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Artificial intelligence in robot control systems

A Korikov
Tomsk State University of Control Systems and Radioelectronics, Tomsk, Russia
Tomsk Polytechnic University, Tomsk, Russia
E-mail: korikov@asu.tusur.ru

Abstract. This paper analyzes modern concepts of artificial intelligence and known definitions of the term "level of intelligence". In robotics artificial intelligence system is defined as a system that works intelligently and optimally. The author proposes to use optimization methods for the design of intelligent robot control systems. The article provides the formalization of problems of robotic control system design, as a class of extremum problems with constraints. Solving these problems is rather complicated due to the high dimensionality, polymodality and a priori uncertainty. Decomposition of the extremum problems according to the method, suggested by the author, allows reducing them into a sequence of simpler problems, that can be successfully solved by modern computing technology. Several possible approaches to solving such problems are considered in the article.

1. Introduction

The The Artificial Intelligence (AI) and robotics are of interest practically to each person of our world. AI is the branch of computer science, concerned with making computers behave like humans. The term has been introduced in 1956 by John McCarthy [1]. Among many AI definitions we prefer definition given in [2]. AI is the property of the computer or of the neural network which consists in their reaction to data almost in the same way as a person reacts to information. In the monograph [2] the theory of AI is described as the science about agents who receive results of perception acts of the external environment and perform rational operations. AI defines the present and the future of the technological industry and the equipment. Robotics includes many achievements of AI [3]. Robots differ from usual technical systems by a new property, generated by synergy of mechanical, electronic and computer components of robots and AI. There is a question of assessment of new quality of the robots with AI. How to determine the level of intelligence of the robot? How the system theory and the theory of artificial intelligence answer this question? How to use the AI methods and methods of technical systems synthesis when designing intelligent robots? Let's try to answer these questions.

2. On estimation of robot intelligence

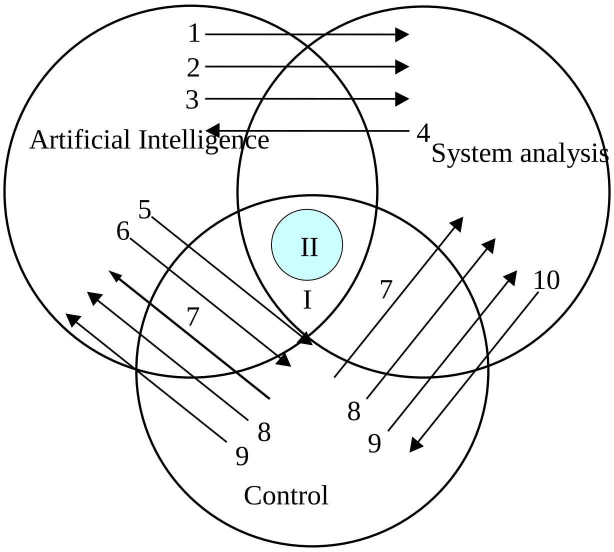
First, let's answer a question of robot intelligence degree assessment on the example of estimation of intelligence degree of natural systems. The idea of human intelligence degree assessment by tests and the notion of IQ – intelligence quotient, which is defined on the basis of these tests, was offered and developed in the beginning of 20th century. The IQ is used in many countries of the world for the achievement of the most different purposes. For the assessment of intelligence degree of AI systems various AIQ intelligence coefficients were suggested in [4], such as absolute intelligence coefficient (AAIQ), relative intelligence coefficient (RAIQ) and comparable intelligence coefficient (CAIQ). Brief distinctive characteristics of these estimates are explained in [5]. Also, the authors of [5, 6] point to the common flaw of such estimates, which consists in their subjectivity since they are based on expert assessments.

Some researchers make attempts of objective AIQ assessment. So, for instance in [6] the concept of intelligence "levels" of AI systems was introduced, which are human machine interface, event forecasting, adaptation and self-learning, events, knowledge and decision making databases, and, finally, the execution level. The term "intelligence level of AI systems" is defined in [6] in a way, that is similar to the concept of "stability of automatic control systems". System stability can be defined "in the small", "in the large" and "in general", therefore the intelligence of AI systems in [6] is also defined "in the small", "in the large" and "in general". Intelligence "in the small" means that system performance is restricted to the two bottom levels, intelligence "in the large" – to the three bottom levels; and in case of intelligence "in general" it covers all five levels. The analogy of AI system intelligence and system stability has its advantages and disadvantages. It is beyond argument that such analogy increases the objectivity of AIQ assessment, but at the same time in the theory of non-linear automatic control systems (ACS) the stability "in the small" of the ACS doesn't follow from the stability "in the large". It is necessary to correct the discussed analogy in a sense that will become obvious after reviewing the concepts of "intelligence in the small" and "intelligence in the large", suggested in [6].

The problems of intellectual robot control are on the intersection of control theory and the theory of AI. They substantially match the problems of development of the intelligent automated industrial management systems (AIMS) arising on a joint of electronics and informatics as a combination of electronic and computer devices [5]. The development of AIMS is induced by control theory, the theory of AI, system theory and system analysis. Intersection of these theories forms area I (Figure 1). The area I on Figure 1 is defined as the intelligent control [7] or control which has the property of "intelligence in the small" [6]. It is possible to define systems, implementing intelligent control, as AI systems, which has the property of intelligence "in the small" [6]. The subarea II is a part of the area I on Figure 1. This subarea defines the control, which has the property of "intelligence in the large" and corresponds to intellectual control [5, 7]. Arrows on Figure 1 illustrate the cross impact of three scientific theories while numbers 1 through 10 designate concepts and methods, which are transferred from one theory to another and create solving methodology for unformalized (semistructured) problems of complex dynamic systems control. For example, arrow 1 on Figure 1 shows that the theory of AI enriched the theory of system analysis with data processing methods, and arrow 4 points out that techniques of systems analysis are used in the theory of AI.

Concepts of adaptation and intelligence used in robotic have been approbated in control theory. Tsypkin in [8] identified three stages in the control theory: determinism, stochasticity and adaptivity. We are witnessing the development of new, fourth stage of the control theory: intelligence. The former three stages are specified by solving of formalized problems, while the latter one focuses on unformalized (semistructured) problems [8].

Systems of intelligent control (SIC) are based on five principles [5, 6]: interaction of systems with an external environment; system openness; forecasting external environment and internal behavior changes; layered system architecture; system survival capability in the case of a failure of communication with the highest levels of system structure.



1. Data processing	6. Learning
2. Formal linguistics	7. Adaptive control optimization
3. Sets of heuristics	8. Dynamic feedback
4. System analysis	9. Control system dynamics
5. Computer memory	10. Coordinating control

Figure 1. Interaction of basic theories of intellectual robotics.

These principles of SIC design allow defining the terms "intelligence in the small" and "intelligence in the large" [6]:

1. SIC are referred to as intelligent-in-the-large systems if they are organized and perform in full accordance with five principles given above.
2. SIC are referred to as intelligent-in-the-small systems if they aren't organized and don't perform in full accordance with five principles given above, but use knowledge databases, automatic control or behavioral models in order to overcome vagueness of input data.

Examples of both types of SIC are described in [5 – 7]. From the definitions given above it follows that intelligent-in-the-large SIC is also intelligent-in-the-small. These concepts correspond to the known concepts of "weak-AI" and "strong-AI" [2]. The concept of "intelligence in general" remains ill-defined as in the theory of AI there is no predominating point of view on an interpretation of this level of intelligence yet.

One of the founders of the system theory William Ross Ashby [9] enunciated the law of requisite variety which considers limit implementability of system. This law for control systems can be formulated as follows: controlling subsystem V_{cs} should be more diverse (complex) than controlled subsystem (controlled object V_{co}): $V_{cs} > V_{co}$. Therefore, the controlling subsystem of SIC should have the variety (complexity) of methods, models, algorithms and controls larger than complexity of an object. The law of requisite variety has also the second corollary which is defined as follows: if variety at top levels of SIC structure increases, then variety at lower levels is restricted and, vice versa, increase in variety at the bottom levels disintegrates top levels. This corollary is also referred to as the law of hierarchical compensations (Sedov law).

The coefficient of intelligence (AIQ for SIC) is proportional to variety (complexity) of solvable tasks (tests, problems). This statement and two corollaries of the law of requisite variety lead to the following consequences for the systems of intelligent robot control (SIRC):

- SIRC with large variety of the software has a high level of intelligence (high coefficient of intelligence AIQ). Therefore, the architecture of such SIRC is complex, multilayered and has multiple loops.

- SIRC with large variety at top levels and, respectively, with a high level of intelligence at these levels should have limited variety at the bottom levels (restriction on degree of intelligence). This restriction at the bottom levels provides automatism of execution, high accuracy and high-speed performance. Therefore, increase in intelligence "in the large" restricts intelligence "in the small".

3. Multilevel control systems with optimization

The robotic technology uses many mathematical methods of a research. Methods of optimization are especially attractive [5, 7, 10, 11]. Systems of control with optimization (SCO) use these methods. Multilevel control systems with optimization (MSCO) can be described by the block diagram which is submitted in Figure 2.

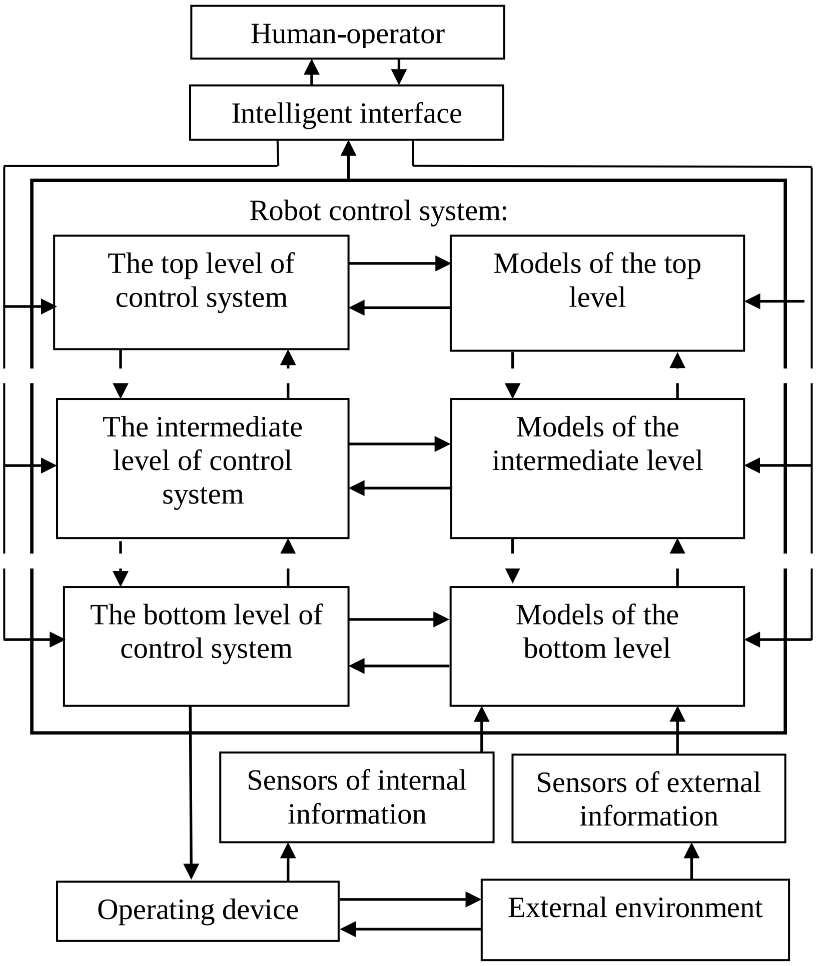


Figure 2. Structure of MCSO of the robot.

Functioning of the MCSO is based on the extremal principle which lie in the fact that some functional of J (x) from state vector x (motion trajectory or structures) the MCSO of the robot accepts extremal value. Overall performance the OCS of the robot is defined by the accuracy of determination of extremal value (minimum or maximum) x^* a state vector of this functional: x^*= argextr J (x). Purpose the MCSO consists in determination of state variables – arguments of a functional of J(x) which provide point of extremum (minimum or maximum) this functional. Our approach we will consider on examples three-level, two-level and single-level the MCSO of robots. Decision-making at all levels the MCSO of robots is based on the solution of extremum problems of different types. Problem description of research of MCSO is offered in our article [11]. Formalization of this problem description consists in the job of three sets: X_E - a set of states of the external environment (EE) which interact with the robot; X_O - set of states of controlled object (CO); X_M - set of states of the MCSO models. Therefore general case of the state space of the researched system represents the Cartesian product of the listed sets: $X = X_E \times X_O \times X_M$. Each point x of space of X is the characteristic of a status of the robot, his OCS and interactions of the robot with an external environment. Functioning of the robot represents movement of a point x in space of X, that is means its transition in space of X of one status to other status on some path:

$$\mathbf{x}(\mathbf{c},\mathbf{u},t)=\left[\mathbf{x}_{\mathrm{e}}(\mathbf{c},t),\mathbf{x}_{\mathrm{o}}(\mathbf{u},t),\mathbf{x}_{\mathrm{m}}(\mathbf{x}_{\mathrm{o}},t)\right].$$

The vector of the controlling signals is designated as u, and the vector of parameters of models of system of control of the robot is designated as c. The vector of parameters of models c consists of three components: $c = (c_t, c_m, c_b)$. That is, components of vector of c are vectors of parameters of models of the top level of c_t, the intermediate level of c_m and the bottom level of c_b of system of control of the robot. The state vector the MCSO of the robot consists of vectorial components: $x=(x_e, x_o, x_m)$; $x_e \in X_E$, $x_o \in X_O$, $x_m \in X_M$.

Efficiency of functioning the MCSO of the robot is estimated by the job of target functions of $F_i (i = 1, 2, ..., n)$ and restrictions of $H_j (j = 1, 2, ..., m)$ on a set of trajectories of the MCSO of the robot in the state space X. The control system of the robot solves the following extremum problem:

$$J\left\{F_1\left[\mathbf{x}(\mathbf{c},\mathbf{u},t)\right],...,F_n\left[\mathbf{x}(\mathbf{c},\mathbf{u},t)\right]\right\}\to \underset{\mathbf{x},\mathbf{c},\mathbf{u}}{extr}, \tag{1}$$

$$H_j\left[\mathbf{x}(\mathbf{c},\mathbf{u},t)\right]\geq 0, \quad j=1,2,...,m. \tag{2}$$

This task is the task on search of an extremum of a functional of J in case of restrictions of H_j (j = 1, 2,…, n), that is it is required to define c, u and to find x which meet a condition (1) in case of restrictions (2). The decision of similar tasks sophisticates dimensionality of the task, its polymodality, prior uncertainty, etc. Our papers [6, 11] offer a technique of the decision of such tasks. Decomposition of the task (1) by this technique supposes its partition on tasks of three levels which correspond to three MCSO levels in Figure 2. The functional of J is set by the human-operator. The top level the MCSO defines components of a vector c_t^* and creates the sequence of local goals of

$$F_i\left[\mathbf{x}\left(\mathbf{c}_{\mathrm{t}}^*,\mathbf{c}_{\mathrm{m}},\mathbf{c}_{\mathrm{b}},\mathbf{u},t\right)\right], \quad i=1,2,...,n,$$

as the solution of the following extremum problem:

$$J\left\{F_1\left[\mathbf{x}(\mathbf{c},\mathbf{u},t)\right],...,F_n\left[\mathbf{x}(\mathbf{c},\mathbf{u},t)\right]\right\}\to \underset{\mathbf{c}_{\mathrm{t}},\mathbf{x}\left(\mathbf{c}_{\mathrm{t}},t/\mathbf{c}_{\mathrm{m}},\mathbf{c}_{\mathrm{b}},\mathbf{u}\right)}{extr} \tag{3}$$

in case of restrictions (2).

The intermediate level of MCSO solves extremum problems:

$$F_i\left[\mathbf{x}\left(\mathbf{c}_{\mathrm{t}}^*,\mathbf{c}_{\mathrm{m}},\mathbf{u},t\right)\right]\to \underset{\mathbf{c}_{\mathrm{m}},\mathbf{x}\left(\mathbf{c}_{\mathrm{m}},t/\mathbf{c}_{\mathrm{t}}^*,\mathbf{c}_{\mathrm{b}},\mathbf{u}\right)}{extr} \tag{4}$$

in case of restrictions (2).

The bottom level of MCSO solves tasks of coordinate or parameter optimization of CO. Coordinate optimization of CO defines the combination of input coordinates (variables) CO providing x_o extremum – one of components of a vector $x_O \in X_O$ which characterizes quality of operation of CO. Parameter optimization of CO defines a set of parameter values of CO which provides an extremum of criterion of the quality Φ created at the lowest level of MCSO. Thus, the lowest level of MCSO solves one of the following extremum problems:

$$x_{\mathrm{o}}\left[\mathbf{x}_{\mathrm{m}}\left(\mathbf{c}_{\mathrm{t}}^*,\mathbf{c}_{\mathrm{m}}^*,\mathbf{c}_{\mathrm{b}},t\right),\mathbf{u}\right]\to \underset{\mathbf{c}_{\mathrm{b}},\mathbf{u}}{extr}, \tag{5}$$

$$\Phi\left[\mathbf{x}_{\mathrm{o}}(\mathbf{u},t),\mathbf{x}\left(\mathbf{c}_{\mathrm{t}}^{*},\mathbf{c}_{\mathrm{m}}^{*},\mathbf{c}_{\mathrm{b}},t\right),\mathbf{u}\right]\to \underset{\mathbf{c}_{\mathrm{b}},\mathbf{u}}{extr} \qquad (6)$$

in case of restrictions (2).

Thus, the extremum problem (1) is reorganized into set of simpler extremum problems (3) - (6). These tasks make a clear physical sense in case of control of specific CO. The top levels of MCSO use methods of an artificial intelligence, and lower – methods of automatic control. Let's show it on examples of production control (PC) and the transport robot (TR).

The top level of MCSO of PC solves the problem (3). The decision of the task (3) is presented in the form of the law of control of PC, initial and boundary conditions. The intermediate level of MCSO of PC solves the problem (4), that is realizes setup of parameters in the selected law of control of PC. The bottom level of OCS of PC solves the task (5) or the task (6). The circuit of control consists of the lowest level of OCS, CO and sensors of information on a status of CO and represents the known systems of extremal control (extremal ACS) [6, 7, 10-12].

The same transparent physical sense of the task (3)–(6) has in case of control of TR: The OCS of TR is intellectual system of navigation and control of TR (SNCTR). The top level of SNCTR solves the problem (3), plans a global route of movement of TR in the region and defines location of TR in the coordinate system connected to this region. The intermediate level of SNCTR solves the problem of a kind (4), orients TR on locality of relative to navigation reference points and plans a local route of its movement. The SNCTR bottom level solves problems (5) or (6) and exercises optimum driving of TR on locality.

4. Conclusion

Research in the field of AI is currently being conducted intensively and very diversely. In our work an attempt is made to answer the question: is it possible to determine the measure of intellectuality of robotic systems? The criteria of intellectuality of robotic systems are considered. Estimates of the intelligence of robotic systems are associated with their complexity and diversity. In the case of robotic systems, the definition of SIC as systems that act rationally and optimally is relevant [2].

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