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Robotics: From first-order cybernetics to third-order cybernetics

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Abstract

The general principles of cybernetics of various orders were formulated half a century ago. However, these principles were used primarily in philosophy, sociology, biology, economics and similar fields that can be called humanitarian. Engineering specialists practically did not use these principles in their work. In this article, an attempt is made to consider and formulate these principles, in the tasks of controlling robotic systems, in terms of cybernetics of the first, second and third orders. A new principle of classification of robotic systems is proposed, which is based on linking to generations of cyberneticians. It should be noted that the proposed principle can be extended to other areas of engineering and technical fields, for example, cognitive architectures, artificial neural networks, or genetic algorithms.

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Keywords: first order cybernetics; second order cybernetics; third order cybernetics; cyber-physical system; robotic; control system.

1. Introduction

Division into "orders" in cybernetics, which in its most general form can be defined as the science of systems control, which is based on the processing of information about their state. This is a very conventional definition, but it allows us to highlight the main features of the subject of research and the means used for this. The purpose of this article is to consider and formulate the basic principles and tasks of control of a class of robotic complexes (RC) in terms of cybernetics of various orders. RCs belong to complex cyber-physical systems, and in this area, in my opinion, all the most complex cybernetic theories and methods used in practical projects are concentrated at this point in time. Considering the RC class, it should be immediately specified that the methods and algorithms that are used in the design of the RC control system will be considered. It should be noted that many principles and approaches to their design and implementation, which turn out to belong to cybernetics of various orders, were developed by scientists

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and engineers without any consideration of the problems of cybernetics of various orders. Therefore, it is interesting to analyze, generalize and comprehend this experience from the point of view of understanding the tasks facing cybernetics of the first, second and third orders.

2. Cybernetics of the first, second and third orders

Despite the fact that the idea of dividing cybernetics into orders arose in the 70s of the last century, there are no de facto standard definitions of the essence of these cybernetics for engineering applications, including robotics.

2.1. Cybernetic of the first orders

Classical cybernetics, as defined by Norbert Wiener, is the science of the general laws of control and information transfer in machines, living organisms and society [1]. It is important to emphasize that in N. Wiener's definition of cybernetics, “machines” are in the first place, and only then “living organisms and society”. N. Wiener was a mathematician and worked on projects for technical systems. Despite the "classical definition" of cybernetics, in various articles one can find quite different interpretations of this definition. Below are some examples. "Determination of the essence of classical cybernetics, which is based on the ideas of classical scientific rationality" [5]. “Cybernetics of the first order corresponds to the classical scientific rationality, is based on the paradigm“ subject - object ”[6]. "The first cybernetics deals with observable systems and deals with allopoetic machines" [8]. “From a cybernetic point of view, each system reduces entropy, creating some form of space-time and cognitive order. In the case of first-order cybernetic systems, the triplet of computer-communication control is its means ”[10].

Cybernetics of the first, second and third orders was not defined by scientific and technical workers!

2.2. Second order cybernetics

The creators of the second order cybernetics paradigm in the 50s of the last century are considered to be quite serious and well-known scientists: A.S. Beer (operations research, social systems), W.R. Ashby, (psychiatrist, cyberneticist), W.S.McCulloch (neurophysiologist, neural networks, one of the creators of cybernetics) began to develop "second order cybernetics", which differs from the classical cybernetics of N. Wiener [2]. In [3], is given a fairly detailed historical information about the role of some scientists, for example, H. von Foerster (physicist, mathematician, cyberneticist), and G. Bateson (philosopher, cyberneticist, sociologist, anthropologist), in the development of the second order cybernetics concept. They made a reorientation of classical cybernetics ideology to the nature of biological knowledge and orientation to the subject. Even in the definition of classical cybernetics, there are quite different interpretations of it, and in the definition of second-order cybernetics, all the more there is no single formal clear definition. Below are examples of definitions by some authors: H. von Foerster in his article "Cybernetics of Cybernetics" [3], distinguished between first-order cybernetics - the cybernetics of observed systems and second-order cybernetics - the cybernetics of observing systems. Proponents of "second-order cybernetics" argue that knowledge is a biological phenomenon (Humberto Maturana, biologist), that each individual constructs his own "reality" (H. von Foerster), and that knowledge is "consistent" but not "identical" to the world of sensory experience Ernst von Glasersfeld (philosopher) [3].

In contrast to the "Wiener" one-dimensional ("coordinate") - multidimensional ("coordinate" - "parametric" - "structural") "second order cybernetics". A.S.Beer et al. Note that it was initially focused on the control of objects in the bio- and noosphere, incl. - on the management of relations in societies and, in particular, on the management of human relations, manifested, for example, in the evolution of financial flows of industrial enterprises. In the works of the aforementioned authors, it is stated [3], “second order cybernetics” is “complexity management”, which does not consist in responding to changes in the control object, as is the case in “Wiener cybernetics”, but in responding to the tendencies of these changes. This, in turn, is carried out by influencing the "integrity and internal connectivity of control objects and through this, homeostasis and self-organization are maintained in them" [3].

Due to the hyperdimensionality of the number of states describing the objects of "second order cybernetics" ... such influences, despite the need to maintain all the aforementioned "homeostasis" and "self-organizations", in any cybernetic system of "second order", there can be three and only three (no more ! others simply have nowhere to take), i.e. in addition to the "Wiener" influences on coordinates in the systems of "second-order cybernetics" there should be two more influences, namely, the effects on the parameters and the effect on the structure of the object. As a result, it turns out that the criterion for the necessity of transition from a purely "Wiener" one-dimensional coordinate control to that of a coordinate-parametric one and further on to a structural one is the failure to fulfill the R. Kalman criterion for the control object [3]. This is practically the only concrete way to determine whether a system belongs to second-order cybernetics!

Another version of a more or less clear definition can be found in articles by a number of authors, for example [4,6]. Such a definition looks like this: "... the concept of second-order cybernetics was introduced to emphasize the difference between the cybernetics of the observed systems and the cybernetics of the observing systems. In second-order cybernetics, the observer himself is regarded as a cybernetic system engaged in building a model of another cybernetic system "

However, there are a large number of more non-specific formulations, below are some examples.

"Cybernetics of the second order is based on the ideas of non-classical scientific rationality" [5].

"The second cybernetics deals with observation systems or with autopoietic (living machines)" [8].

"In the case of second-order cybernetic systems, the decrease in entropy is triggered by the integration-learning-adaptation triplet" [10].

2.3. Third Order Cybernetics

A relatively new paradigm that formulates a renewed understanding, methodology and range of tasks that modern cybernetics deals with, for example [4-7]. In third order cybernetics, the first place comes out: the intellectual component of the system, the active participation of a person in its functioning, and, what is important, not only as an operator, but also as a partner. Third order cybernetics considers the system more as an active interactive element in a complex control scheme. Currently, the main work on third order cybernetics is carried out by scientists from the fields of sociology, biology, economics, psychology of emotions, art theory and philosophy. There are very few examples of this paradigm use in the field of technical and engineering sciences.

In Russia, the methodological ideas of third order cybernetics are developed in the works of Academicians of the Russian Academy of Sciences VS Stepin, VA Lektorskiy and Professor VE Lepskiy [6, 7], who are the main popularizers of this paradigm in Russia. In their publications and speeches, first of all, the philosophical and methodological foundations of this paradigm are discussed. In the works of V.E. Lepsky, in particular, a number of examples of the use of this methodology in the field of economics are given.

It must be stated that, as for second-order cybernetics, there is no single formal definition of third-order cybernetics. Below are the definitions of some authors, which show a fairly large number of interpretations:

The author introduces the concept of the author [5] about cybernetics of the third generation as "economic cybernetics of self-developing poly-subject environments", which should be based "on the ideas of post-nonclassical scientific rationality."

"In [3, 4], it is proposed to focus on the intellectual component, on the self-development of systems in the process of their functioning, when an essential factor in the development of control decisions is the comprehension of the value-target orientations of the subject."

"Cybernetics of the third order is formed on the basis of post-nonclassical scientific rationality. The focus is on the self-developing polysubject (reflexive-active) environment. The leading paradigm is "subject - metasubject" (self-developing polysubject environment) "[6].

The third order studies mutually observable systems, and the object of its analysis is language, as a cognitive machine that creates a common area of interaction between living systems [8].

Cybernetics of the third order is based on four values: the preservation and development of man, the preservation of mankind, the preservation of the biosphere, the preservation and development of the technosphere [7, 11].

R.G. Mancilla [9] expresses the opinion that "... from the perspective of third order cybernetics" in sociology and political science, "Power, Culture and Institutions" are important.

In the case of cybernetic systems of the third order, this order is considered by the triplet holism-arising-evolution [10].

In [4], examples are given and references are made to various projects that are classified as cybernetics of the third order:

- the main attention is paid to the analysis and empirical generalization of large amounts of data obtained in the course of observing the development of events in society and the behavior of people in individual social groups, building on their basis predictive-analytical or multi-agent models;
- Conducted a debriefing of civil unrest in six different countries in the Latin American region that took place between November 2012 and August 2014;
- the influence of social networks and news agencies on protest moods among the population was considered;
- to select key messages from various datasets on the Internet, the authors used logistic-regression models;
- multi-agent model for describing social processes;
- multi-agent simulation of crowd behavior based on cellular automata.

The general principles of cybernetics of the fourth and even fifth orders are also formulated, for example [12,13]. but I will not cover these paradigms in this article.

The summarized result of this overview is presented in Table 1.

Table 1. Cybernetics order.

Cybernetics order	Main signs	Areas of use in humanitarian sphere	Areas of use in engineering - technical sphere
cybernetic first order	general laws of the control processes and transmission of information; observable systems; allopoietic machines; classical scientific rationality; paradigm “subject - object”.		observable systems; computer communication control
cybernetic second order	cybernetics observing systems; response to trends in the object of management; triplet integration-training-adaptation; homeostasis support and self-organization	management of bio- and noosphere objects; relationship management in societies; relationship management people	control of cyber-physical systems using mutable programs or using an operator
cybernetic third order	self-developing polysubjective (reflective-active) environment; attention to the intellectual component; empirical generalization of large data volumes; Power, Culture and Institutions.	sociology; political science; economy; culture	intellectual component of cyber-physical systems
cybernetic fourth order			

The main conclusions that can be drawn from the analysis of Table 1:

- cybernetics of various orders in the humanitarian sphere are used much more often than in engineering - technical sphere;
- the formulations of the orders of cybernetics for humanitarian areas are more "blurred" than for engineering - technical sphere.

3. Paradigms of cybernetics orders in scientific and engineering projects

There are very few examples of cybernetic paradigms use in scientific and engineering projects. If we look at the application of the ideologies of cybernetics of various orders in the engineering and technical field, then the main class of their applications should be the class of cyber-physical systems. However, you can find only a few examples of the use of paradigms in the description of scientific and technical projects.

In the preprint [4], the authors, one of the few, consider third-order cybernetics in relation to the problem of modeling antagonistic conflicts, using the third-order cybernetics paradigm as a new approach to solving the problem based on game theory. It also shows works that solve a similar problem using the theory of finite automata. The proposed methodology is reduced to the formal task of assessing the conditions of movement of opponents in some hypothetical territory, conditionally reflecting the space of their states, and such characteristics of the state of the subject of the conflict as impact and maneuverability are considered [4]. The method is implemented through the use of software agent technologies. The preprint also shows the possibility of using the proposed approach in robotics. This work is work in the field of modeling social conflicts and behavior of large masses of people, but through the use of a formal mathematical apparatus, the proposed method can be used in engineering projects.

It is possible to formulate the main difference between the ideology of third-order cybernetics: in it, not only in the control loop, but also as one of the links of a complex cyber-physical system, a person is included, and in addition, the ideas of intellectual methods are actively used in the control system. Since the methods of intelligent control are actively used not only in robotics, for example [20,21], but also in many other areas, for example [18, 19], it is advisable to extend the ideas of this article to these areas.

4. Generation-Based Classification in Robotics

Robotic complexes (RC) are a very large class of cyber-physical systems. In various fields of technology, there are classification systems that characterize the generations of this technology. Typical examples are generations of computers or generations of super - computer technology. In these classifications, the basic principle is that each specific sample belongs to the time of its development. This makes it easy to classify a specific piece of equipment in one class or another and to characterize it with general properties characteristic of the technologies of a given period. Similar principles are used for classifications of RC generations. Such classifications can be found, for example, in articles on the Internet [16-17]. However, in more serious articles, which consider RC projects, located according to the years of their implementation, but with reference to an increase in their functional and intellectual capabilities. At best, the following division into RC generations is given:

1. Robots of the first generation - programmed robots (programmed robots).
2. Robots of the second generation are sentient robots.
3. The third generation of robots - intelligent robots. They are fundamentally different from the second generation robots in the complexity and perfection of the control system, which includes elements of artificial intelligence. [15-17].

The main disadvantage of such classifications: the general principle is that they are based only on the reference to a period of time, that is, to specific technologies and, in fact, consider the development of robotics in the historical plane. This is a simple and convenient principle, but it does not take into account the complexity, methods and degree of intelligence of the RC control system. Therefore, this classification is not very interesting to the scientific and engineering community! Professor Hans P. Moravec [13, 14] proposed a more interesting and correct, in my opinion, principle of classification, which depends on the "intellectual capabilities" of the RC. According to his classification, RCs of the first generation have intellectual capabilities comparable to a lizard, the second - with a mouse, and the third - with a monkey. And only the fourth - corresponds to the human intellect. It's a good idea, but how to measure the intelligence level of a mouse or a monkey? This idea is not very suitable for practical use.

4. Proposed classification

It is proposed to consider generations of robotic systems based on the principle of their linking to generations of cybernetic systems. It appears that this will be a more objective classification of existing robotic systems. In this regard, we can consider, for example, the next 4 generations of RC.

1. The first generation is robots with rigid control systems. it is important to note that such technical systems existed 50 years ago and still exist today. and we can confidently assume that they will continue to exist in the future. It is important that they are developed using a variety of technologies, but they have a general principle of the control system. As an example: modern manipulators that work in the conveyor of automobile production and perform the

same fixed operation. It is important to emphasize that both a modern robotic arm for an automobile conveyor and a similar manipulator of the last century will belong to the first generation, since their control system is designed according to the same principles, but their production technologies are completely different.

2. It is proposed to refer to the second generation the class of RC the control system of which is built, first of all, on the principle of the presence of a human operator in the system. At present, this management principle is dominant in terms of the number of actually operating RCs in practical areas. In such control systems, the RC is a significantly more flexible technical system compared to the first generation robots. It can change its functionality depending on the environment and the situation, but this is primarily due to the active role of the human operator. As an example, we can again cite a RC-class robotic arm on an automobile conveyor. However, in this case, the manipulator has a complex control system, which, partially analyzing the external environment and practicing the commands of the human operator, can perform a large number of operations in a semi-automatic mode.

3. Robots of the third generation are systems that are characterized by the fact that the independence of decisions made by the RC control system becomes the main principle for its control system. At the same time, an important circumstance characterizing this class of robotic systems is the fact that such technical systems can function as part of a team consisting of both people and other robots. In addition, the autonomy of such robots is very high. As an example, there is an example from the field of factory robotics: robots - manipulators working on the assembly line of cars that work in the community of other robots, as well as in the community with humans. In this case, both robots and people, performing each their own set of operations, can be in close proximity to each other and perform some complex operations, helping each other. Such RCs require intelligent algorithms in the control system.

4. Robots of the fourth generation are fully autonomous RCs. It is possible that in the future this class will have to be divided into several more generations, for example, to separate into a separate generation RSs capable of self-reproduction. But this is a matter of the future.

Table 2 summarizes the proposed classification of RCs based on the order of cybernetics. The main features and typical examples given in this table can be easily expanded and adjusted. This table illustrates the proposed principle and is not final.

Table 2. Proposed classification system for RC.

Robot Generations	Name – orders cybernetics	Main features	Typical examples
Robots of the first generation	programmed robots – first order	hard-coded simple robots	robot manipulators, cobots
Robots of the second generation	adaptive robots – second order	limited autonomy; principle "one operator-one robot"	robot manipulators, humanoids, collaborative robot or cobots, drones
Robots of the third generation	intellectual robots third order	semi-autonomous robots with a high degree of autonomy, teams of robots and people	exoprostheses, service robots, operating indoors and serving a heterogeneous group of rehabilitation medical center users (patients, health workers, visitors), humanoids, medical operating robots, UAV drones, nano robots, collaborative robot or cobot
Robots of the fourth generation	independent robotic complexes (RC) – forth order	full autonomy, self-reproduction	examples are ???

At present, the practical activities for the development and operation of the RC can be found in robots of all the four generations listed. Some RCs are mass products and are operated in fairly large quantities, while others are only prototypes that are not yet a commercial product. This applies, first of all, to robots of 3-4 generations, but all this is already a reality of today!

Conclusion

- The proposed classification is based on the linkage to generations of cyberneticians. In practice, this means that it is based on the complexity and intelligence of the RC control system.
- This classification is independent of the technology used to manufacture the RC.
- This classification is independent of the RC mechatronic circuit used.
- This classification does not depend on the "world of the robot" and the type of its purpose: stationary, mobile, ground, copter or UAV (drone), surface, underwater, space, alien, etc.
- This classification is independent of the types of sensors and actuators used in a particular RC.
- Of course, the proposed principle can be clarified and requires further detailing.
- Many of the ideas and thoughts presented in the article are found in some works. But the author of this article thinks that these principles should be "fixed" more rigidly and concretely.

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