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Original article

Development of a Human-Machine Interface Based on Hybrid Intelligence

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Abstract
The principles of harmonization of interactions between natural and artificial intelligence as part of ergo-technical systems are considered. An updated concept of the man-machine system has been developed within the framework of digitalization of management of socio-economic systems that have an arbitrary set of NON-factors that allow their implementation by soft models. Within the framework of modeling such an interface, studies of the synergy of artificial intelligence of an automated system of the technical component of the ergo-system and the natural intelligence of a human operator are of particular importance. It is shown that the requirement of universality, the ability to perform various management tasks, and its compatibility with a number of functional subsystems of the control object itself - the machine - are important for the interface. The article presents the general structure of the interaction of a dual human-machine intelligence and an object, the environment and an intelligent control system, and highlights soft models. This often allows us to correct the actions of the operator that can lead to undesirable consequences. The article considers bionic approaches to the concept of hybrid, human-machine intelligence. The article considers adaptive hybrid intelligent control schemes for a man-machine system, a variant of their classification and a method of construction. Accordingly, for the implementation of this approach, a method is proposed that includes a combination of algorithms and methods of traditional formal logical thinking and fuzzy logic.

Keywords: human-machine interface, soft mathematical model, hybrid intelligence, algorithm, ergatic system.

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Оригинальная статья

Разработка человеко-машинного интерфейса на основе гибридного интеллекта

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Аннотация
В статье рассмотрены принципы гармонизации взаимодействий между естественным и искусственным интеллектом в составе эрготехнических систем. Обновленная концепция человеко-машинной системы была разработана в рамках цифровизации управления социально-экономическими системами, имеющими произвольный набор НЕ-факторов, позволяющих их реализовать с помощью мягких моделей. В рамках моделирования такого интерфейса особое значение имеют исследования синергии искусственного интеллекта автоматизированной системы технической составляющей ergo-системы и естественного интеллекта человека-оператора. Показано, что для интерфейса важно требование универсальности, способности выполнять различные задачи управления и его совместимости с рядом функциональных подсистем самого объекта управления - машины. В статье представлена общая структура взаимодействия двойного человеко-машинного интеллекта и объекта, окружающей среды и интеллектуальной системы управления, а также выделены мягкие модели. Это часто позволяет скорректировать действия оператора, которые могут привести к нежелательным последствиям. В статье рассматриваются бионические подходы к концепции гибридного человеко-машинного интеллекта. В статье рассматриваются адаптивные гибридные интеллектуальные схемы управления человеко-машинной системой, вариант их классификации и способ построения. Соответственно, для реализации данного подхода предлагается метод, включающий комбинацию алгоритмов и методов традиционного формально-логического мышления и нечеткой логики.

Ключевые слова: человеко-машинный интерфейс, мягкая математическая модель, гибридный интеллект, алгоритм, эргатическая система.

Автор заявляет об отсутствии конфликта интересов.

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Introduction

The development of modern ergotechnical systems (further - ETS) is associated with the peculiarities of information processing, and therefore their most important component is the ergatic subsystem "human – information". Such systems include a technical system " consisting of an operator (a group of operators) and the information with which it interacts (they interact) in its activities during the information exchange process accompanied by the expansion of their application areas"[1]. At the same time, a significant part of its (or all the main) functions of a person delegates to artificial intelligence [1]. It is common to speak [2,3] about hybrid-intellectualized human-information interaction, which is understood as "Intellectualized (clearative-creative) interaction of a person with information, carried out using machine-activated (computer-activated) his mental activity"[2].

The main directions of creation and application of such systems in the past are:

- study and exploration of the Earth from space, monitoring of ground areas [4,5,6,7];
- pilotless aerial vehicles for various purposes [8,9,10];
- robotic systems (both ground-based and aerospace)[3] [11,12].

The characteristic features inherent of ETS are the presence of " a person as an integral part of the system as a whole, a software and technical component and artificial intelligence (further - AI) the main elements of which are the knowledge base and the intelligent interface. It is artificial intelligence that plays an important role in the functioning of ergo-technical systems"[13].

For modern ergo-systems, the effective functioning of the system as a whole is important, so it is the operator's qualifications that comes to the fore. ETS, as a rule, include the following components (subsystems): informational, management, modeling of the control object, decision-making, adaptation.

Informational subsystem is a set of sources (sensors) and corresponding processing algorithms that provide information about the current technical condition of the ETS elements, perform the function of monitoring its technical condition.

The decision-making subsystem (DMS) comes to the fore in the functioning of the ETS as a whole. "The control of the correctness of the operator's actions today is carried out according to the result of completing the task... Accordingly, in modern ETS, the result of the task performed by the operator is recorded, but it is practically impossible to influence the ergatic element to improve the operational characteristics of the system in real time in case of its incorrect actions to prevent the failure of the task"[13]. Under these conditions, the ergatic element becomes increasingly inefficient. In addition, in the context of rapidly developing technical capabilities of modern ETS, it is necessary to modernize, and in some cases create completely new, very expensive means of training and retraining operators.

Methods and models

A promising scientific solution to the problem of organizing the control of the operator's actions and the necessary information impact on it is to integrate into the existing structure of the ETS a special control mode and information impact on the ergatic element, which is implemented in the form of an additional intellectual subsystem. Moreover, when modeling such a human-machine interface, it is particularly important to study the synergy between the artificial intelligence of the automated system of the technical component of the ergo-system and the natural intelligence of the human operator.

The synergetic basis of artificial intelligence

Generalizing «existing views on complexity and complex systems, formulating and detailing the characteristic properties of complex systems within the synergetic paradigm» [19], note that the complexity is:

- a set of system elements connected in a non-trivial way by original connections with each other;
- dynamic network of elements connected according to certain rules;
- complexity is the internal diversity of a system, the diversity of its elements or subsystems, which makes it flexible, able to change its behavior depending on the changing situation;
- multi-level system (there is a complexity architecture);
- openness of a system that exchanges matter, energy, and information with the environment;
- ambiguity of the boundary of a complex system (the vision of its boundaries depends on the position of the observer);
- this is the possibility of emergence of emergent phenomena and / or properties;
- systems with memory, they are characterized by the phenomenon of hysteresis, when changing the mode of operation, the processes resume according to the «old channels»;
- they are regulated by feedback loops: negative, which ensures the restoration of balance, a return to the previous state, and positive, which is responsible for rapid, self-reinforcing growth, during which complexity blooms [19, c. 77–78];

It is obvious that the properties of complex systems described in [19-21] are also applicable to ergasystems with artificial intelligence, which is a function of the complexity of a self-organizing system.

Hybrid intelligence of ergatic systems and bionic effects

As shown in [22, 23], the artificial intelligence system of an "ergatic system is a system of organized complexity, in which the interaction of elements and functional areas is based on non-random relations set by the designer in certain contexts, which continuously change, following the logic of the evolution of the task called by the operator.

1 GOST R 43.4.1-2011. *Informacionnoe obespechenie tehniki i operatorskoj dejatel'nosti. Sistema "Chelovek - Informacija"* [Informational ensuring of equipment and operational activity. System "man - information"]. Standartinform, Moscow; 2013. (In Russ.)

2 GOST R 43.0.2-2006. Informational ensuring of equipment and operational activity. Terms and definitions. Standartinform, Moscow; 2007. (In Russ.)

3 Kramarov S.O., Mitjasova O.Yu., Khramov V.V., Temkin I.O., Groshev A.R. *Modul' formirovanija geosistemy* [Geosystem Formation Module]: Certificate of official registration of computer program system 2020615607, 2020. Available at: https://elibrary.ru/item.asp?id=43885288 (accessed 28.08.2020). (In Russ.)

The functional complexity of the ergatic system can be estimated by analogy with the cognitive complexity of a person in terms of the number and types of tasks to be solved. Its complexity (and intelligence) can be determined in relation to specific tasks to be solved, to the complexity of the software used in the control computer of the system, with the volume and degree of differentiation of the system's contacts with the environment and the operator"[13].

As a criterion of intelligence, a number of authors [23, 24] suggested using the length of the algorithm being executed and the number of cycles that allow it to be implemented. The author of this study proposes to clarify and modify this approach – to introduce a measure of the algorithm's information – the Kolmogorov complexity measure - into the quantitative assessment [20, 23].

Let «{\displaystyle P}***P*** - a program that implements an intelligent algorithm (above the parameters for ***y*** the state of the ETS) (in any programming language) the output of which is the line {\displaystyle x}***x***, that {\displaystyle P} ***P*** is description of {\displaystyle x} ***x***.

$$x=P(y) \quad (1)$$

The length of the description is the length {\displaystyle P} ***P*** as line. In the course of determining the length {\displaystyle P} ***P*** the lengths of the subroutines used in ***P*** {\displaystyle P}. Then the intellectual component is calculated in terms of the length of any integer constant {\displaystyle n}***n***, which appears in {\displaystyle P} ***P*** {\displaystyle P} is the number of bits required for the representation {\displaystyle n}***n***, equal (roughly speaking) {\displaystyle \log _{2}n}$\log_2 n$» [25].

It is believed that «lambda calculus can give the simplest estimate of complexity. If the description of x is represented by the string s, then its program description can have the form:

function GenerateFixedString()
return *s*

If the description ***s*** is {\displaystyle s}, ***d(s)*** {\displaystyle d(s)} of the minimum length that is, it uses the smallest number of characters, then it is called the minimum description {\displaystyle s}***s***, and length ***d(s)*** {\displaystyle d(s)} {\displaystyle d(s)}, that is, the number of characters in this description - *Kolmogorov complexity* {\displaystyle s}***s***, ***{\displaystyle K(s)}K(s)***» [26]. In other words, $K(s) = |d(s)|$.

The emergence of ergatic systems with artificial intelligence requires considering the interaction of the natural intelligence of the system operator with the artificial intelligence embodied in the technical part of the ergatic system. In the studies, some general definitions of intelligence and intellectual symbionts operating in the ergatic system and arising in the "process of combining artificial and natural intelligence and the environment of activity"[27] are given.

1. Intelligence is a form of active "self-organization of a complex system, involving the user immersed in the environment in creative changes. It is connected with the environment as a mechanism of its organization, which ensures the processes of self-organization of the system endowed with it.
2. Natural intelligence is organizing complexity in an organized environment, and artificial intelligence is organizing complexity in an organized environment.
3. Hybrid and diffuse intelligences are symbionts that include the organizing and organized complexity of systems in their synergistic and symbiotic interactions as a tool for achieving the goal of an actor in an organized and organized environment"[26]. Moreover, if hybrid intelligence involves the mutual adaptation of natural and artificial intelligence, although with a flexible boundary between them, then diffuse intelligence is a synergistic union and "almost mental fusion" [27].

The concept of "symbiotic diffuse intelligence, which is a system that includes natural and artificial intelligence in their synergistic interaction in a complex artificial environment. The higher the level of artificial intelligence distributed in the environment of the ergatic system, the more effective, all other things being equal, the human intelligence. The properties of symbiotic diffuse intelligence depend on the ability of the user's natural intelligence to master the interface and the intellectual component of the environment"[28].

The effective interaction of natural and artificial intelligence enhances the capabilities of human intelligence in an artificial environment, but at this stage, only within certain limits provided by technology.

Methodology for improving the quality of functioning of the ergotechnical system using soft models

As mentioned above, real ergasystems are affected by NON-factors. Moreover, a significant number of them is associated with the ergatic element [29]. In the conditions of hybrid, especially diffuse intelligence in the ETS, it is necessary to use methods and models of control of the ergosystem that are adequate to "fuzzy calls" [30].

As a basic variant of this approach, a mathematical model of the ergatic element (further - EE) is developed, which implements the statement that the process of solving a problem by a person consists in the use of artificial neural networks (further - INS) with self-learning to develop optimal control by modeling it based on known solutions to typical problems. "The activity of the EE in the control circuit of the functioning of the ETS is considered as the process of converting a certain initial state of the technical system into a state that ensures the performance of functional tasks with the required quality. With this approach, the task of ensuring the required quality of ETS functioning by a human operator can be represented by a tuple Z:

$$Z = \langle P, M_{акт}, M_{тр} \rangle, \quad (2)$$

where ***P*** **-** the algorithm of actions for transferring the ETS from the active state to the required one; $M_{акт}$ – the current (current), i.e. the soft model of the technical state of the system available at the time under consideration; $M_{тр}$ – a soft model of the required technical state of the system with attributes that characterize its normal (desirable) state" [30].

In the process of functioning of the system, a specialist (integrated – hybrid or diffuse intelligence) needs to compare the available (current) soft model of the state of the ETS, described by a fuzzy vector of its parameters, with the desired soft model. The procedure of fuzzy benchmarking is performed [31,32], on the basis of which a new, achievable soft model (ETS states) is formed (or selected, if available), which provides an effective level of quality of ETS management by the ergatic element. Examples of the implementation of the proposed approach to managing the dynamics of ETS, in relation to monitoring objects of agriculture and forestry, mining, railway infrastructure research, and educational space management are described in detail in [7,31-33].

Conclusion

In recent years, traditional methods of artificial intelligence, such as expert systems, fuzzy systems, artificial neural networks, genetic algorithms, etc., are increasingly being combined into integrated (hybrid and, less often, diffuse) intelligent systems that allow not only to increase the efficiency of managing a wide range of national economic tasks, but also to ensure the introduction of Lean technologies, supporting the main directions of digitalization of the economy.

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