

A Sign-Oriented Mobile Robot-Control System

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Abstract—This paper deals with mobile robot control-system (CS) architecture from the point of view of a sign system. The approach is based on the interpretation of a sign as the symbol–denotation–signification triad in terms of the CS semantic network. It is shown how the mechanisms for the generation and perception of phrases can be implemented within the proposed approach. An important role in communication via language between robots is played by the emotion mechanism. The problem of the implementation of contagious behavior is considered as an example.

Keywords: language, sign system, robot, robot emotions, control system

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INTRODUCTION

Investigations in the field of language interaction in robotics can be conditionally divided into two main areas. The first one is the creation of languages and means of communication between a human (operator) and a robot. This was the first type to appear. This type is about the development of different kinds of control and command interfaces. The second area is the creation of means of communication between robots themselves. This area is becoming increasingly important with the growth of interest in systems of swarm robotics. In such systems, the successful solution of a number of problems requires that communication links be established between the members of a group of robots.

The vast majority of papers in the field of machine to machine communication are devoted to the establishment of communication channels between robots. Purely linguistic aspects of the communication between the robots themselves are considered quite rarely. As an example, in [9], the SWARMORPH-script language was presented, which makes it possible to describe the rules that govern the generation of a distributed form of morphology of a group of robots. In this case, using the local communication mechanism, robots exchange phrases that contain the identifiers of the required motion rules. A different approach was proposed in [3], where the robot-communication problem was considered based on the language of multifrequency acoustic signals. In this paper, language-specific aspects are reduced to the construction of a formal model, in which each language symbol corresponds to a sequence of multifrequency acoustic signals. In addition to the above, the robot language is defined as a set that consists of the alphabet, B (a finite set of symbols), the set of pho-

nemes, F , correspondences between them, R , and the gap, $L = (B, F, R, S)$. However, this formalism does not refer to the syntax but rather to the lexical level of the language description.

In other words, problems of linguistic communication between robots are mostly limited to the creation of the command line interface, where a command is given not by an operator but by a robot. Generally speaking, in most cases, the problems of the development of formats of messages, protocols, and establishment of communication channels are considered.

In this paper, we propose a different approach to the problem of the establishment of linguistic communication between robots, namely, from the point of view of the representation of the robot-control system (CS) as a sign system.

1. A SIGN AND THE CONTROL SYSTEM

Let us assume that the robot (agent) control system is based on the semantic web. In this case, on the basic (functional) level the semantic network is presented as an abstract neural system. Our basic assumption is that such a CS configuration can be interpreted as a sign system; consequently, it can implement the procedures of linguistic communication.

By considering a sign as the classical triad of name (symbol)–denotation (denotatum)–signification (significatum) and by correlating it with the neural structure of the control system, the linguistic perception mechanism is naturally formed [6, 8].

The sign name is interpreted as part of the source language phrase. The denotation of the sign is a directly excited vertex or a set of vertices and the signification can be considered as a complex of second-

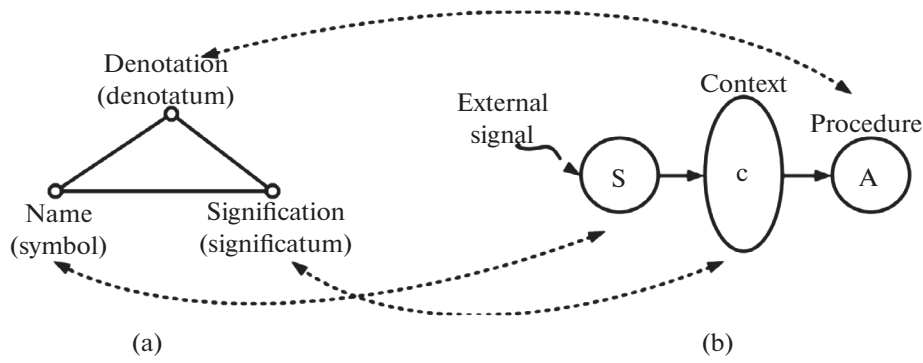


Fig. 1. Sign (a) and subnetwork (b).

any excitations that result in a new state of the system, which can also be also associated with the implementation of the effector or behavioral functions. Figure 1 shows a schematic image of the sign (Frege's triangle) and the corresponding control-system subnetwork.

In Fig. 1b, the subnetwork details have the following interpretation. Generally speaking, a certain external signal, S , causes the reaction of the system, i.e., the implementation of the procedure, A . In this case, if there is a direct link between S and A , then we have a primitive stimulus–response system in which all the arguments about semantics are meaningless. This means that there should be a mediator between S and A , which can determine the relationships between stimuli and responses of the system. This mediator is called the context, C .

This interpretation describes the device of the lowest semiotic system. In this sign system, abstractions and secondary links are not generated as is the case in the developed semiotic systems. However, this is sufficient for the description of simple systems of both a biological nature and robots (agents) with reduced cognitive abilities. Such arguments are quite abstract. Therefore, before turning to the consideration of the linguistic aspects of the sign-interpreted control system, let us consider a more specific example task.

2. THE MODEL PROBLEM

Let there be a set of agents or robots in a model environment that are subject to certain behavioral rules. The environment is a surface with obstacles for robots. In addition to the obstacles, the environment has “feeding areas,” areas with food. It is important that the food grows in the vicinity of the obstacles.

The robot behavior rules are simple. They are determined by the needs of the robots and the state of their sensors. The robots attempt to stay away from obstacles (safety and comfort needs). When the robot begins to feel hunger, it searches for food near the obstacles despite the fact that the robot “does not like”

obstacles (a strong need for food). In addition, the robots attempt to stay closer to their “congeners,” as well as to escape from the “predators” that live in the environment. Schematically, the robot-control system structure is shown in Fig. 2.

The vertices of the block “Needs” determine the level of significance of external signals and influence the choice of a particular action. The vertices of the block “Sensors” determine the robot's reception quality. “Gates” are a layer of some intermediate vertices that define, generally speaking, the mechanism of implementation of the emotional component of the robot behavior. The block “Actions” is a set of robot behavioral procedures. They can be considered as certain complexes of vertices that implement procedures that are responsible for the execution of complex actions. In this system, it is assumed that at this control level we are interested not in basic actions but in behavior. As an example, the procedure “Walk” implies testing a random walk, the discovery of a “congener,” and motion toward it (the desire to stick together). In a sense, it can be assumed that the “Action” block elements are command neurons. It is argued that at any given time the robot executes only one behavioral program. That is the reason that a number of service neurons, SNs, which are responsible for the execution of the winner-take-all procedure, i.e., leaving only one active output from the set, was added to the system. Externally, the robot behavior is described by a set of rules, viz.,

$$R_n : Cond_1 \wedge \dots \wedge Cond_i (a_n).$$

As an example, the rule “eat” can be represented as:

IF “Need for food” (N_{food}) & “See food” (S_{food})
THEN “Eat” (a_{eat}) where N_{food} and S_{food} are confidence factors and a_{eat} is the rule conclusion factor.

This system was described in detail in [1]. Let us consider only the emotional component, which will be crucial in the future. The CS emotional component is based on the so-called need-information theory of

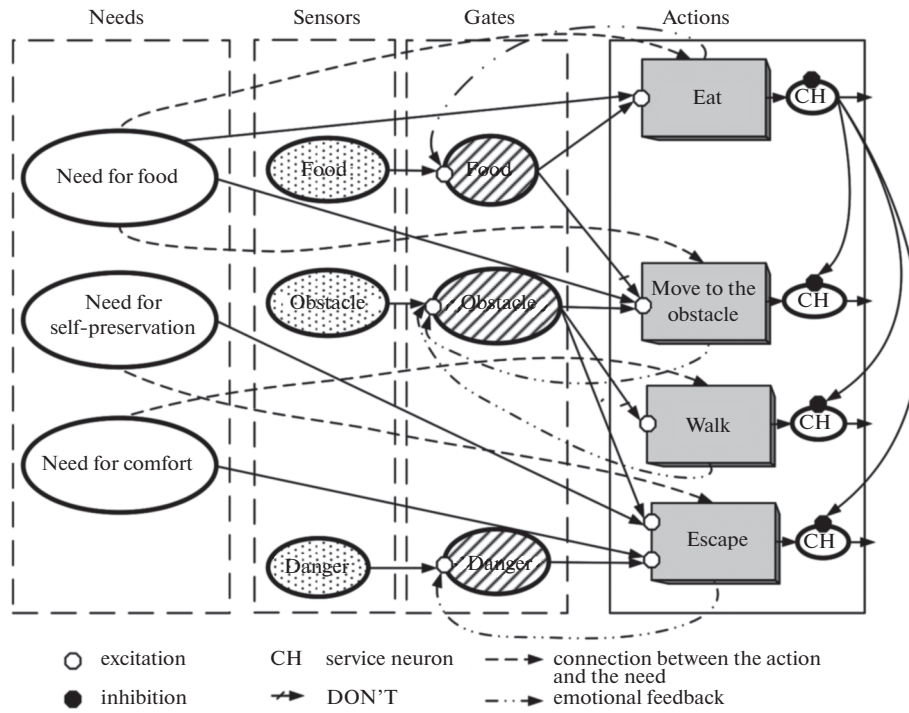


Fig. 2. The control-system structure.

emotions of P.V. Simonov [7]. It is assumed that emotions are the assessment of the current need (its quality and value) and the possibility of its satisfaction. In the general qualitative form, the relationship between these factors is described by the following formula:

$$E = f(N, p(I_{need}, I_{has})), \quad (1)$$

where E is the emotion, its size, quality, and sign, N is the strength and quality of the current need, $p(I_{need}, I_{has})$ is the assessment of the possibility to satisfy the need based on the innate and acquired life experience, I_{need} is the information about the method that is necessary to satisfy the need, and I_{has} is the information about resources that are available to the agent.

A case of assessing expression (1) can be as follows: An individual assesses its current I_{need} needs, or what it should do in the current situation (to eat, find food, to avoid obstacles, run, etc.). It then assesses the options for addressing these needs, I_{has} . The difference between I_{need} and I_{has} defines the emotional assessment of the current situation. On the technical side, emotions define the positive feedback in the control circuit.

Let us represent expression (1) as follows:

$$E = N \times (I_{need} - I_{has}), \quad (2)$$

where E is the emotion and N is the strength and quality (by Simonov) of the current need.

It is possible to assess all the confidence factors a_i for all the rules at any time. Simultaneously, a_i can be interpreted as the value of the projected need for the action I_{need}^i . The assessment of resources for the satisfaction of needs can be represented by a_i , the actual factor rule. As noted, a robot can perform only one action at a time. If the robot performs the action a_k (other actions are suppressed), then

$$a_i^{actual} = \begin{cases} 1, & \text{if } i = k \\ 0 & \text{otherwise} \end{cases}$$

Thus, local emotional assessments are determined for all actions a_i :

$$E_i = N_i (a_i - a_i). \quad (3)$$

The full assessment of the emotional state of the robot is the sum

$$E = \sum_{i=1}^n E_i.$$

Figure 2 shows that the influence of emotions on the execution of an action is implemented as a positive feedback loop between the output signal (current activity) and behavioral rules.

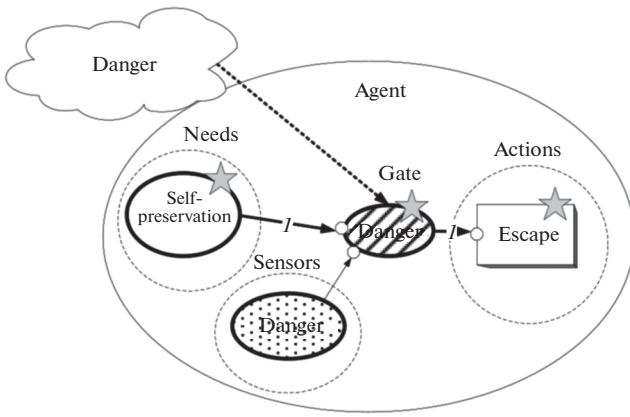


Fig. 3. Symbol perception by an agent.

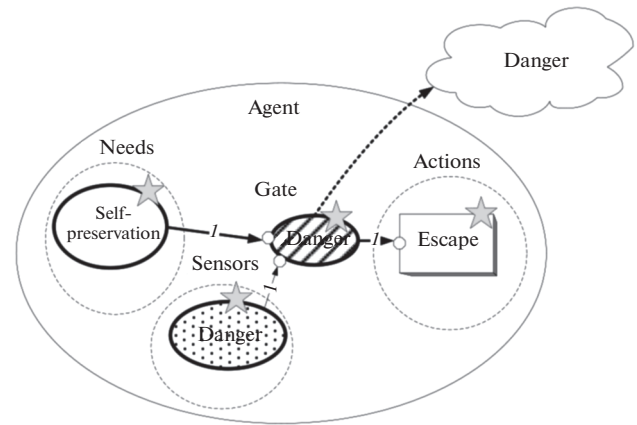


Fig. 4. Symbol generation.

3. LANGUAGE AND COMMUNICATIONS

Let us return to the linguistic aspects. Thus, the sign interpretation in terms of the considered CS is as follows: name (symbol)—recorded external signal, denotation (denotatum)—triggered behavioral procedure, signification (significatum) represented by the gate in the CS structure. The gate determines what we can call context. Generally speaking, in our system the signification is a complex of excitation/inhibition; the system transforms from one state to another.

Language Structure

Investigations in the field of robot communication sometimes lead to the development of very specific languages, such as the star-free language in [13] or special language means that allow agents built based on finite state machines to operate in complex environments [12]. However, again, this all relates to the question of describing the format of transmitted messages. For our problem, we will use a very simple language, in which words—signs have only one major immediate value. Moreover, language phrases are represented by sets of words—symbols that do not form grammatical structures.

Language Perception

In the proposed model, problems of the preprocessing and analysis of the phrases are not considered. It is assumed that the number of input symbols directly excites the vertices of the semantic web denoted by them (because of the fact that the denotation of the input symbol determines the vertex or a set of vertices of the network). Figure 3 shows part of the control system. Let the external phrase be represented by a set that consists of one element (symbol) “Danger.” This symbol is perceived by the only network element, the corresponding vertex—value “Danger.”

The gate excitation coupled with the presence of the respective needs leads to the activation of the action “Escape.” In fact, the issue of whether the external symbol will cause some direct motion activity or the gate excited by it will cause a complex of internal excitations is insignificant. It is important that the perception of symbols of the input phrase leads to secondary external excitations. In other words, for the system only the appearance of the excited vertex is important and what excited it, a sensor signal or a phrase, is insignificant. In fact, usually in robotic systems external phrases, such as language constructs, are a type of emulation of robot sensors.

Generation of Phrases

If the perception of a phrase can in some sense be reduced to the consideration of the sensor system, the generation of phrases is a somewhat more complex phenomenon. The mechanism of the phrase generation by the agent is based on the assumption that the initiator of the generated linguistic message is a complex system of unmet needs. In other words, at a basic level, the system informs about its current needs by generating phrases in the form of a set of symbols as the names of the corresponding denotatum vertices. Depending on the complexity of the semantic network and the level of abstraction, generated phrases can reflect different levels of needs and assessments of the possibilities of their satisfaction. It is important that the language initiation defined by the actual needs of the agent (robot) is directly related to the implementation of the emotional component of the control system. Figure 4 shows the same part of the CS. In view of existing needs and the signal from the sensor, the gate “Danger” is in an excited state and generates the symbol “Danger.”

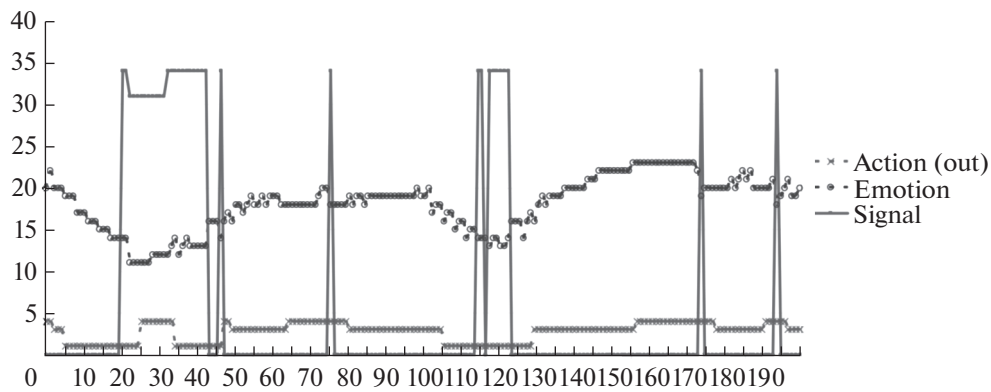


Fig. 5. The dependence of the generated symbols on the emotional state of the robot.

Here, it is important that the initiator is the gate as an action context rather than the action itself, as it might seem. This is due to the following considerations. First, the number of generated phrases should match the number of perceived phrases, while the number of gates in Fig. 2 is not equal to the number of actions. Secondly, the linking of generated phrases with actions will lead to the fact that the system will simply accompany every action with the generation of the corresponding symbol. Incidentally, such a technical trick is used when it is necessary to monitor the status and actions of a robot (agent).

Emotions and speech

The control system comprises a set of gates. Let us assume that the output symbol is generated by a gate that has the minimum value of local emotion (3) (the largest negative emotion). In other words, the system begins to generate phrases associated with unmet needs. At least, this does not conflict with both intuitive notions and ethological observations. As an example, the classical ethology considers fixed action patterns, which play a key role of sign stimuli in the field of communication. Such sign stimuli presented by the subject activate the innate response program of another individual communicant causing a fixed set of actions that correspond to the situation and the received signal [4].

Let us consider the following computational experiment. Let there be an agent (robot), whose behavior is determined by the control system shown in Fig. 2. Let us feed values of the current needs and a sequence of external signals from the input sensors to the system input. In accordance with the level of the input signals and their emotional state, the robot will form an output response. Figure 5 shows the results of the robot response to its emotional state (Emotion) in the form of its actions (Action) and generated output symbols (Signal).

The emotional value is determined by a variety of relationships between current needs and values obtained by robot sensors (not shown in the graph). The y axis is generalized and the plotted values have different dimensions and scales. We are interested only in the mutual influence of these characteristics, namely the fact that the generation of output symbols (Signal) is linked to the decrease of the overall emotional level (Emotion), i.e., the robot begins to “speak” when it feels the most negative emotions.

As noted, most of the papers on the problems of language interaction are limited to the description of protocols and features of information channels. In this paper, in contrast, the emphasis is made on high-level language aspects. Nevertheless, it appears that the proposed sign-oriented architecture affects such purely low-level problems as the establishment of information channels and even the form of representation of a signal.

The Information Channel

The main characteristics of the information channel that are of interest to us are its *direction* and *channel capacity*. Above all, the local nature of communication is understood under the direction. Generally speaking, the vast majority of models of swarm robotics have the local nature of interaction. As an example, in [14] a rationale for the benefits of directed local communication was given based on examples of different tasks, from foraging to “come to me.” In the considered scheme of the sign-oriented CS, the locality and direction of the channel are determined only by means of its physical implementation. The *channel capacity* is a more interesting aspect. The considered principle of the sign-oriented system configuration can explain the low rate of exchange of messages (signs) that is observed in nature. If the sign affects the denotatum vertex as an excitation signal, the speed or frequency of this effect should be commensurate with the slow pro-

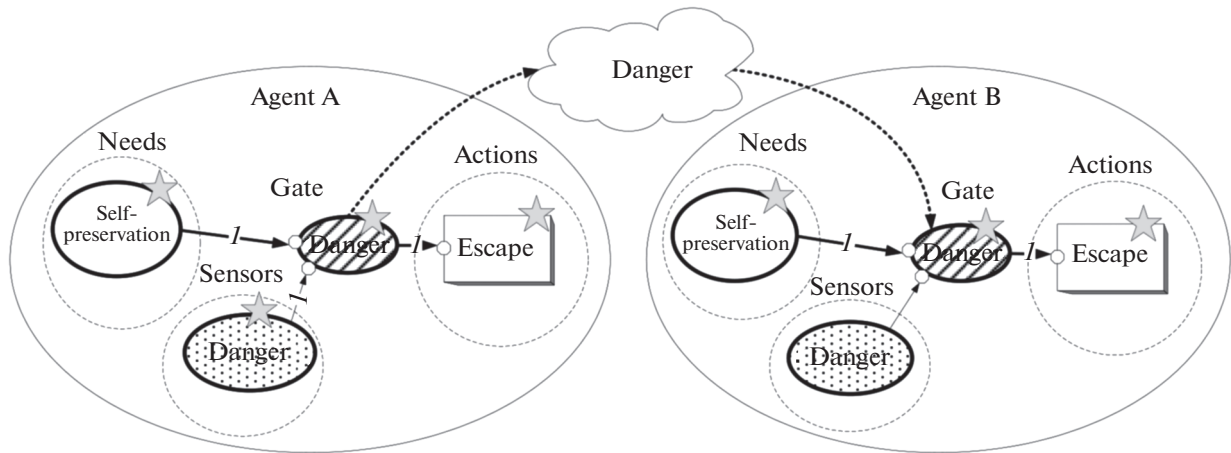


Fig. 6. The generation and perception of a phrase.

cesses of propagation of excitations in the semantic (agents) or neural (biological objects) networks. In this respect, it is possible to solve the inverse problem, i.e., to determine the speed of thought processes based on the channel capacity.

Fuzzy Analog Signals

The signal type, analog and discrete (digital), is an interesting aspect of the channel establishment. I.P. Karpova [2] considered the implementation of the analog signal representation in the case of a local interaction. This made it possible to consider the transmitted messages as fuzzy values. The use of fuzziness made it possible to significantly increase the reliability of communication compared to a digital representation. In addition, the analog form of the transmitted signals and the implementation of the corresponding response mechanism to them increase the energy efficiency of a group of robots. This occurs because the use of the fuzzy analog waveform leads to expansion of the communication language alphabet. Computational experiments were carried out on the predator–victim model, in which the victims exchanged warning signals of varying intensities, such as “danger” or calls for help.

4. EXAMPLES OF SOME TASKS

The thus-determined mechanism for the generation and perception of phrases makes it possible, if not explain, then at least take a fresh look at both some of the known mechanisms of behavior and communication in the animal world and some aspects of a purely technical nature.

Contagious Behavior

The essence of this behavior is that some action of a member of the group is repeated by other members, as a result of which a general concerted action of the entire group occurs. This is the action of an alarm that causes the group to flee. In other words, contagious behavior can be seen as an example of the more general phenomenon of imitative behavior.

Suppose we have a vertex “danger” that is excited by some other complex of vertices, including sensor vertices. The agent–initiator receives a signal of danger. For some period of time it will experience negative emotions (because of the chain “signal received—it is necessary to escape—danger is near”). This will lead to the generation (utterance) of a phrase that contains the symbol “Danger.” Other members of the group will receive this signal. The external initiation of the vertex “danger” of the corresponding networks occurs (although the corresponding input sensor vertices are not excited). The excitement is then transmitted to the elements linked to the vertex “danger,” which will eventually lead to the execution of certain motion functions. This situation is illustrated in Fig. 6.

In this case, the agent–initiator A forms a phrase {“Danger”}. The phrase is perceived by the agent–recipient B, while the recipient’s B gate “Danger” is excited when there is no confirmation signal from the corresponding sensor. Next, the recipient B performs the action “Escape.” As can be seen, with such a linguistic configuration imitative behavior is formed in a natural way.

Command control

Command control can be considered in terms of imitative behavior. In this case, the same scheme of the direct excitation of the denotatum vertex is used.

The action “Escape” is initiated by the message “Danger” received by the recipient. In this case, the message is regarded as a command. In fact, the command control in such a sign CS is a more complicated mechanism than imitative behavior. Command control requires the use of a learning mechanism, i.e., the generation of additional links between the gate and the procedure initiated by it.

Recognition of the status of group members

In swarm robotics, the problem occurs of the state recognition of agents—neighbors. In a sense, this is the basis for the implementation of a variety of mechanisms, for example, contagious behavior. The state recognition problem has both a purely technical aspect associated with the need to have an advanced reception system and a model theoretical aspect associated with the need to determine the complex of features that define significant observed states. As mentioned above, one of the “tricks” often used in swarm robotics systems is clear warning (targeted or broadcast) of neighbors about the condition of the robot, or what action it is performing at the moment. In the simplest case, this is light signaling, as with the robots of the Swarmanoid project of the Swiss Federal Institute of Technology in Lausanne [10, 11, 15]. Usually, the recognition problem is postponed by researchers under the assumption that there is always the possibility of further expansion of the recognition system. The sign-oriented control system, in which phrases are generated directly based on its structure, is the most natural and does not require third-party external mechanisms for the generation of messages and their recognition.

CONCLUSIONS

A robot-control system is a complex object that can be viewed from different perspectives, viz., from the point of view of an automatic control system, neuroinformatics, a functional “black box” system, etc. In this paper, an approach to a control system as a sign system was proposed. This made it possible to consider the problem of linguistic communication between robots. It is clear that language as a sign system is a complex multiaspect phenomenon, the main functions of which manifest themselves in communication. This paper did not address problems of human languages, since it was believed that analogies with the animal world are more appropriate for robotics. However, even in ethology, language models are very limited and contradictory. The same ethology does not provide exhaustive answers to the questions of what communication, and even signals, are. As an example, communication can be considered as an exchange of signals between the direct participants of a double contact. On the other hand, communication in the animal world is, according to [4], the long process of the continual adjustment of each of the communicants to the

behavior of the partner. The “signal” concept also poses problems. In this paper, the signal concept differed from that adopted in ethology in which there is a wide variety of definitions of the term, e.g., [5]. Here, the signal was understood as an influence directed to certain nodes of the network regardless of the nature of this influence, environment, communication means, etc. It follows that the communication aspect of the language itself remained outside the scope of this paper.

First of all, the implementation of various types of models of the social behavior of robots (language is a social phenomenon by definition) should be noted among the most obvious development prospects of the sign-oriented approach to the control-system architecture. In addition to the contagious type of behavior discussed above, there are a number of local social behavior mechanisms based on linguistic interaction (conflict and ritual behavior, division of labor, assimilation of experience, etc.). In this case, we are talking about communications in the broadest sense, where a transmitted and perceived symbol is represented by a signal of a very different nature, from acoustic effects to a demonstration signal.

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