Intelligent Control and Systems

DOI: https://doi.org/10.15407/kvt208.03.033

GRITCENKO V.I., Corresponding Member of the NAS of Ukraine,
Directorate Advisor
https://orcid.org/0000-0002-6250-3987, e-mail: vig@irtc.org.ua
SUKHORUCHKINA O.N.,
Senior Researcher,
System Information Technologies Department,
https://orcid.org/0000-0002-7441-6661, e-mail: sukhoru@irtc.org.ua
International Research and Training Center for Information Technologies
and Systems of the National Academy of Sciences of Ukraine
and the Ministry of Education and Science of Ukraine.
40, Akad. Glushkov av., Kyiv, 03187, Ukraine

FROM COMMAND CONTROL TO THE AUTONOMY OF MOBILE ROBOTS

Introduction. *The urgent needs of the modern technological order and the development of intelligent information technologies, covering a wide range of scientific areas, have led to the emergence of new principles for the organization of robot control systems. The main goal of modern robotics is to minimize direct human involvement in the control loop when the robot performs tasks in a weakly deterministic non-stationary environment. Historically, robotics for such operating conditions has progressed from remote command control to autonomous systems with the possibility of supervision by human. The influence of intelligent control on increasing the degree of autonomy of service mobile robots is considered. The important subsystems in the organization of intelligent control systems for autonomous mobile robots and the objective difficulties of their practical implementation are shown.*

The purpose of the paper *is to discuss the influence of intelligent control on the level of autonomous capabilities of robots in dynamic and incompletely defined conditions and the objective difficulties of creating universal approaches to the implementation of autonomous service robots control systems.*

Results. *The ways of increasing the autonomous capabilities of mobile robots are considered. The role of the supervisory control principle on the way to reducing human participation in the processes of remote control of service robots is given.*

Conclusions. *The use of the proposed structural solutions of the service mobile robot intelligent control system and the methodology for organizing its activating subsystem made it possible to significantly increase the autonomous resources of the robot when performing complex tasks in a weakly deterministic nonstationary environment.*

Keywords: *autonomous mobile robot, intelligent control system, supervisory control.*

INTRODUCTION

A significant part of modern scientific research and practical developments in robotics is aimed at increasing the autonomous capabilities of mobile robots operating in a dynamic and not completely defined environment, when traditional approaches to the theory of automatic control of moving objects lose their effectiveness. The topicality of the development of new control principles has been discussed about 50 years. In the same years, the autonomy of the purposeful activity of robots began to be associated with the development of a new theory of intelligent control [1–5]. In fact, significant advances in autonomous robotics in a realistic environment have begun to appear since the early 2000^{s}. The competition on projects Robotics Challenge, initiated by DARPA (Defense Advanced Research Projects Agency) of US Department of Defense, provided a significant impetus to this [6].

The last decade has been marked by the emergence of so-called service robots with a variety of design solutions [7]. These are robots that partially or completely replace humans when performing certain tasks for defense purposes, in medical care, education, agriculture, courier services, in the areas of hotel services and catering, for household assistance etc. While for industrial robots autonomy is necessary only within the boundaries of their deterministic workspace, strictly associated with a specific production process, the conditions for the functioning of service mobile robots are less predictable, the actual goals of current actions are more difficult to determine and formalize, which introduces fundamental differences in the implementation of autonomous control systems for such robots.

Original design solutions for mobile platforms and sensor equipment with microprocessor-based data processing and interpretation, extended use of artificial intelligence technologies, a variety of functional applications — these are the general characteristics of service robotics innovations, that are regularly covered in the media today. However, not all of them have the ability to act autonomously when performing tasks in a real environment. There are scientific discussions about various paradigms of intelligent control, knowledge representation structures and ways to operate with them when the robot automatically chooses its purposeful actions in one situation or another [8–12].

In an effort to overcome the objective difficulties of creating robotic devices capable to perform complex tasks in dynamically changing environments with minimal human participation, the transition from the command principle of robot actions remote control to the need for only supervision by the user is important [13]. Such transition became possible due to the development of intelligent control systems and information technologies of imaginative perception and machine intelligence.

The purpose of the paper is to discuss the impact of intelligent control on the level of robots autonomous capabilities in dynamic and not fully defined conditions and the objective difficulties of creating universal approaches to the implementation of control systems of autonomous service robots.

PROBLEM STATEMENT

Let a mobile robot (MR) as a control object be in some real surroundings, which we will call the outside robot environment (RE). For each system functioning in a real environment, both biological and technical, a RE exists in the form of some model obtained by mapping its properties that this system is able to perceive. The actual MR equipping with a set of hardware, technological, algorithmic and software implementations of the perception of the certain properties of robot environment and its objects and determines the possible types of interactions of the robot with their surroundings.

The control problems of MR, the surface of motion of which is a horizontal plane, are considered. Note that this constraint characterizes the real operating environment for service indoor robots with a wide range of purposes and makes it possible to significantly simplify the mathematical models of MR motion and RE models.

In the general case, the task of an autonomous MR control system will be understood as transferring the robot from its current state MR_0 to a given goal state MR_G without human intervention. Goal states MR_{G_i} and MR_{G_j} , $i \neq j$ are considered different if they differ by a set of parameters that define them, not only by their values. A specific task with a goal state MR_{G_i} will be called a task Tsk_i . Since the MR interacts with RE in one way or another, we will talk about the current and goal states of pairs $< MR_0, RE_0 >$ and $< MR_G, RE_G >$, respectively. Here RE_0 and RE_G are subsets of the characteristics of the RE model that are related to the process of performing a specific task by the robot.

Of practical interest is the MR control system (CS) that supports the performing the set of a certain class tasks $Tsk = \{Tsk_i\}, i = 1,..., N,\ \ N > 1$, and capable of sequentially selecting and activating tasks from this set, necessary for the robot to achieve a given goal state of the pair $< MR_G, RE_G >$ without human intervention.

Let us note the features of the autonomous MR control system problem in the considered formulation:

– the states of RE and MR in the general case are not completely known, and the state of RE can change regardless of the MR actions;

– the state of a pair $< MR, RE >$ at a point in time t is described by a set of variables that can be represented by various data structures and types including with asynchronous changes in their values over time, and only estimated rather than exact values available for some variables;

– assessment of the current states of the MR and RE should be performed by the resources of the CS, bringing the values of all necessary variables to a single system time;

– the goal state of the pair $< MR_G, RE_G >$ can be specified at the abstract-conceptual level (including verbally) with unknown values of all or part of the variables determining this state.

THE PRINCIPLE OF SUPERVISORY CONTROL

Today, service MRs usually have a human-machine interface for their remote use via wireless networks. Remote control (or telecontrol) of the robot's actions has developed in two directions — in the form of a command (manual) mode and a semi-automatic one [14, 15]. The human operator, receiving the necessary information from the remote CS of MR, in the first case forms the commands for direct control of the robot executive organs, in the second case — periodically transfers control to the automatic system that implements a particular available program of certain MR actions. The operator is responsible for the choice of permissible and expedient current actions of the MR in both cases.

Due to the incompleteness of the information about the RE available to the control object, unpredictable changes in the situation over time and various initial states of the MR when it receives some complex task Tsk_i from the user, a pre-prepared robot action program is not always equally successful in leading it to the desired goal state $< MR_{G_i}, RE_{G_i} >$. The wide variability of the possible values of the variables of the current mutual states of the pair $< MR, RE >$ generates an unlimited set of situations in which the robot finds itself when trying to use the same action program.

In the late 1960^s, it was proposed in remote mode use the principle of supervisory control of robots [16], according to which the operator-supervisor represents the desired complex robot activity to achieve a certain goal as a sequence of simpler actions, for which an automatic control program of the robot's actuators can be prepared and successfully executed. It is customary to talk about shared control with an external activating subsystem implemented by a human operator. In fact, the operator decomposes the desired global goal into a sequence of local subgoals, some of which the MR is able to achieve automatically under the supervision of the operator with possible his intervention if it is necessary to directly control the robot in difficult situations [17].

The main motivation for the further development of the supervisory principle was the reduction of the human role in the robot control processes. New ideas are focused on the implementation of an intelligent component to the control system in the form of an internal activating subsystem, responsible for automatic selection of locally reasonable subgoals, the autonomous achievement of which should lead the MR to the main goal of the user task. The MR CS should have its own resources for autonomous achievement by the robot of a certain set of goal states [15]. In this case, the operator's role is reduced to formulating the main task for the robot and, if necessary, supervising its autonomous functioning to avoid abnormal situations.

The principle of supervisory control remains a priority even with a very high level of autonomous capabilities of the MR control system in cases when the MR performs tasks in areas of special requirements for minimizing the risk of abnormal situations, as well as in conditions that significantly affect the ability of obtaining high-quality information about the operating environment by the on-board robot means (for example, during radiation pollution, in outer space etc.).

INTELLIGENT CONTROL SYSTEM

The definition of an intelligent control system (ICS) for dynamic objects is usually based on enumeration of the expected properties and capabilities of such a system [9, 11, 12]. In [12] examples of fundamentally different ways of implementing technical systems, the functionality of which can replace one or another type of human intellectual activity, are shown. The most promising way to implement ICS for autonomous multifunctional robots is the presence in their control systems of structures and information processes similar to some known forms of brain activity of living beings. Such systems can be implemented by modeling particular low-level structures similar to brain neurons (neurocybernetic direction) or by modeling high-level information processes related to human thinking (direction of knowledge representation and use). Here the second direction is considered.

The success of MR autonomous operation when some data on the state of the control object and its environment is incompleteness and insuperable indetermination depends primarily on the ability of its onboard control system to perceive, analyze and interpret the environment characteristics that are significant for the robot purposeful functioning. Such control system must form models (images) of objects and phenomena, be able to recognize them, and assess robot state and position in the environment [11]. Each of these abilities is associated with a certain type of cognitive activity and requires the practical implementation of an independent task of artificial intelligence with the necessary bringing the relevant methods and software and hardware solutions to operate in real time. The system relationships of such abilities, related to machine intelligence, and the synchronization of distributed parallel information processes in the task of autonomous control of MR actions, related to machine thinking, are essential.

Traditional automatic control theory considers strongly formalized systems to perform, as a rule, one specific also well formalized problem. ICS tasks are weakly formalized even at the level of their formulation [18]. For service MR, a typical example of a weakly formalized control problem with incomplete information is the task "Bring object A to object B", when only the names of objects A and B are specified, their positions are unknown, and the actual mutual state of the pair <MR, RE> is unknown too. In a non-stationary environment there is no guarantee of reliability and consistency of information about the positions of objects A, B and objects-obstacles, among which the robot will move to the goal position, and the MR goal position may not be determined almost until the last moment of movement towards it.

Performing tasks of this type by a robot without human intervention is associated with the solution of some previously unpredictable sequence of independent ICS tasks.

Such tasks can be:

- determining the MR position in RE;
- object recognition and the RE model formation in the area of the MR operation;
- determining the position of goal object A and path of safe motion to it;
- determining the positions of the MR and its gripper suitable for taking an object etc.

Due to the possible movements of objects in the MR workspace, not related to its actions, the alternation of ICS tasks that are relevant at the current time cannot follow a pre-determined plan. In difficult conditions of information incompleteness, an intelligent system needs to have an internal mechanism for choosing a well-formalized task from the class available to it, which is relevant to the current situation.

The structure of MR ICS assumes a number of software and hardware modules that implement the basic set of functions necessary for the robot to autonomously perform a certain set of tasks, depending on the purpose of a particular robot [19]. Due to the specifics of the functional purpose of these modules, each of them represents a particular subsystem of the CS (Fig. 1), namely:

– the information subsystem, the purpose of which is the formation of generalized RE models and MR states in the internal memory structures of the ICS and their dynamic editing, performing the collection, processing and interpretation of the current data of various sensory devices of the robot;

– the motion subsystem has the purpose of moving the MR platform and its actuators to specified positions, performing the appropriate control of the drives of the robot moving parts;

– the communication subsystem is responsible for the information interaction of the MR with other external technical systems, as well as with the user to receive target tasks from him and support the human-machine interface in the supervisory mode of operation;

– the activating subsystem, interacting with the information subsystem, is responsible for the reactivity and activity of the CS, reacting to changes in the RE by determining the current goals, choosing the rules for achieving them, and activating the corresponding actions of the MR.

The approach to the experimental implementation of the MR ICS adopted by the authors is based on the ideas of the functional systems theory on the brain activity of evolved biological organisms [20]. By analogy with this theory, information feedbacks of the autonomous intelligent control of a technical system should concentrate active processes of interpreting a certain part of the current information around identifying local goals of the robot's actions that bring the MR closer to obtaining a useful result on the user's task. It is the activating subsystem that supports the robot's ability to self-assess its state in the environment and make decisions about the necessary purposeful actions [18].

For the software implementation of the methodology of forming the necessary informational feedbacks the principle of the acceptor of action result was used [20]. In our case, the ICS constantly generates a model of the expected informational equivalent of the result of the MR current actions and compares it with the parameters actually observed by the onboard devices of the robot, corresponding to the state of the pair <MR, RE>, which allows to timely detect the need to change the current goal of the autonomous MR action (Fig. 2) [21].

Such approach to the organization of the internal activating subsystem of the ICS provided the service MR prototype with the ability to autonomously perform in a partially defined nonstationary environment such tasks as "Come to object", "Bring object A to object B", "Track object" etc. [22].

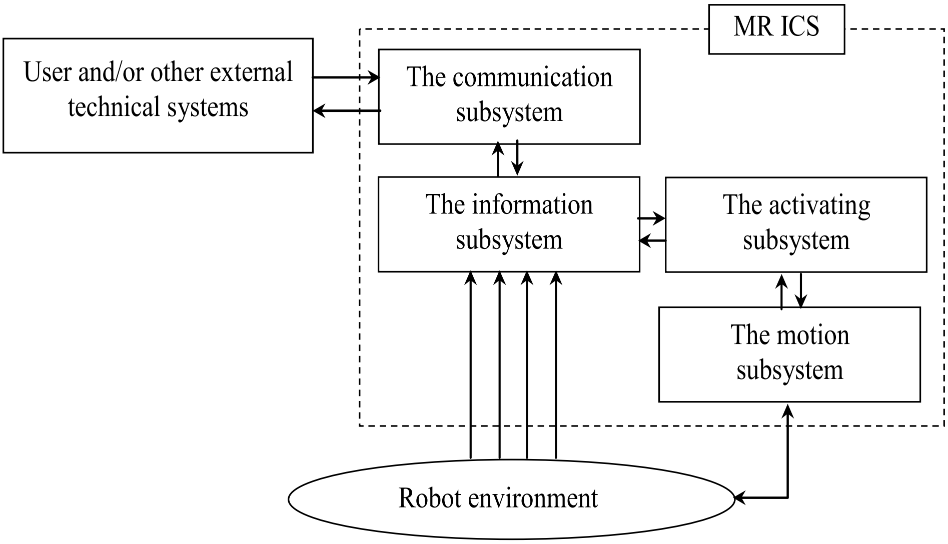

Fig. 1. Basic subsystems of MR ICS

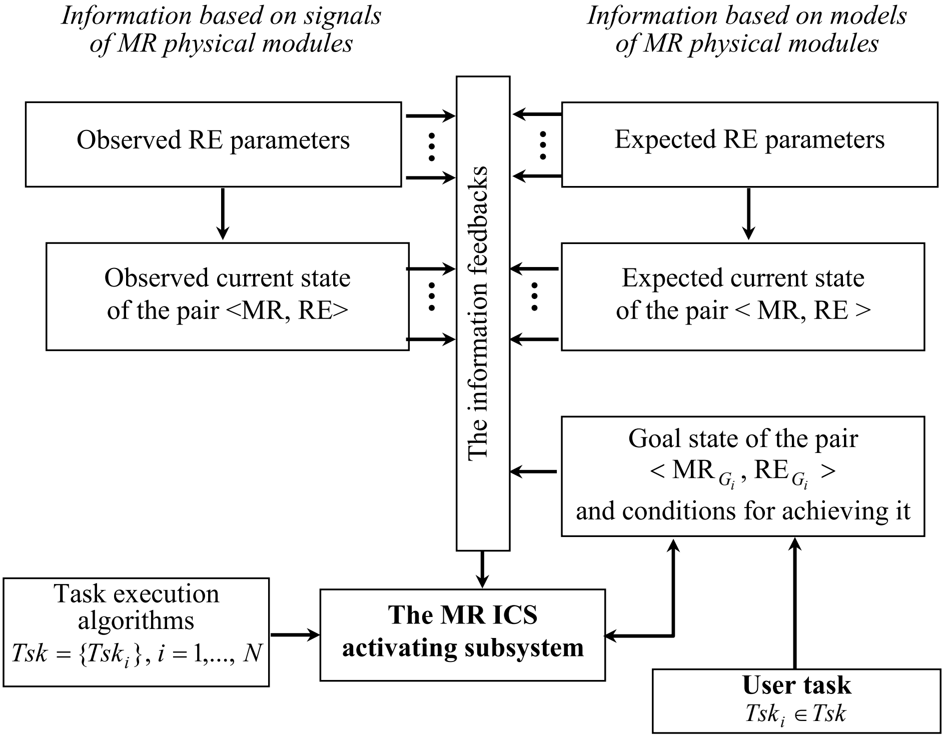

Fig. 2. The functional organization of MR ICS

DIFFICULTIES OF PRACTICAL IMPLEMENTATION OF AUTONOMOUS MOBILE ROBOT INTELLIGENT CONTROL SYSTEM

When the robot performs tasks, different information processes, which are generated by different functionally necessary subsystems of the ICS in the context of the realized goal, come into interaction. Each of the subsystems of the MR ICS operates with data of a different nature. Each type of data objectively has its own representation structures in CS memory and its own time period for computational processes for their analysis and interpretation. Such asynchronous processes with heterogeneous data types require structural matching and time synchronization of the internal processes of the functioning of the system as a whole [23].

In the software for IMS MR, non-conflict functioning of parallel and interacting real-time information and computing processes should be implemented, such as:

– recognition of objects in the current onboard video camera images and determination of these objects positions relative to the coordinate system of the robot environment model;

– analysis, interpretation and formation of the models of surrounding objects according to rangefinder data;

– dynamic generation in the ICS memory and visualization of the models of spatial scenes as 3D models of the robot and its surrounding objects in the user interface;

– determination of the current goals of the MR actions, relevant information feedbacks, target positions and parameters for controlling the safe MR movement to these positions;

– direct control of MR wheel drives, gripper or other actuators of the robot;

– generation text and/or synthesized voice messages about the current MR actions in the session log and user interface.

At the same time, for some information processes the data sources are physical devices for perception the real world characteristics, for others, the corresponding mathematical or simulation models. Each of the active information processes of the ICS can face uncertainties of critical state parameters of both the MR itself and its environment, which generates a very high level of complexity in the design, software implementation and testing of parallel thread computing. Estimation of a number of the pair <MR, RE> current state parameters cannot be objectively performed without errors of the random type.

Now, in the intelligent control theory there are no unified approaches to practical implementation of the strategic and tactical problems of the autonomous MR control. The search for principles for determining and formalizing the current goals of autonomous MR actions, structures for knowledge representation in the long-term and operation memory of the technical system, creation of information technologies for the automatic new knowledge formation and its handling remain extremely relevant for developers of mobile robots capable of performing complex tasks without human involvement in poorly defined dynamic environments.

CONCLUSIONS

The paper shows important functional modules and subsystems of mobile robots control system and the key role of intelligent control systems in the emergence of autonomous capabilities of mobile robots to operate successfully in a non-stationary environment. At the same time, intellectual control, as a scientific direction, is aimed at a systematic approach to the application of methods and tasks of artificial intelligence and the development of appropriate information technologies. However, the practical implementation of MR ICS faces a number of serious questions to which the intelligent control theory does not have universal answers today.

First of all, a technical system for efficiency of purposeful actions in non-deterministic environments must automatically form its own image (or model) of the functional surrounding and be able to evaluate its state in it (the property of reflexion). Significant expansion of the MR autonomous working capacity in non-determined environment requires the development and improvement of intelligent technologies for interpreting data on objects and phenomena of different nature, especially weakly structured data with incomplete a priori knowledge about these objects, phenomena and processes. The ability to classify situations and make decisions about appropriate MR actions in the current situation to achieve the main goal is the basis of another intellectual technologies direction. The development of an autonomous MR intelligent control system as a whole requires a systemic interconnection of a number of similar technologies.

The approach to the internal activating subsystem organization, as the most important component of the MR ICS, given in the paper, is successful with significant simplifications for mathematical models of RE perception and MR motions. In this case, the MR motion surface is a horizontal plane, the objects surrounding the robot are considered as solid bodies, which can be approximated with an acceptable error by a finite number of convex polytops. Such simplifications are acceptable for the so-called indoor robots, allocated in robotics in a special class, which often includes unmanned vehicles for driving on the highway.

The weakening of these restrictions, for example, for MR operating the complex profile rough terrain, surrounded by objects and phenomena of various nature, is the subject of searching for other ways to organize the ICS. Today such MRs, which are especially in demand in military applications, have only limited capabilities to autonomously perform some typical actions under the supervision of an operator. However, in the military actions conditions, especially relevant, for example, MR, as ground unmanned vehicles, capable of delivering cargo to combat positions and help evacuate the wounded under difficult situations without human intervention.

Society's demand for autonomous mobile robots that can replace a person when performing difficultly formalizable tasks under conditions of incomplete information and various types of uncertainties generates a special interest in searching for new scientific and technological solutions for the organization of autonomous control systems.

REFERENCES

1. Fu K.S. Learning control systems and intelligent control systems: An intersection of artificial intelligence and automatic control. *IEEE Trans. Automatic Control*. 1971. pp. 70–72.
2. Saridis G.N. Toward the realization of intelligent controls. *Proc. IEEE*. 1979, vol. 67. Iss. 8, pp. 1115–1133. DOI: 10.1109/PROC.1979.11407.
3. Meystel A. Intelligent control: Issues and perspectives. *Proc. IEEE Workshop Intelligent Control*. 1985. pp. 1–15.
4. Antsaklis P.J., Passino K.M., Wang S.J. Towards intelligent autonomous control systems: Architecture and fundamental issues. *Journal of Intelligent and Robotic Systems*. 1989, vol. 1. pp. 315–342.
5. Simmons R., et al. Autonomous task control for mobile robots. *Proc. of the Fifth International Symposium on Intelligent Control*. IEEE Computer Society Press, Los Alamitos, CA. 1990, pp. 663–668.
6. DARPA Robotics Challenge. https://www.darpa.mil/program/darpa-robotics-challenge [Last accessed 24.04.2022]
7. World Robotics — Service Robot Report. International Federation on Robotics, 2018. https://ifr.org/downloads/press2018/Executive_Summary_WR_Service_Robots_2018.pdf
8. Guha A., Dudziak M. Knowledge based controllers for autonomous system. *Proc. IEEE Workshop Intelligent Control*. 1985, pp. 134–138.
9. Saridis G.N. Intelligent control-operating systems in uncertain environments. In book: *Uncertainty and Control*. 2006, pp. 215–236. DOI: 10.1007/BFb0007285
10. Rapoport G.N., Gertz A.G. Artificial and biological intelligence. Generality of structure, evolution and processes of cognition. Moscow: KomKniga, 2005. 312 p. (in Russian)
11. Makarov I.M., Lokhin V.M., Manko S.V., Romanov M.P. Artificial intelligence and intelligent control systems. Moscow: Nauka, 2006. 333 p. (in Russian)
12. Zhdanov A.A. Autonomous artificial intelligence. Moscow: BINOM, Laboratoriya znaniy, 2008. 359 p. (in Russian)
13. Gonzalez A.G.C., Alves M.V.S., Viana G.S., Carvalho L.K., Basilio J.C. Supervisory control-based navigation architecture: A new framework for autonomous robots in industry 4.0 Environments. *IEEE Trans. on Industrial Informatics*. 2018. 14(4). P. 1732–1743. DOI: 10.1109/TII.2017.2788079
14. Sheridan Thomas B. Telerobotics, automation, and human supervisory control. MIT Press, Cambridge, 1992.
15. Cheng G., Zelinsky A. Supervised autonomy. *A Framework for Human-Robot Systems Development, Autonomous Robots*. 2001. 10(3), pp. 251–266.
16. Ferrell W.R., Sheridan T.B. Supervisory control of remote manipulation. *IEEE Spectrum*. 1967. 4(10), pp. 81–88.
17. Jones P.M., Jasek C.A. Intelligent support for activity management (ISAM): An architecture to support distributed supervisory control. *IEEE Transactions on Systems, Man, and Cybernetics, Special issue on Human Interaction in Complex Systems*. Vol. 27. No. 3. May 1997, pp. 274–288.
18. Chechkin A.V. Activating subsystem is the main feature of the intelligent system. *Intellektualnye sistemy*. Moscow: Izd-vo MGU. 2001, **6**. Iss. 1–4, pp. 91–110. (in Russian)
19. Sukhoruchkina O.N. The structures and information processes of mobile robot intelligent control. *Zbirnyk naukovykh prats Instytutu problem modelyuvannya v energetytsi im. G.Ye. Pukhova NAN Ukrainy*. Kyiv, 2012. No. 62, pp. 93–101. (in Russian)
20. Anokhin P.K. Key questions of the theory of functional systems. Moscow: Nauka, 1980. (in Russian)
21. Sukhoruchkina O.N. Activating subsystem of mobile robot intelligent control, *Sbornik dokladov Vserossiyskoe nauchno-tekhnic. konferentsii "Ekstremalnaya robototekhnika" (Rossiya, Sankt-Peterburg, 25–26 sentyabrya)*, Izdatelstvo "Politekhnika-servis", Sankt-Peterburg, 2012, pp. 101–105. (in Russian)
22. Sukhoruchkina O.N., Progonnyi N.V. Intelligent Control of Mobile Robot when Tracking a Moving Object. *Journal of Automation and Information Sciences*. 2019. 51(11), pp. 50-62. DOI: 10.1615/JAutomatInfScien.v51.i11.50

23. Sukhoruchkina O.N. On parallel information processes of intelligent control of a mobile robot. *Trudy XXI Mezhdunar. nauchno-tekhnic. konferentsii "Ekstremalnaya robototekhnika"*. Sankt-Peterburg: Izdatelstvo "Politekhnika-servis". 2010, pp. 338–340. (in Russian)

Received 06.06.2022

ЛІТЕРАТУРА

1. Fu K.S. Learning control systems and intelligent control systems: An intersection of artificial intelligence and automatic control, *IEEE Trans. Automatic Control*. 1971. P. 70–72.
2. Saridis G.N. Toward the realization of intelligent controls. *Proc. IEEE* . Vol. 67. Issue 8. 1979. P. 1115–1133. DOI: 10.1109/PROC.1979.11407.
3. Meystel A. Intelligent control: Issues and perspectives. *Proc. IEEE Workshop Intelligent Control*. 1985. P. 1–15.
4. Antsaklis P.J., Passino K.M., Wang S.J. Towards intelligent autonomous control systems: Architecture and fundamental issues. *Journal of Intelligent and Robotic Systems*. 1989. Vol. 1. P. 315–342.
5. Simmons R., et al. Autonomous task control for mobile robots. *Proc. of the Fifth International Symposium on Intelligent Control*. IEEE Computer Society Press, Los Alamitos, CA. 1990. P. 663–668.
6. DARPA Robotics Challenge. https://www.darpa.mil/program/darpa-robotics-challenge [Дата звернення: 24.08.2022]
7. World Robotics — Service Robot Report. International Federation on Robotics, 2018. https://ifr.org/downloads/press2018/Executive_Summary_WR_Service_Robots_2018.pdf
8. Guha A., Dudziak M. Knowledge based controllers for autonomous system. *Proc. IEEE Workshop Intelligent Control*. 1985. P. 134–138.
9. Saridis G.N. Intelligent control-operating systems in uncertain environments. In book: Uncertainty and Control. 2006. P. 215–236. DOI: 10.1007/BFb0007285
10. Рапопорт Г.Н., Герц А.Г. Искусственный и биологический интеллекты. Общность структуры, эволюция и процессы познания. М.: КомКнига, 2005. 312 с.
11. Макаров И.М., Лохин В.М., Манько С.В., Романов М.П. Искусственный интеллект и интеллектуальные системы управления. М.: Наука, 2006. 333 с.
12. Жданов А.А. Автономный искусственный интеллект. М.: Бином. Лаборатория знаний, 2008. 359 с.
13. Gonzalez A.G.C., Alves M.V.S., Viana G.S., Carvalho L.K., Basilio J.C. Supervisory control-based navigation architecture: A new framework for autonomous robots in industry 4.0 Environments. *IEEE Trans. on Industrial Informatics*. 2018. 14(4). P. 1732–1743. DOI: 10.1109/TII.2017.2788079
14. Sheridan Thomas B. Telerobotics, automation, and human supervisory control. MIT Press, Cambridge, 1992.
15. Cheng G., Zelinsky A. Supervised autonomy. *A Framework for Human-Robot Systems Development, Autonomous Robots*. 2001. 10(3). P. 251–266.
16. Ferrell W.R., Sheridan T.B. Supervisory control of remote manipulation. *IEEE Spectrum*. 1967. 4(10). P. 81–88
17. Jones P.M., Jasek C.A. Intelligent support for activity management (ISAM): An architecture to support distributed supervisory control. *IEEE Transactions on Systems, Man, and Cybernetics, Special issue on Human Interaction in Complex Systems*. Vol. 27. No. 3. May 1997. P. 274–288.
18. Чечкин А.В. Активирующая подсистема — главная особенность интеллектуальной системы. *Интеллектуальные системы*. М.: Изд-во МГУ. **6**. Вып. 1-4. 2001. С. 91-110.
19. Сухоручкина О.Н. Структуры и информационные процессы интеллектуального управления мобильным роботом. *Збірник наук. праць Інституту проблем моделювання в енергетиці ім. Г.Є. Пухова НАН України*. Київ, 2012. Вип. 62. С. 93–101.
20. Анохин П.К. Узловые вопросы теории функциональных систем. М.: Наука, 1980.
21. Сухоручкина О.Н. Активирующая подсистема интеллектуального управления мобильным роботом. *Экстремальная робототехника. Сборник докладов*

Всероссийской научно-технич. конференции. Санкт-Петербург: Изд-во «Политехника-сервис», 2012. С. 101–105.
22. Sukhoruchkina O.N., Progonnyi N.V. Intelligent Control of Mobile Robot when Tracking a Moving Object. *Journal of Automation and Information Sciences*. 2019. 51(11). P. 50-62. DOI: 10.1615/JAutomatInfScien.v51.i11.50
23. Сухоручкина О.Н. О параллельных информационных процессах интеллектуального управления мобильным роботом. *Экстремальная робототехника. Труды XXI Междунар. научно-технич. конференции*. Санкт-Петербург: Изд-во «Политехника-сервис». 2010. С. 338–340.

Отримано 06.06.2022

Гриценко В.І., член-кореспондент НАН України,
Радник при дирекції Міжнародного науково-навчального центру
інформаційних технологій та систем
НАН України та МОН України
https://orcid.org/0000-0002-6250-3987, e-mail: vig@irtc.org.ua
Сухоручкіна О.М.,
старш. наук. співроб., відділ системних інформаційних технологій,
https://orcid.org/0000-0002-7441-6661, e-mail: sukhoru@irtc.org.ua
Міжнародний науково-навчальний центр
інформаційних технологій та систем
НАН України та МОН України,
пр. Акад. Глушкова, 40, м. Київ, 03187, Україна

ВІД КОМАНДНОГО КЕРУВАННЯ ДО АВТОНОМНОСТІ МОБІЛЬНИХ РОБОТІВ

Вступ. Актуальні потреби сучасного технологічного устрою та розвиток інтелектуальних інформаційних технологій, які охоплюють широкий спектр наукових напрямів, сприяли появі нових принципів організації систем керування роботами. Основна мета сучасної робототехніки — мінімізація безпосередньої участі людини в контурі керування під час виконання роботом завдань в умовах слабо детермінованого нестаціонарного середовища. Історично робототехніка для таких умов функціонування проходить шлях від дистанційного командного керування до автономних систем з можливістю супервізорного контролю людиною. Розглянуто вплив інтелектуального керування на підвищення ступеня автономності мобільних роботів сервісного типу. Показано важливі підсистеми в організації інтелектуальних систем керування автономними мобільними роботами та об'єктивні складнощі їх практичної реалізації.

Метою статті є обговорення впливу інтелектуального керування на рівень автономних можливостей роботів у динамічних та не повністю визначених умовах та об'єктивних труднощів створення універсальних підходів до реалізації систем керування автономними сервісними роботами.

Результати. Розглянуто шляхи підвищення автономних можливостей мобільних роботів. Наведено роль принципу супервізорного керування на шляху до зниження участі людини у процесах дистанційного керування сервісними роботами.

Висновки. Використання запропонованих структурних рішень інтелектуальної системи керування мобільним роботом сервісного типу та методики організації його підсистеми активації дали змогу суттєво підвищити автономні ресурси робота для виконання складних завдань у слабо детермінованому нестаціонарному середовищі.

Ключові слова: *автономний мобільний робот, інтелектуальна система керування, супервізорний контроль.*