

BEHAVIOR CLASSIFICATION OF CONTROL UNIT OF SYSTEMS

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ABSTRACT

Context. The behavior of the system is included in the basic concepts that characterize its functioning. In an event-driven system, behavior is modeled using a state machine. Known classifications of behavior take into account the genus and type of automaton. At the same time, in modern systems, control automata are integrated into hierarchies and have a number of new properties that are not reflected in their classifications.

Objective. The purpose of the work is to systematize the forms of specifying the behavior of integrated systems and methods for changing the behavior in the process of their use. The novelty of the proposed classification lies in taking into account the behavior of new types of non-binary, semantic, controlled and changeable individual automata and the structures of these automata.

Method. The essence of behavior is presented as the ambiguity of reactions to the input signals of the control automaton, which manifests itself in a certain pattern of changing its states and outputs. When classifying behaviors, the expediency of exploratory behavior is determined. Such ways of achieving the goal as adaptation, change or absorption of the environment, change in the goals of behavior are noted. According to the level of complexity of behavior, systems with predetermined, regulated, organizing, predictable and autonomous behavior are distinguished. Along with the automaton model of behavior, the importance of modeling behavior in the form of a combination of statements is noted. The importance of describing the possible and emergency behavior of the system is noted. A classification of the system's behavior in terms of constancy and variability is proposed. The structure and principles of the implementation of changeable behavior within the framework of the processes of external control of the automaton and its self-government are described. Based on the concept of arity of behavior, the functional and technological behavior of a finite automaton are singled out. As part of the classification of behavior by the level of formation, the switching, combinational and automatic behavior of states, as well as the behavior of the automaton in the contours of activity and the typical behavior of the automaton in the hierarchy, are described.

Experiments. With the use of the proposed classification features, the behavior of control devices of monitoring systems for power transformer parameters, object temperature control and integrated hierarchical systems is analyzed.

Results. The proposed classification describes the directions for specifying behavior in complex integrated systems according to 13 main and 84 detailing features, which facilitates the process of designing behavior and highlights new system capabilities.

Conclusions. The actual problem of systematization of the behavior of control devices of systems has been solved. Classification features give directions for the use of standard solutions for describing the behavior of the system, which simplifies the process and reduces the complexity of designing its functional structure.

KEYWORDS: system behavior, control automaton, hierarchy of automata, integrated system, behavior classification.

ABBREVIATIONS

A is actuators;
CA is control automata;
CO is the control object;
CU is control unit;
IOA is input operational automata;
MOA is the intermediate operational automata;
OA is operational automata;
OOA is output operating automata;
S is sensors.

Y_1 is OOA outputs (actuator inputs);
 Δ is an array of automaton outputs;
 $\Delta[i]$ is the i -th output in the array Δ ;
 λ is the transition function;
 μ is the function of the automaton outputs;
 Ψ is an array of automaton transitions;
 $\Psi [i, j]$ is the transition from i to j in the array Ψ .

INTRODUCTION

The tasks of cognition of a person and an artificial, for example, a technical system qualitatively coincides: based on the information received, understand and predict their actions, actions and behavior. At the same time, human behavior is studied as a means to satisfy his needs, achieve a goal, adapt to the external environment, as a system of actions or a manifestation of a two-link “stimulus-response” scheme [1]. The same motives for studying behavior are applicable to the processes of studying the behavior of technical systems. The concept of the behavior of a technical system is interpreted by researchers in different ways and develops along with the development of ideas about systems and the use of new types of behavior.

Behavior (British English: behaviour) is a set of actions and manners performed by individuals, organisms, systems or artificial objects in some environment. This is the calcu-

NOMENCLATURE

$C_{from i}$ – is control inputs from the i -th level;
 $C_{from (i+1)}$ – is control inputs from $(i+1)$ -th level;
 $C_{to (i-1)}$ is control outputs to the $(i-1)$ -th level;
 H_{ij} is the probability characterizing the change of state with the number i to the state with the number j ;
 Q_{ij} is the probabilities characterizing the appearance of the output with the number j , if the current state of the automaton has the number i ;
 S is the set of automaton states;
 s_0 is the initial state of the automaton;
 X is the set of automaton inputs;
 X_1 is IOA inputs (sensor outputs);
 Y is the set of automaton outputs;

lated response of a system or organism to various stimuli or influences, internal or external [2]. From the point of view of behavioral informatics, behavior consists of an actor, an operation, interactions and their properties [3].

As noted in [4], behavior is one of the levels of description of technical systems during their design. According to [5], behavior is included in the basic concepts that characterize the functioning and development of the system. It is associated with the ability of the system to move from one state to another. These transitions are connected by cause-and-effect relationships, and in the process of functioning, one of the possible options for transitions is selected. The logic of choice characterizes the behavior of the system. More details about the behavior of the system can be judged after determining the process model in which the behavior is used: continuous, event-driven or hybrid [6, 7].

The object of study is the process of designing the behavior of event-driven systems.

The subject of study is the classification of the behavior of such systems. Classifications of the behavior of control automata of control systems are known according to the type and type of automaton [8, 9]. At the same time, complex technical systems, as a rule, are integrated, hierarchical, with various forms of implementation and relationships between the behavior of their control automata, with a description of the system behavior not only with the help of automata, but also in the form of knowledge [10–15]. The paper [16] noted the need to determine the combination and integration of system behaviors. In [17], the behavior of a system is defined as a way of interaction in a hierarchy of environments and agents immersed in these environments. At the same time, it is noted that the model of interaction between the control and operational automata should be considered as the ideological prototype of insertion models of such interaction [18, 19].

In the known literature, there is no classification of the forms for specifying the behavior of systems for technical purposes, as well as ensuring that this behavior changes during the operation of the system. As a consequence, this leads to an incomplete use of the possibilities of adapting the behavior of the system and a decrease in the effectiveness of its application.

The purpose of the work is to systematize the forms of specifying the behavior of integrated and cognitive systems and methods for changing behavior in the process of using a technical system.

1 PROBLEM STATEMENT

The generalized model of the technical control system [8] is shown in fig. 1. It includes a control object, which is connected to the control device with the help of sensors and actuators. In turn, CU is subdivided into operational and control automata, and OA – into input, intermediate and output operational automata. The system with the structure of Fig. 1 can have continuous, event-driven, and hybrid behavior. Continuous behavior is carried out in the

circuit: CO – S – IOA – MOA – OOA – A – CO. In this circuit, operating automata perform the functions of a process controller in the control object. The regulation law determines the continuous behavior of the system. Event-driven behavior is performed in the circuit: CO – S – IOA – CA – OOA – A – CO. The IOA automata in this circuit perform the functions of converters of signals from sensors into the inputs of the control automaton, and the OOA automata act as converters of the SA outputs into actuator control signals.

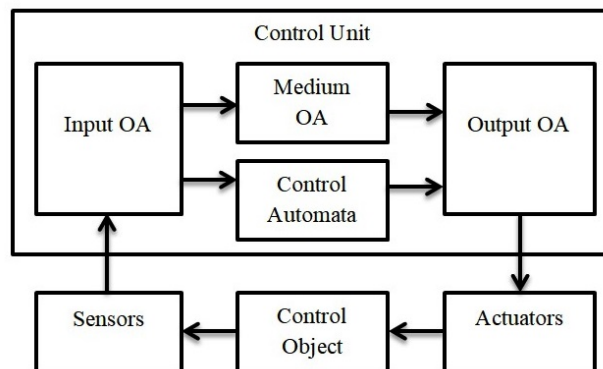


Figure 1 – Structure of the control system

With hybrid behavior, several continuous and event-based control loops can operate in the system, which affect each other [11]. In the classical version of the hybrid system, in each state of the control automaton in the event-driven circuit, the corresponding circuit of continuous behavior is activated.

The classical CA model is a finite automaton [8], which is described by a tuple:

$$\langle X, Y, S, s_0, \mu, \lambda \rangle. \quad (1)$$

At the same time, the behavior of the technical system is given by the functions of outputs μ and transitions λ and characterizes the possible ambiguity of the dependence of the state of outputs Y CA on its inputs X .

To illustrate this situation, in [9], an example of the behavior of a control automaton with the input “Your feet are stepped on in transport” and different values of the output “Your actions” at the first and fifth such event are given.

The described structure of the CA of the “classical” control system can be implemented in hardware (in the form of a logical node with memory elements) [20] or in software (in the form of a program that runs in the operating environment of the system’s computing device) [21]. Changing the behavior of such a system occurs by replacing this circuit/program with new ones that represent new functions μ and λ . In this case, it may be necessary to change the sets X, Y, S and the nodes that form them (operating machines, sensors and actuators).

The task of the study is to analyze the known methods for constructing control systems, to identify and classify ways to specify behavior in the system.

2 REVIEW OF THE LITERATURE

In [22, 23], a variety of approaches to the study of behavior is noted, but it is noted that they are united by the representation of behavior as a process within which the system interacts with the environment. That is, this behavior is a response formed by the system to signals from the environment.

In [22], system behaviors are divided into normative (ritual, imitative, and role-playing) and situational (analytical, play, and entertaining) types. But such a classification does not reflect the form of implementation of behavior using finite automata.

In the dictionary [24] there is an article “Automaton with a variable structure”, which emphasizes the importance of this area of research on control automata. At the same time, she gives a link to the article “Stochastic automaton”, that is, an automaton in which, instead of transition and output functions, in the general case, probability distributions of a discrete type are specified. For transitions, the probabilities H_{ij} are given, and for the output, the probabilities Q_{ij} . Depending on the success or failure of the actions of the stochastic automaton, H_{ij} and Q_{ij} are recalculated, which leads to a change in the structure and behavior of the control automaton.

In [23, 25, 26], the collective behavior of control automata and multi-agent systems are considered, in which the behavior is formed by changing their impact on the external environment as a result of the reaction of the environment or other automata/agents to this impact. This topic requires a separate consideration, therefore, in this paper, the behavior of only one automaton is considered.

In [27], the issues of behavior reconfiguration in discrete-event systems are considered, the concept of a controlled discrete-event system is introduced, in which input events can be disabled by an external controller-supervisor. Such a shutdown makes it possible to change, within certain limits, the behavior of the control machine. At the same time, we note that switching off the automaton inputs does not exhaust all the possibilities of supervisory control.

It can be seen from the literature review that control automata are being studied from various angles, but there is no study and classification of automaton behavior of hierarchical integrated and cognitive systems.

3 MATERIALS AND METHODS

Automaton behavior in the system is proposed to be classified according to the following features:

- goal;
- a way to achieve the goals of behavior;
- the level of difficulty;
- type of model;
- type of behavior in relation to the mode of operation of the system;
- stability;
- arity;
- the level of formation of behavior;
- type of management in the hierarchy;
- function;

– the nature of the processes.

These signs, in turn, are subdivided into signs of the second rank, and so on. Each feature is assigned an alphanumeric code that reflects its place in the classification. An example of an alphanumeric feature code is shown in Fig. 2.

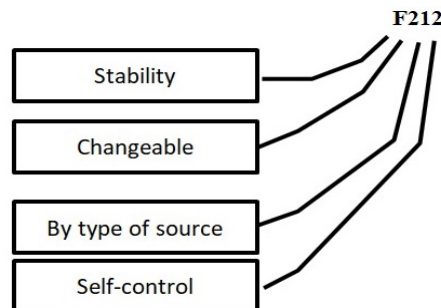


Figure 2 – An example of an alphanumeric feature code

The structure of the signs of behavior is shown in Fig. 3.

We will distinguish between the basic and research goals of behavior. The basic goal (A1) of behavior is effective management based on existing knowledge. But, with the development of knowledge-based systems, the goal of research (A2) of the object and / or control device, the environment was added to it to improve the efficiency of control behavior in the future [28–30].

Behavioral goals can be achieved through parametric (B11) or structural (B12) adaptation [31], transition to a more favorable environment (B2), inclusion of a part of the environment into the system (B3) or change in behavioral goals (B4).

By the level of complexity, we will distinguish (in ascending order of complexity) systems with predetermined (C1), regulated (C2), organizing (C3), predictive (C4) and autonomous behavior (C5).

Predefined behavior is the simplest behavior with fixed functions of operating and control automata of the system control device. Regulated behavior provides for the possibility of changing the parameters of operational automata leading to a change in the conditions for the formation of an event at their output.

Organizing behavior changes the functions of outputs and/or transitions of the control automaton. That is, with this behavior, it is allowed to change all elements of the control automaton tuple.

Predictive behavior assumes the presence in the control device of a system of operating automata in which the model of the object and the environment is executed. As a result of the flow of predicted parameters arriving at the inputs of these automata, the object model enters a certain state, which is taken into account when planning future behaviors.

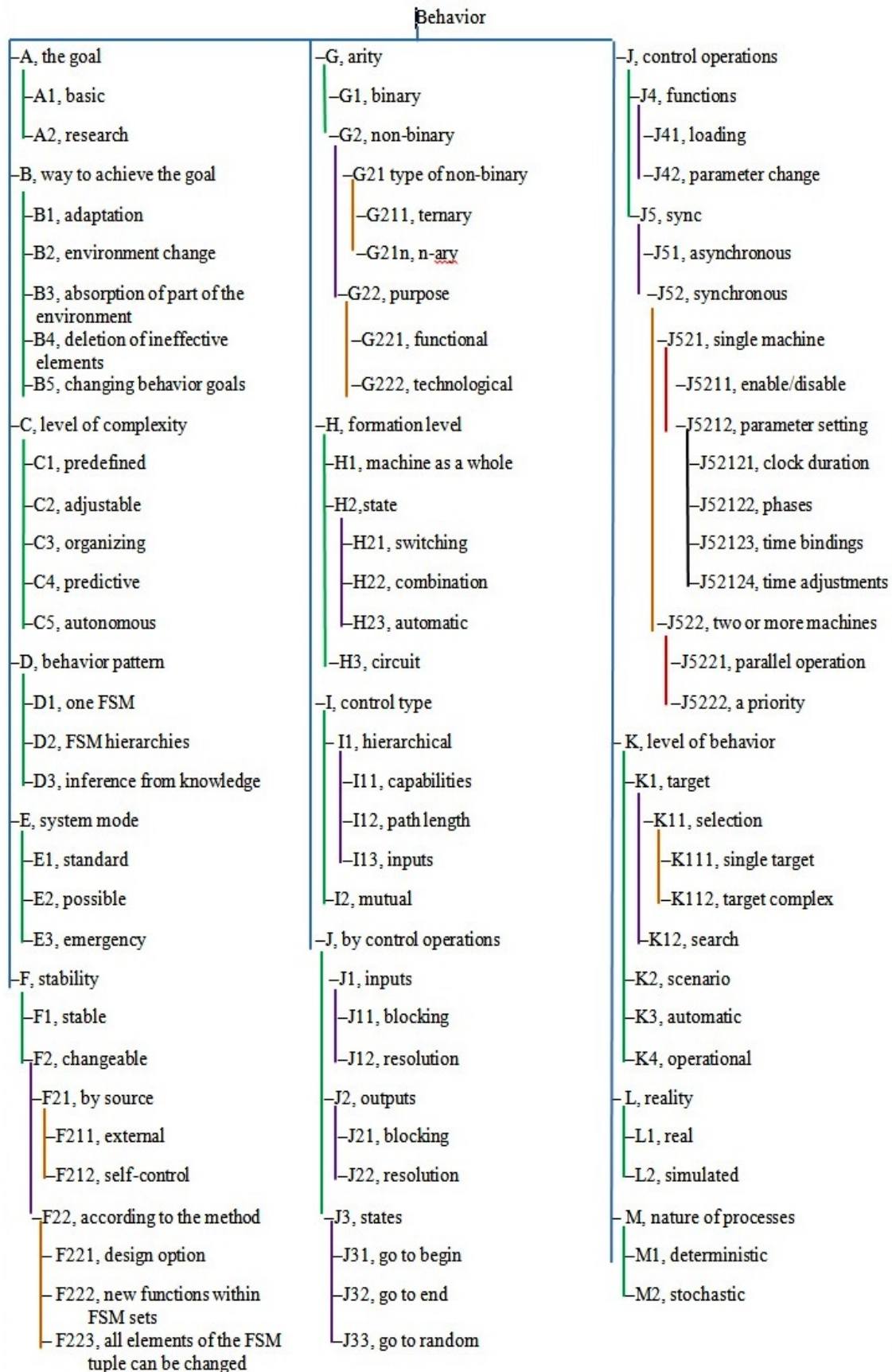


Figure 3 – The structure of classification features

Autonomous behavior implies, at a minimum, the participation of the system in the choice of a set of goals for its functioning. In an extended version of autonomous behavior, the system itself performs a search and formulates the goals of its functioning and builds its behavior under them.

By the type of behavior model, we will distinguish between setting behavior using the functions of one (D1) or some hierarchy (D2) control automata and behavior based on logical inference (D3) from knowledge stored in the system base [14]. The advantage of a behavior model based on logical inference is the ability to share knowledge that describes the normal (normal) behavior of the system and knowledge that does not fit into this behavior.

The characteristic of behavior regarding the mode of operation (E) of the system includes the following gradations: regular (E1), possible (E2) and emergency (E3). Regular behavior corresponds to the goals of the current level of development of the system and knowledge about it. Deviations from regular behavior can be caused by a change in the properties of the system object or control device (its development or degradation), knowledge about them and their influence on the process of achieving the goal of the system functioning. At least some of these deviations are recognized as possible, rechecked and become part of regular behavior. Emergency behavior is a response to unacceptable system states. In complex systems, emergency behavior takes on many gradations and is not reduced to a trivial “turn everything off” action.

The classification of behavior in the categories of stability (constancy) (behavior F1) – variability (behavior F2) allows, on the one hand, to characterize the predicted results of the system’s functioning under conditions of constant external influences, and on the other hand, the degree of flexibility of the system’s behavior when these conditions change.

Changeable behavior (F2) is classified according to the source (initiator) of changes (F21) and the way they are carried out (F22). The control device in a system with variable control contains elements of the implementation of one or another variant of the type of control and control inputs, with the help of which the current control variant is selected. Changes in the behavior of the system or its subsystem may be initiated by an external control device (F211) and/or be the result of self-management actions (F212).

Changing behavior can be done in the following ways:

1. Activation of a behavioral variant from a certain set of transition functions, outputs of the automaton and the initial state s_0 of the automaton, laid down in the design of the system (F221).

2. Synthesis of new behavior within the existing sets of inputs, outputs, states (F222) or by changing these sets (F223).

The next classification feature G is the arity of behavior. The behavior of a finite automaton can be classified based on the arity of the elements of its sets. Arity determines the number of values that an element of each of the sets of the automaton can take – inputs, outputs, states

[12]. We will distinguish between binary (G1) and non-binary (G2) automata. And by the type of nonbinarity – ternary (G211) and, in the general case, n -ary (G21n). Classical finite automata have binary elements of sets. So the binary element of the state set has two meanings “active” and “passive”.

In the presence of non-binary sets of the automaton, we will distinguish between the behavior of G221 for the implementation of the target function of the system and the technological behavior of G222 of the control automaton [32]. In the first case, the outputs of the control automaton depend on the purpose of operation and the properties of the system object. In the second, it depends on the features of the implementation of this behavior, such as the controllability of the structure, the mechanisms for transferring activities from one state to another, the possibility of generating outputs depending on the value of the state, and others.

The behavior of the automaton can be classified according to the level of formation (behavior H):

- The behavior of the H1 automaton as a whole. Such behavior, as already noted, is specified by the output and transition functions.

- The behavior of H2 at the state level. The behavior of the automaton is specified through the set of behaviors in its states [34]. The behavior of an active state describes the logical (causal) relationships of state inputs to its outputs and actions. In [35], a variation of the behavior of H2 is described, which is specified on a certain subset of states of the automaton. In this case, different behaviors are implemented in other subsets. Such an automaton is called multi-behavioral.

- The behavior at the level of logical connections of the state with the control objects (behavior H3). In [34], activity contours are proposed that describe the function of the control object, that is, the processes resulting from the impact on the object from the control device and the reactions of the object, which are fixed by the control device.

The type of control behavior in the hierarchy of control automata is also a classification feature of behavior I. Subtypes of this behavior are hierarchical (I1) and mutual (I2) behavior. There is an extensive class of hierarchical systems in which their subsystems form an integrated system [10]. The interoperability of subsystems located at neighboring levels is ensured by the behavior of typical interconnection elements that consist of a controlled and controlling automaton or are covered by a mutual control loop [13].

We classify the operations of controlling the behavior of J according to the elements of the controlled automaton that they affect: control of inputs X (behavior of J1); control of outputs Y (behavior of J2); state control S (behavior J3); control of functions μ, λ (J4 behavior) and synchronization control (J4 behavior). Details of these behaviors are provided in the next section.

In an integrated multilevel system, different levels implement different behavior [10, 13, 15, 34]. Therefore, belonging to the functional level of the system is a classi-

fication feature K, according to which we will distinguish between the behavior of the target (K1), scenario (K2), automatic (K3) and operational (K4) levels.

The result of the target behavior is the choice of the current goal of functioning and the activation of the scenario behavior automaton, which selects the current scenario for achieving the goal. This script selects and activates a variant of automatic behavior, and so on.

A feature of cognitive systems is the use of operations for predicting the results of decisions made on the choice of goals, scenarios, and so on. In the course of forecasting, the behavior of the object and the control device is modeled in a certain flow of events. Thus, the behavior in the system can be not only real (L1), but also simulated (L2).

According to the nature of the processes occurring in the system, deterministic (M1) and stochastic (M2) behavior is distinguished [36, 37]. With the behavior of M1, the results of repeated repetition of any admissible sequence of values at the inputs of the automaton must be the same. At the same time, with the behavior of M2 and the same conditions at the inputs, the results may differ in the trajectory of the change of states and the outputs in them.

Thus, in the behavior of the control automata of the systems, classification features are distinguished for choosing the types of behavior in the system during the design process.

EXPERIMENTS

The task of the experimental part of the work is to identify behavioral properties in known technical systems that could be classified according to the proposed features. If a certain type of behavior is missing in a known system, then the principles of its implementation and the advantages of using it are described. The author has not been able to find a technical system in which it is advisable to use all the described behaviors, because the systems in the examples given have some subsets of the proposed behaviors. Examples of systems for experiments with the classification of behaviors are control systems for traffic lights, elevators, conveyors, machine tools, robots, power transformers, vehicles, and technological processes. The variety of types of behavior increases significantly for "smart" varieties of such systems.

Such systems are characterized by the presence of a cognition subsystem with knowledge form converters, whose work expands the knowledge base for management, and an activity subsystem in the form of a hierarchy of control automata that use this knowledge to improve management efficiency.

Behavior A1 is basic and is implemented with different efficiency in all event-driven systems. An example of the behavior of A2 is given in [28]. Its essence lies in the activation of the cooling modes of the power transformer, which are not used in the current operating conditions. The information obtained as a result of such behavior on the technical condition of the elements of these systems makes it possible to increase the cooling efficiency.

The reason for launching adaptive mechanisms (behavior B1) may be a change in the object of the system, environmental parameters, or the technical state of system elements [31, 34]. Thus, a reaction to a change in the mass of an object of the system can be an increase in the waiting time for its heating. Forced cooling is used to thermally stabilize an object under conditions of an increase in ambient temperature. If individual elements fail, the load is redistributed to serviceable elements or redundant ones are connected.

An example of the actions of a transport robot aimed at achieving the goal of functioning in the optimal temperature regime can be the search for a location with protection from solar radiation or with a large wind blowing, that is, a change in the environment (behavior B2).

An example of achieving goals by including part of the environment in the system (behavior B3) is the power transformer control system. If the increase in the temperature of the transformer elements due to the increase in load could not be compensated by cooling, then the load can be limited. For this purpose, the object load control circuit is included in the control system.

A transformer control system can also serve as an example of a system with dynamically changing behavior goals (behavior B4). So the original goal of "maximizing service life" under certain conditions can be changed to the goal of "provide a sustainable energy supply, ignoring the accelerated wear of equipment".

An example of C1 behavior predetermined at the design stage is the operation of a control unit based on a classical finite state machine [8, 9]. For example, the event "Object overheating" occurs at the same temperature of the object. The processing of this event in the control machine always leads to the transition of the machine to the "Emergency" state and the action "Turn off the heater". If the outputs of the control machine control the parameters of the operating machines (for example, "Superheat temperature") of the control unit, then the behavior of C2 takes place. The behavior of C3 implies a change in the structure of the operating and/or control automata of the control unit. Predictive Behavior C4 uses simulation results to improve management efficiency. For example, predicting system load and ambient temperature can optimize the performance of a facility's cooling/heating system.

Autonomous behavior of C5 is characteristic of biological systems, starting with the simplest bacteria [38]. The principles of implementing the autonomy of these systems are used, for example, in the construction of artificial agents for the search control of robots [29].

The behavior model D1 given at the set-theoretic level by a tuple (1) has two varieties: Mealy and Moore automata [8, 9]. These automata differ in the way they bind outputs. For Moore automata, the current output value depends only on the current state. And for Mealy automata, the value of the output depends on the input that caused the transition to this state. An example of D1 behavior is the behavior of digital nodes with memory, traffic light control systems, and others. A variation of the

behavior of D1 is the behavior of recognizing the input sequence [8].

The D1 model is included in more complex behavioral formalisms, such as the state diagram of the UML language [39], the Harel formalism implemented in the Stateflow software of the MathLab system [40], the programming language SFC (Sequential Function Chart) [41] and others.

The behavior of D2 involves the selection of sub automata and the modeling of the processes of their interaction. Possible variants of interaction include embedding a sub automaton in the state of a super automaton and integrating sub automata. The nesting of the automaton in the state by goals is similar to the use of subroutines in programming – it allows you to increase visibility, reduce the dimension of the model. The integration of automata is used in the construction of hierarchies, in which the control element at the i -th level is the control object at the $(i + 1)$ -th level of the hierarchy, which ensures the interoperability of control processes [13]. For example, it is the processes of choosing the goal of the functioning of the system and the strategy for achieving it.

The behavior specified by the state machine functions can be described in the form of a combination of statements (D3 behavior) and processed by means of logical inference. For example, the statement “If the current state is S_i and the signal X_k has arrived, then go to the state S_j ” corresponds to an arc in the automaton graph between these vertices.

We will consider the behaviors of E using the example of a simple heating control system. The behavior of E1 is to turn on the heater if the temperature of the object is less than θ_1 and turn it off if this temperature is greater than θ_2 . The behavior of E2 takes into account the possibility of a delay in heating due to changes in the characteristics of the object. Such a delay is not considered as a sign of an accident and is investigated further. An example of the behavior of E3 in such a system is the introduction of additional states for processing events recognized as emergency. For example, it is the state of “Emergency” in which the emergency shutdown of the furnace is performed if the temperature of the object exceeded θ_3 .

Variable behavior of automata F2 is the main and promising type of behavior of systems in the category F.

The structure of external control F211 and self-control F212 at the i -th level of the system is shown in Fig. 4 [34].

The CA machine has four groups of outputs:

- Y group is connected to OOA inputs;
- group $C_{from i}$ is connected with the control inputs of the OA, through which the parametric adaptation is performed;
- group $C_{to (i-1)}$ controls the structural adaptation of SA at the $(i-1)$ -th level;
- group X is connected to additional information inputs of the CA, the impact on which can bring the CA to additional states, thereby changing the structure of the CA by self-control (behavior F212).

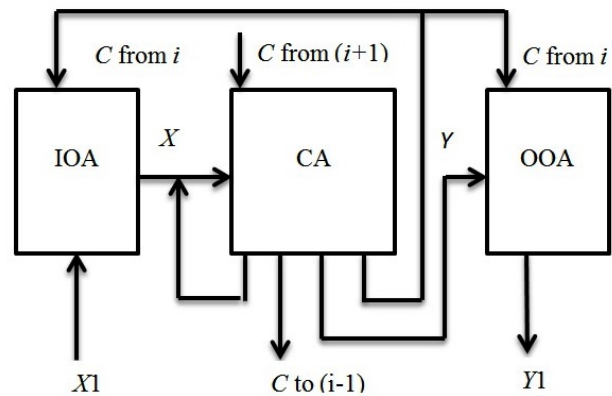


Figure 4 – Structure of external control and self-control at the i -th level of the system

The behavior of F221 for the automaton of the i -th level (Fig. 4) is set by the code at the inputs $C_{from (i + 1)}$, which activates one of the variants of the automaton specified during the design. The same kind of behavior is possible to change the IOA and OOA functions using $C_{from i}$ inputs,

If in the process of the system functioning, the functions of the control automaton are performed by a universal program, and the specifics of a particular automaton are described by data arrays in matrix form, then a change in the structure of the control automaton (behavior F222 – F224) is reduced to changes in its arrays of transitions Ψ ; and outputs Δ .

The main operations of changing the structure of such a control automaton are:

- adding / removing (i, j) -th transition (ADDIN / DELIN $\Psi [i, j]$) in the array of transitions Ψ ;
- adding / deleting the i -th output (ADDOUT / DELOUT $\Delta [i]$) in the array of outputs Δ ;
- adding / removing state (ADDS $[n + 1]$ / DELS $[n - 1]$) in the arrays Ψ and Δ , which boils down to increasing / decreasing the size of these arrays;
- assignment of a new initial state s_0 of the control automaton.

In [32], the behavior with features G211 (ternary) and G221 (technological) was used to reduce the dimension of the control automaton graph. At the same time, the essence of technological behavior is that the activity of the outputs is manifested in a certain neighborhood of the active state.

In the classical automaton with tuple (1), the behavior H1 takes place, which is specified by the functions of the automaton. The work [12] describes an automaton in which the behavior is specified by a set of behaviors in its states. We will consider such behavior as a variant of H1 behavior with the possibility of implementing various variants of H2 behavior in different states.

The classical behavior of H22 is combinational and lies in the fact that the action (output) in the state does not depend on which input caused the state to be activated. The output will be the same for any variant of entering the

state. The work [33] describes commutation, combinational, and automaton behaviors. The switching behavior of H21 defines a hard coupling when the state is activated: each state input corresponds to one of its outputs. With the combinational behavior of H22, the state of the output is determined by a logic function from the inputs that are associated with this output. For the classic state behavior mentioned above, it is the binary logical OR function. In other cases, it is possible to use other functions and implement the behavior corresponding to them. With the automaton behavior of H23, the state of the i -th level of the system is described as a state machine of another, usually lower ($i-1$)-th level, which is initialized at the moment when the state of the i -th level becomes active.

In [14], the behavior of H3 is implemented as a chain of logical statements that form the contour of activity. This behavior was used to diagnose the technical condition of the elements of the heating control system of an object, such as actuators, sensors and operating machines, which made it possible to expand the possibilities of adapting the system.

When studying the behavior of I1 using a simulator [42], the following typical control algorithms were identified: control with a sequential increase/decrease in functionality (behavior I11), increase/decrease in the length of the path in the control cycle (behavior I12), decrease/increase in the number of automaton inputs used (behavior of I13). The combination of these options determines the typical behavior of the control at that level of the hierarchy.

We classify the behavior control operations J according to the elements of the controlled automaton that they affect:

The behavior J1 of control of inputs X is blocking J11 / allowing J12 all or part of the inputs from the set X . In this case, blocking all inputs will lead to a stop, "freezing" the automaton in a certain state, and blocking some of the inputs will lead to a change in the functions μ and λ .

The behavior J2 of controlling outputs Y is blocking J21 / allowing J22 all or part of the outputs from the set Y , outputs of a certain state from the set S . In the case of blocking all outputs, it should be taken into account that the state of the control object can change under the influence of external factors.

Behavior J3 of state control S is the reset of the automaton to the initial state J31, the transition to the final state s_0 J32 or to an arbitrary given intermediate state J33.

The behavior J4 of the control of the functions μ , λ is the loading of the new function J41; changing the parameters of the J42 function by blocking / allowing all or part of the transitions defined by the mapping $\lambda: S \times X \rightarrow S$ or outputs defined by the mappings $\mu: S \times X \rightarrow Y$, $\mu: S \times X \rightarrow Y$ in some "maximum" mapping. The behavior of J42, unlike the behavior of J41, requires that the maximum mapping be set beforehand. As a result of loading a new function, it is possible to change the type of automaton, that is, the replacement of a Mealy automaton by a Moore automaton and vice versa.

The J5 behaviors are J51 asynchronous and J52 asynchronous synchronization behaviors. For synchronous automata, this behavior has features that depend on the number of automata.

The timing control behavior of a single synchronous machine includes enabling/disabling the timing input J5211, setting the clock duration J52121 and the phases of the timing signals J52122, how they are related to the system time J52123, and the time correction J52124. In this case, blocking the synchronization signals is equivalent to blocking all inputs of the automaton. Synchronization control of the execution of several automata is the task of the higher control automaton, which is reduced to the implementation of the behavior of allowing / disabling parallel operation of controlled automata at the current time J5221, changing the priority level of the execution of automata J5222 [34].

We will choose the system of continuous monitoring of the technical condition of a power transformer [43] as the object of classifying the behavior of the control device on the basis of K. At the target level of behavior, this system is represented by the target selection behaviors K411 and K412. The selected goal or set of goals is associated with the active state of the goal machine. When this state is activated, the output events of the input operational automata and the knowledge base of the target system level are used.

Examples of goals for the behavior of the K4 system include extending the life of the transformer, ensuring the required load current, regardless of the accelerated wear of the transformer, and others. An example of the scenario behavior of K3 for the purpose of extending the service life is the scenario of increasing the cooling regime.

The reality of the system's behavior, in accordance with the classification feature L, consists in the use of physically real input information and influences on the system object. This behavior is basic. In cases where the physically real information is incomplete and/or the impact on the system object is destructive, the behavior of L2 modeling of the object, the environment and the system control device is used. Simulation results are used both in real time and for predicting the parameters and state of the system. For example, the simulation results of ambient temperature and load current are used to feed-forward control the cooling of a power transformer.

With deterministic behavior, transitions from one state of the automaton to another on the initiative of the controlling automaton itself and at random times are unacceptable. Another type is non-deterministic behavior, in which the probabilistic nature of the formation of outputs in an automatic state takes place.

As noted in [44], in systems with M2 behavior, nondeterminism appears due to various reasons, such as the level of abstraction, system simplification in modeling, partial controllability/observability of the input/output ports of the system.

RESULTS

During the experiments, the behavior of the control devices of the systems was classified according to 13 main features, which were detailed according to 40 features of the second, 23 of the third, 13 of the fourth, four of the fifth and four of the sixth levels.

Comparison of the classification of the behavior of the control devices of systems with known classifications is shown in the petal diagram in Fig. 5.

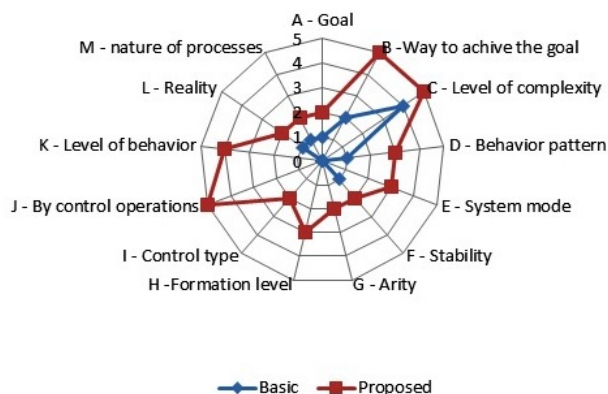


Figure 5 – Comparison of the number of classification features in the directions of the basic and proposed classifications

As can be seen from the diagram in Fig. 5, the number of classification features in all areas of the proposed classification is increased by 1–5 features compared to the base one. A number of new features have been introduced, such as H, I, J, K.

DISCUSSION

Experiments on examples have shown the practical value of the proposed classification for describing the variety of reactions of complex systems.

The classification makes it possible to single out new possibilities in the behavior of systems, such as the behavior of mutual control in the loops of continuous and event control; exploratory behavior, system expansion behavior and continuous revision of current system goals; setting a system behavior model as a result of logical inference, taking into account possible and emergency behaviors; external control or self-management of the control machine of the system; application of behavior with increased arity; formation of switching, combinational and automaton behaviors at the level of a separate state of the automaton; inclusion in the composition of the behavior of knowledge presented in the contours of the automaton activity and the interaction of control automata in a hierarchical integrated system.

The use of new behaviors increases the adaptive properties of systems, reduces the dimension of their behavior model, and increases the knowledge base that is used to select behavior. The carried out structuring of classification features simplifies the process of designing the structure of the behavior of the control device of the system.

The proposed classification is not final and will be corrected and supplemented as systems develop, including those with cognitive behavior.

CONCLUSIONS

The actual problem of systematization of the behavior of control automata of control systems is solved.

The **scientific novelty** of the results obtained lies in the fact that the classification of the behavior of control automata of control systems has been further developed, which takes into account the hierarchical integrated structures of the control devices of systems, the behavior of new types of non-binary, semantic, controlled and changeable individual automata and the structures of these automata.

The **practical significance** of the results obtained lies in the fact that they allow us to form standard solutions and, as a result of their use, simplify the process, reduce the complexity of designing the functional structure of the system.

Prospects for further research are to study combinations of technical solutions for the construction of control devices of systems proposed on the basis of their classification for the construction of a wide class of systems.

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КЛАСИФІКАЦІЯ ПОВЕДІНКИ ПРИСТРОЇВ КЕРУВАННЯ СИСТЕМ

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АНОТАЦІЯ

Актуальність. Поведінка системи входить у основні поняття, що характеризують її функціонування. У підсвоєкеруваній системі поведінка моделюється за допомогою кінцевого автомата. Відомі класифікації поведінки враховують рід і тип автомата. Разом з тим, у сучасних системах керуючі автомати інтегровані в ієрархії та мають низку нових властивостей, які не відображені у їх класифікаціях.

Ціль. Метою роботи є систематизація форм завдання поведінки інтегрованих систем та методів зміни поведінки у процесі їх використання. Новизна запропонованої класифікації полягає в обліку поведінок нових типів небінарних, семантичних, керованих та змінюваних окремих автоматів та структур цих автоматів.

Метод. Сутність поведінки представлена як неоднозначність реакцій на вхідні сигнали керуючого автомата, яка проявляється у певній закономірності зміни його станів та виходів. При класифікації поведінок визначено доцільність дослідницької поведінки. Відзначено такі способи досягнення мети як адаптація, зміна або поглинання довкілля, зміна цілей поведінки. За рівнем складності поведінки виділені системи з визначеною, регульованою, організуючою, прогнозованою та автономною поведінкою. Поруч із автоматною моделлю поведінки відзначено важливість моделювання поведінки як комбінації висловлювань. Відзначено важливість опису можливої та аварійної поведінки системи. Запропоновано класифікацію поведінки системи в категоріях сталості та мінливості. Описано структуру та принципи реалізації мінливої поведінки в рамках процесів зовнішнього управління автоматом та його самоврядування. Спираючись на поняття арності поведінки, виділено функціональну та технологічну поведінку кінцевого автомата. У рамках класифікації поведінки за рівнем формування описані комутаційна, комбінаційна та автоматна поведінка станів, а також поведінка автомата в контурах діяльності та типова поведінка автомата в ієрархії.

Експерименти. Із застосуванням запропонованих класифікаційних ознак проаналізовано поведінку пристроїв керування систем моніторингу параметрів силового трансформатора, керування температурою об'єкта та інтегрованих ієрархічних систем.

Результати. Запропонована класифікація визначає напрями завдання поведінки у складних інтегрованих системах за 13 основними та 84 ознаками що деталізують, що полегшує процес проектування поведінки, виділяє нові можливості систем.

Висновки. Вирішено актуальне завдання систематизації поведінки пристроїв управління систем. Класифікаційні ознаки дають напрями використання типових рішень опису поведінки системи, що спрощує процес, зменшує трудомісткість проектування її функціональної структури.

КЛЮЧОВІ СЛОВА: поведінка системи, керуючий автомат, ієрархія автоматів, інтегрована система, класифікація поведінки.

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КЛАССИФИКАЦИЯ ПОВЕДЕНИЙ УСТРОЙСТВ УПРАВЛЕНИЯ СИСТЕМ

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АННОТАЦИЯ

Актуальность. Поведение системы входит в основные понятия, характеризующие ее функционирование. В событийно-управляемой системе поведение моделируется с помощью конечного автомата. Известные классификации поведения учитывают род и тип автомата. Вместе с тем, в современных системах управляющие автоматы интегрированы в иерархии и имеют ряд новых свойств, которые не отражены в их классификациях.

Цель. Целью работы является систематизация форм задания поведения интегрированных систем и методов изменения поведения в процессе их использования. Новизна предложенной классификации заключается в учете поведений новых типов небинарных, семантических, управляемых и изменяемых отдельных автоматов и структур этих автоматов.

Метод. Сущность поведения представлена как неоднозначность реакций на входные сигналы управляющего автомата, которая проявляется в определенной закономерности смены его состояний и выходов. При классификации поведений определена целесообразность исследовательского поведения. Отмечены такие способы достижения цели как адаптация, изменение или поглощение окружающей среды, изменение целей поведения. По уровню сложности поведения выделены системы с предопределенным, регулируемым, организующим, прогнозируемым и автономным поведением. Наряду с автоматной моделью поведения отмечена важность моделирования поведения в виде комбинации высказываний. Отмечена важность описания возможного и аварийного поведений системы. Предложена классификация поведения системы в категориях постоянства и изменчивости. Описана структура и принципы реализации изменчивого поведения в рамках процессов внешнего управления автоматом и его самоуправления. Опираясь на понятие арности поведения, выделены функциональное и технологическое поведение конечного автомата. В рамках классификации поведения по уровню формирования описаны коммутационное, комбинационное и автоматное поведение состояний, а также поведение автомата в контурах деятельности и типовое поведение автомата в иерархии.

Эксперименты. С применением предложенных классификационных признаков проанализировано поведение устройств управления систем мониторинга параметров силового трансформатора, управления температурой объекта и интегрированных иерархических систем.

Результаты. Предложенная классификация описывает направления задания поведения в сложных интегрированных системах по 13 основным и 84 детализирующим признакам, что облегчает процесс проектирования поведения, выделяет новые возможности систем.

Выводы. Решена актуальная задача систематизации поведения устройств управления систем. Классификационные признаки дают направления использования типовых решений описания поведения системы, что упрощает процесс, уменьшает трудоемкость проектирования ее функциональной структуры.

КЛЮЧЕВЫЕ СЛОВА: поведение системы, управляющий автомат, иерархия автоматов, интегрированная система, классификация поведений.

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