such as cognitive: psychology, sociology, linguistics, modeling, anthropology, economics, communicative and cognitive pragmatics, etc., allows you to build fundamentally new modeling methods. This approach is due to the fact that “cognitive modeling in a short time at a qualitative level allows:

- to carry out an express analysis of the interaction of the acting factors determining the possible scenarios of the situation;
- to identify trends in the development of situations and the intentions of the subjects involved in them and to identify possible mechanisms of interaction” [1] of these subjects, in the interests of the state;
- to develop a strategy for using trends in the development of socio-economic and political situations in the country and the world in the national interests of Russia;
- to develop and justify the necessary and sufficient control actions on the situation;
- to evaluate “options for the development of the situation taking into account the consequences of these impacts and compare them” [2].

When managing organizational systems, it is often necessary to deal with poorly structured management tasks and unclear situations that arise during decision-making. This is usually due to a lack of information about the state of the system itself in the conditions of “turbulence” [1] of the external environment. “The lack of sufficient knowledge about the system concerning which management decisions are made is not the only uncertainty caused by subjective reasons, where there is a whole set of NON-factors” [3], where it is necessary to highlight “uncertainty, inconsistency, ambiguous (complex structure of the relationship between the goals of the development of socio-economic systems, described by several models) and as a consequence, the complexity of the formation of criteria for evaluating management decisions” [4].

Identification of NON-factors, their formalization and adequate accounting are among the main tasks that have to be solved when creating models and methods and

algorithms for decision-making in complex, hierarchical education systems. In this case, as practice has shown [5–8], a cognitive approach focused on the fuzzy structuring of knowledge about the system and the processes occurring in it turns out to be very productive.

Within the framework of the cognitive approach, which allows taking into account the peculiarities of linguistics of various linguistic characteristics of people, it is possible to use appropriate fuzzy cognitive maps that “define causal networks reflecting the subjective perception of researchers about the system in the form of a set of semantic categories called factors or concepts” [9]. Cognitive maps in this case are built and configured by experts in the relevant fields. “But even a long and careful adjustment of the cognitive map leaves it a rather crude and subjective model” [2] of reality. Nevertheless, the cognitive model is a fairly effective tool for rapid assessment analysis of a specific situation.

## 2. Theoretical preparation of the research

The mathematical apparatus used to represent cognitive models is based on fuzzy logic. The method of comparison of fuzzy information objects developed by the authors, “fuzzy benchmarking” [4, 9] and the method of fuzzy multiparametric selection, as well as the corresponding algorithms for their implementation [10] allowed to justify the use of these procedures in decision-making in organizational systems and implement them in the practice of university management. In this case, a class of cognitive models based on the so-called fuzzy cognitive maps (further — FCM) can be used, the general principles of which are based on 15 indicators [5–8, 11, 12]. The origins of cognitive modeling were recorded in the works of B. Kosko [13], V. B. Silov [14] and A. A. Kulinich [2]. Development of a group of researchers under the leadership of A. G. Suspensovsky — Software Package IGLA (Intelligent Generator of the Best Alternatives) [11] made it possible to significantly simplify and visualize the main types of analysis of cognitive models.

We are talking about static (structural-target) and dynamic (scenario) analyses. At the same time, the following main tasks are solved:

1. Identification of factors that have “the greatest impact on the target factors and the system as a whole, as well as factors that are most influenced by the system and other factors, which makes it possible to find factors that are most sensitive to control and external influences” [11], as well as to determine the points of the most effective application of control impacts. This allows us to quickly obtain a diagram of causal factors, called the “Ishikawa diagram” [15].

2. Identification of “stable subsets of factors that collectively have a significant impact on the system as a whole, which makes it possible to find and investigate complex control actions that simultaneously affect many factors” [2]. Such a set characterizes the source of emergence for complex systems such as System of Systems [16].

The technique of supporting the control of a robotic system based on cognitive modeling of the FCM can be implemented through the following series of steps [17]:

1. Development of methods and algorithms for identifying the structure and parameters of a cognitive map based on the joint use of heterogeneous data about the system under study [18, 19].
2. Structural and target analysis of the FCM system indicators and alpha-slice analysis [19, 20].
3. Forecasting the state of the system under various influences and searching for control solutions to bring the system to the target state (methods and algorithms of scenario analysis) [21].
4. Visualization of interactive control by the visual image of the FCM [22].

### 3. Practical application of the cognitive approach to modeling and management of the ergatic learning support system

As part of the research conducted by the authors — developers of the system IGLA [6–10], the issues of using a robotic system with hybrid intelligence as a subject have not yet been considered, which was the object of our research described below.

Let  $G(F, W)$  — FCM, where  $F = \{f_i\}$  — set of factors:  $i = \overline{1, n}$ , but  $W = [w_{ij}]$  — the adjacency matrix,  $w_{ij} \in [-1, 1]$ ;

$\Phi = \{\varphi_i\}$  — factor scales:  $i = \overline{1, n}$ , set as a display  $\varphi_i: z_{ik} \rightarrow x_{ik}$ , where  $z_{ik}$  —  $k^{\text{th}}$  linguistic significance of the factor  $f_i$ ,  $z_{ik} \in Z$ ,  $Z$  — an ordered set of linguistic meanings,  $x_{ik} \in [0, 1]$ .

$X(0) = (x_1(0), \dots, x_n(0))$ ,  $x_i(0)$ ,  $\forall I$  — vector of initial values of factors.

Then a weakly structured situation will need to be called a tuple  $\langle G(F, W), \Phi, X(0) \rangle$ .

To do this, it is necessary to find a lot of managers ( $F_{in} \subseteq F$ ) and a set of target ( $F_{out} \subseteq F$ ) factors. At the same time, their composition and significance may change in the process of searching for a management strategy [11, 12]. Thus, many control factors can be determined by expert means, determined by experts, who must identify “the availability of control resources  $R$ , given by the vector of constraints” [11].

$$R = (r_1, \dots, r_m),$$

where  $r_i \in [0, 1]$  — the maximum possible value of the  $i^{\text{th}}$  resource factor.

In turn, resource constraints make it possible to find the maximum possible increments of factor values and form a vector of acceptable increments:

$$P_{in}^{\max} = (p_1, \dots, p_m), p_i = r_i - x_i(0),$$

where  $p_i \in [-1, 1]$ ,  $i = 1, \dots, m$ ,  $x_i(0)$  — the initial value of the factor.

Multiple target factors  $F_{out} \subseteq F$  form a common goal, the components of which  $f_i \in F_{out}$  determined by their target values  $g_i$ .

As a rule, a “fixed management goal” is considered in the form of a vector of target factors  $F_{out}$  and their values  $G = (g_1, \dots, g_q)$ ,  $g_i \in [0, 1]$ , or an “unfixed goal” — the same vector  $F_{out}$  and the desired signs of increments of its components [22]:

$$P_{out}^x = (p_1, \dots, p_q), p_i \in \{-1, 0, 1\}.$$

At the same time, a negative value of the target component means that the value of the  $f_i \in F_{out}$  factor should decrease, “0” — not to change, but the positive — to increase, with an increase in the factor—the causes.

Thus, an unfixed goal qualitatively determines the desired trends in the state of the situation, the direction of its development [13].

The task of developing a situation management strategy, within the framework of cognitive analysis, is to choose such a strategy (alternative)  $U_j \in U^s$ , the use of which in predicting the development of the situation translates it from the initial to the target state  $G = P_{out}^x$ . In detail, such approaches, in relation to organizational and socio-economic systems, were considered in the works [2, 6–9].

When developing a situation management strategy for a given management goal  $G$ , the system user solves two related tasks [2]:

- 1) determination of the set and the necessary significance of the  $F_{in}$  control factors;
- 2) determination of optimal values of increments of control factors  $U = (u_1, \dots, u_q)$  from the set  $F_{in}$ .

The solution of the first problem is based on the choice of possible combinations of input factors and their values to achieve the management goal, based on personal preferences and intuitive ideas of the expert [2] or on the basis of a structural analysis of the cognitive map [11].

The solution of the second problem is based on the solution of the inverse problem, which makes it possible to find a single or finite set of strategies for achieving it according to a formulated fixed goal [15–17]. The specific approaches and methods analyzed in this article, as well as the content of decision support in developing a situation management strategy, are described in detail in [14, 18, 19].

### 4. Modeling of management strategies of a training session using hybrid human-machine intelligence

The study was conducted by the authors together with specialists from different universities\*, who acted as research customers and experts in the relevant

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subject area. The aim of the research was “forecasting the development of a robotic educational complex under various initial trends and control influences, as well as the search for effective management solutions to improve their effectiveness” [16].

The determination of the list of key factors affecting the quality of students’ training in the classroom using RTS was carried out with the involvement of a group of experts attracted from the Faculty of Psychology of the Southern Federal University, as a result of which 14 most significant factors were selected, taken as the basis for the formation of many factors of the cognitive model, which were divided into three blocks:

1. *Ergatic block*
  - 1) The student level of knowledge
  - 2) Student motivation
  - 3) Psychological attitude
  - 4) Self-preparation before class
  - 5) The topic of the lesson (correctness)
  - 6) Bad habits
  - 7) Diseases
  - 8) The field of education and scientific research of the teacher
  - 9) Teacher qualification
2. *Technical (robotic) unit*
  - 10) The scope of the didactic functions of the robot
  - 11) Language compatibility
  - 12) Knowledge Base (further — KB) of robot
  - 13) RTS Intelligence
3. *External factors*
  - 14) The threat of a terrorist attack

The results of assessing the significance (degree) of the influence between the above factors are shown in the following Table.

When constructing the cognitive map, we applied the “methodology for identifying the structure and parameters of a fuzzy cognitive model based on the joint use of expert and statistical information” [18].

In the course of the study, a cognitive map was constructed (see Figure). For clarity of the image, the thickness of the arcs is proportional to the intensity of the influences between the factors, while the red color of the vector corresponds to a positive influence, and the blue corresponds to a negative one.

As a result of the structural and target analysis of the constructed cognitive map, it was revealed that the most significant positive influence, for example, on the motivation of a student is exerted by such factors as “The student level of knowledge”.

“The psychological attitude of the student”, readiness for the lesson — preliminary “Self-preparation”. Important factors are the “Qualification of the teacher” and his scientific interest in the subject of classes. A special place in the scheme is occupied by factors related to the robotic component: “Robot intelligence level”; “Robot knowledge base”; “Didactic capabilities of the robot assistant”.

Therefore, it is advisable to provide the main control effects, namely, these factors, choosing them as managers.

In turn, the factors of “Terrorist threats”, “Language compatibility”, “Bad habits” have the

Table

The adjacency matrix of a fuzzy cognitive map

№	Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Level of knowledge	0	0.3	0	0	0.46	0.8	0	0	0	0	0	0	0	0
2	Motivation	0	0	0.5	0.53	0	0	0	0	0	0	0	0	0	0
3	Psychological attitude	0.4	0.5	0	0	0	0	0	0	0	0	0	0	0	0
4	Self-preparation	0.4	0.59	0.52	0	0	0	0	0	0	0	0	0	0	0
5	Lesson topic	0	0.46	0.38	0	0	0.42	0	0	0	0	0	0	0	0
6	Bad habits	-0.1	-0.7	-0.7	-0.7	0	0	0	0	0	0	0	0	0	-0.8
7	Diseases	0	-0.6	-0.6	-0.8	0	0	0	0	0	0	0	0	0	0
8	Field of education	0	0.48	0.52	0.63	0	0	0	0	0	0.54	0.3	0	0	0
9	Teacher qualification	0.6	0.7	0	0	0	0	0	0	0	0	0	0	0	0
10	Scope of functions	0	0.57	0.64	0	0.3	0	0.38	0	0.2	0	0	0	0	0
11	Language compatibility	0	0	0	0	0	0	0.19	0.41	0	0.21	0	0	0	0
12	KB of robots	0	0.75	0	0	0	0.6	0.53	0.6	0	0	0.56	0	0	0
13	RTS Intelligence	0	0.59	0.7	0	0	0	0.71	0.44	0	0.58	0	0	0	0
14	Threat of a terrorist attack	0	-0.6	-0.7	-0.7	0	0	-0.6	0	0	0	0	0	0	0



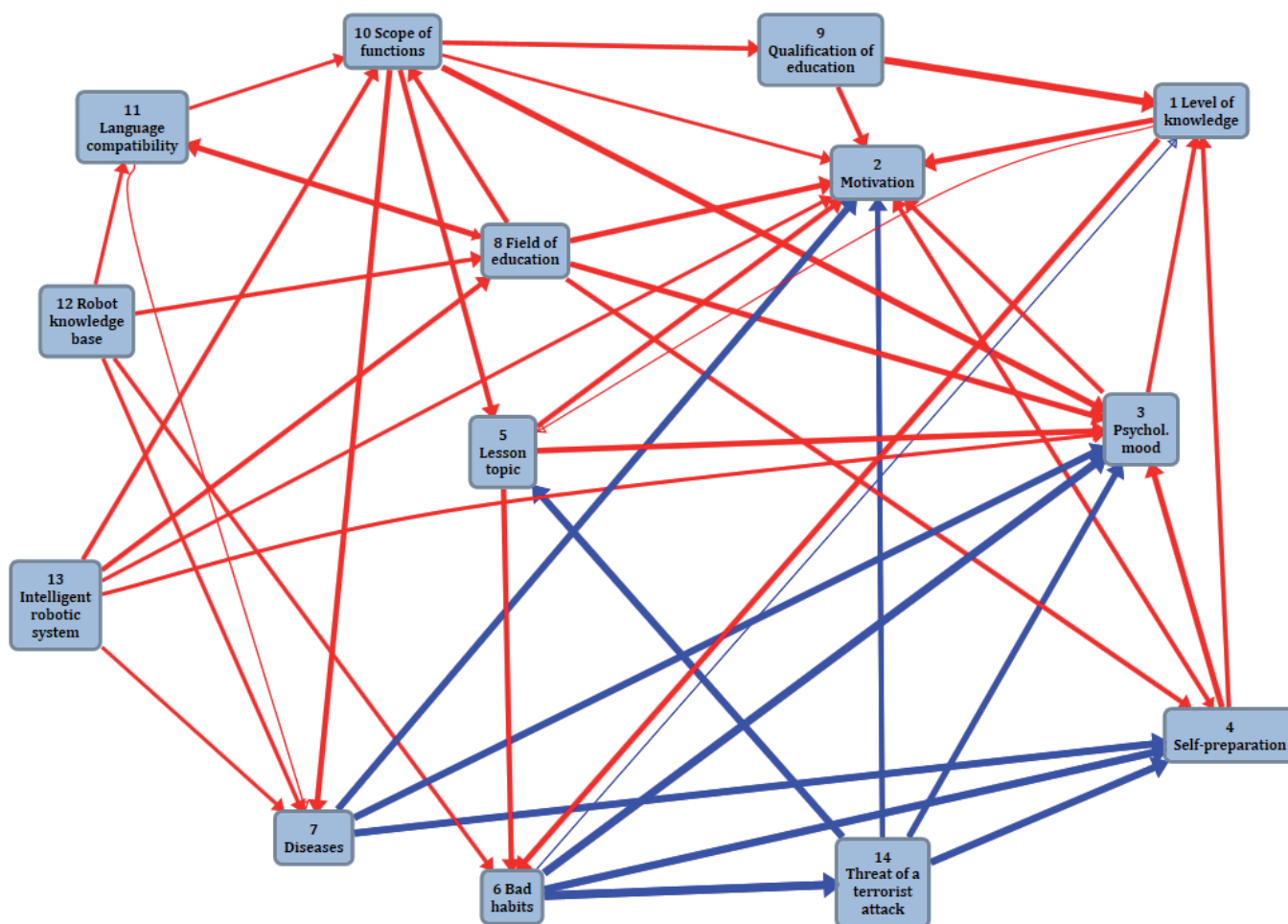


Figure. Fuzzy cognitive map of the organization of the lesson

greatest negative and negative impact on motivation and the level of knowledge, while it also affects the target factors related to health, which indicates the need for its control when modeling control actions. It was noted that the influence of factors on the system in most cases exceeded 0.5, which indicates a high level of confidence in the sign and the intensity of these influences.

## 5. Conclusion

The presented information technology to support cognitive modeling of poorly structured organizational and socio-economic, including educational systems, based on the use of fuzzy cognitive maps, allows you to build and analyze the solution of practical problems of controlling a robotic complex in the educational process.

The application of the proposed cognitive approach in modeling ergatic systems makes it possible to detect hidden relationships between factors that positively and negatively affect the dynamics of the functioning and development of such systems, to identify factors that do not have any noticeable effect, as well as to find the points of the most effective application of

control actions. This makes it possible to assess the consequences of various management decisions and possible risks of implementing various management strategies already at the early stages of express analysis of such systems.

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